Smartphones in Science Teaching

iStage 2

Imprint

iStage 2

Eyes

Ears

Hands

Greeting

"Not without my mobile!" For many young people, and in many cases even for children, mobile devices such as smartphones and tablets are an integral part of their daily lives. The German high-tech association BITKOM concluded in its study "Kinder und Jugend 3.0" (Children and Youth 3.0), which was published in April 2014, that "39 per cent of six to seven-year-olds and 76 per cent of eight to nine-year-olds use the Internet. In the age group of ten to 11-year-olds, 94 per cent, or almost all of the children, are online and spend an average of 22 minutes per day on the Internet." A total of 962 children and teenagers between six and 18 years of age participated in the survey.

In the age group of 12 to 13-year-olds, 85 per cent own smartphones; we can conclude that this age group is fully supplied with these devices.

These figures show that neither the school as an institution nor the economy can ignore the fact that the "digital natives" are growing up with these technologies and regard them as part of their reality.

What does this mean for schools and for commercial enterprises? For one thing, it definitely means that the issues of Internet competence and the use of digital technologies will be, and should be, receiving a more important place in the curricula of various school subjects.

On the other hand, we as companies have to create incentives and opportunities and encourage young people to regard their smartphones as more than just an opportunity to be actively involved in social networks.

Many teachers feel abandoned and unequal to the challenge. For example, they are confronted with the question of how they can integrate the use of the new technical devices into their classroom teaching. In an article in Spiegel Online, one teacher described the dilemma as follows: "I don't know what is possible from a technical point of view. Someone really has to show us what possibilities are open to us … That would really shed some light on the situation." In other words, it's not only the pupils who are looking for orientation in this field and need our support.

At the IT company SAP, we want to help pupils, teachers and parents understand that the new digital technologies and devices can definitely be integrated into classroom instruction in an exciting way. That's why we're delighted that we were able to continue our cooperation with Science on Stage Deutschland on the project "iStage 2: Smartphones in Science Teaching". The first project, iStage 1, which distributed more than 11,000 units of instructional material on the topic of IT in science teaching, met with an enthusiastic response from pupils and teachers all over Europe.

But SAP is not making this project possible as an end in itself. The schoolchildren of today are our potential employees of tomorrow. And the informed acceptance and use of smartphones and tablets has already become an essential component of the world of business. Mobile devices and processes open the door to greater innovation, efficiency and simplified IT. As a result, they are becoming an important key to success for companies and also for personal career development.

Promoting the talented employees of tomorrow, sparking their enthusiasm for the new technologies and enabling them to use these technologies well have long been fundamental aspects of SAP's social commitment. For ten years now, SAP has supported the FIRST LEGO League (FLL) educational programme, which stimulates children's and young people's interest in the natural sciences and technology in a playful way, while at the same time nurturing a wide range of social skills. The aim of FLL is to get children and young people enthusiastic about science and technology by offering them fun and excitement, and to stimulate them to solve complex tasks by working together in teams and using their imaginations.

It's a pleasure to present to you in this iStage 2 brochure a series of interesting and practical experiments that can be carried out with a smartphone. They can also be performed outside the classroom, and are sure to deliver some surprising flashes of insight.

This brochure will provide teachers with the orientation they so urgently need and serve as a source of inspiration for the meaningful integration of smartphones into classroom teach-

ing. For their part, the pupils will discover new perspectives on how to use their mobile phones at school in ways that have nothing to do with Facebook, Twitter or other types of social media.

I would like to thank the teachers from 14 European countries who cooperated to create these teaching units for their tremendous dedication. Without their hard work and intense personal commitment to creating classroom teaching and learning that is in tune with the times, this material would not have been developed. I am convinced that this brochure will provide many teachers with hands-on examples of modern and creative classroom instruction.

Michael Kleinemeier
President, SAP SE, Middle and Eastern Europe

iStage 2—Taking science teaching in Europe to the next level

We've done it again! A group of enthusiastic science teachers from all over Europe came together to talk to one another face to face. You might consider this form of communication common and old-fashioned, but on the contrary, iStage is modern and unique in many ways.

In most European secondary schools, students are not allowed to use their smartphones for good reason: it hampers personal communication in school. However, nearly all students (and teachers) have these powerful little helpers in their pockets. They all have access to the Internet, although the Internet at their school may not work properly. They have the world's knowledge at their fingertips, even if they've forgotten their textbooks at home. Thanks to their little smartphones, they also own high-tech laboratory equipment that most European schools can only dream of. They can measure their GPS coordinates (latitude, longitude), altitude, pressure, acceleration, angle of rotation, magnetic fields, voltage (of stereo input) and, last but not least, they have two high-resolution cameras.

There are thousands of apps to exploit the data provided by all these sensors, so many measurements in natural science can in principle be carried out and analysed with the help of smartphones. The use of smartphones in science teaching can therefore be considered modern.

Personal communication is still important, and each school community has to define its own rules about when to use smartphones. However, simply ignoring their presence is not a good solution. In addition, for the teachers in iStage, personal exchange is one of the key elements of a successful project. iStage is unique because teachers from different countries meet in person to share their views on teaching.

Science on Stage Germany initiated the European exchange process "Teaching Science in Europe" in 2004. In November 2012 the results from "Teaching Science in Europe 4 – iStage" were presented: teaching material developed by teachers for teachers. "iStage 2 – Smartphones in Science Teaching" started with a network meeting at the Science on Stage festival in Słubice, Poland, in April 2013. After the coordinators' meeting in Dortmund, Germany, in July 2013 and an initial workshop with 20 participants from 14 European countries in Vienna in October 2013, the participants started to develop the teaching units and content of this brochure. From November 2013 to April 2014 the exchange between the participants was continued via e-mail and moodle. A second workshop took place in Berlin in May 2014, and the final presentation of this brochure will be in December 2014. This kind of personal exchange between teachers over such distances is unique.

Of course, when only 20 European teachers from 14 different countries develop teaching material within a limited timeframe, the result will be a limited number of examples. Most of the ideas already exist somewhere in Europe, and you can find some of them in one form or other in articles in professional journals. Moreover, there are many more ideas around than the ones presented here. What is special here, however, is the process of bringing them together. It is hard to find material made by teachers from so many different countries for teachers in Europe, but we have successfully created it again.

The exchange processes iStage and iStage 2 are supported by SAP, and we are grateful for the company's excellent cooperation and support. We also thank our participants for their hard work and for all the fun we had together.

With iStage we created a unique process by teachers for teachers for the benefit of our students, and we will do it again.

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Eyes

Vision—our capacity to see what is in our surroundings through the perception of light—is probably the most important of our five senses. It is therefore no surprise that smartphones, as a cybernetic extension of our bodies, are often used as very light photographic and video cameras. Their use has become a natural part of our society, and it is fuelled by very popular social networking websites that encourage users to post their photos and videos to make them instantly accessible to friends or to the world.

But beyond image capture, a wealth of "apps" are being developed that expand the vision capabilities of smartphones by combining image capture with complex image analysis that the ever faster processors in newer versions of such devices are able to carry out in real time or with very little delay. Images can thus be analysed to recognise QR codes leading to Web pages, to identify texts, or to compare texts to databases of stored images retrieved from the Internet. This enables the user to recognize a company logo just by pointing a smartphone camera at it, or to tag friends who appear in a photo.

Furthermore, integration of imaging devices with the GPS coordinates and other positional and orientation data provided by the smartphone sensors allows the clever integration of images with data; as a result, the number of applications using augmented reality views is rapidly increasing and creates displays that a few years ago were only imagined in science fiction movies. For example, some applications inform the user about the objects seen through the camera, whether they are terrestrial landmarks or celestial objects.

Thus, when we think of exploiting the smartphone as a measuring tool in natural science projects, it is obvious to consider projects that explore the potential of smartphones to sense light, position and orientation. This is the shared element of the three teaching units we present in this section, which concern topics from astronomy, geometry and chemistry.

In "Smart Astronomers: From the Classroom to the Sky", the students will learn how to measure the position of the sun and stars using the smartphone as an astrolabe. They will then use the experience they have acquired to measure the circumference of the Earth in collaboration with a geographically distant group of students.

In "iSky: Smart Measurements of the Heavens", the students use the smartphone to determine their distance from faraway objects by measuring angles. Here, collaboration between geographically separated groups would allow the measurement of distances to objects in outer space.

In "How Deep Is Your Blue?", the smartphone serves as a colorimeter, which is used to determine the concentration of a solution by simple image analysis.

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Smart Astronomers: From the Classroom to the Sky

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1 | Summary

This teaching unit is about parallax measurements—how to determine distances in the universe.

Distances in space seem unreal to our students. The parallax effect is an abstract idea that is difficult to understand. Starting with outdoor hands-on activities, we measure distances using mobile devices and simulate distance measurements in the classroom, on the school campus and to the moon. In an international collaboration project we can also determine the altitude of the ISS.

▸ **Keywords:** parallax method
▸ **Disciplines:** physics, astronomy, mathematics, geometry, trigonometry
▸ **Age level of students:** 14-18 years
▸ **Android apps:** Distance and Parallax, Stellarium, ISS Detector, Theodolite droid, Compass, Smart Protractor, Smart Measure
▸ **iOS apps:** Stellarium, Theodolite, Angle Meter, Compass

2 | Conceptual introduction

In most European countries astronomy is not an independent subject, but is integrated into physics. Parallax measurements and calculations are also part of mathematics. In some countries astronomy is studied in the first year of high school.

A difficult problem in teaching astronomy is how to determine the distances of planets, stars, galaxies and other objects in the sky. How can astronomers measure the distances to these objects? For objects up to about 100 light years away they use a trigonometric method to measure a visual phenomenon called the parallax effect.

Preconditions: Students must know the basic star classification system (HR diagram, colour and temperature), how stars evolve, and how astronomical distances are measured. They must be familiar with basic geometry and trigonometric functions.

3 | What the students do

3 | 1 General introduction to the parallax method—measuring distances on the school campus

FIG.1 **Parallax shift observing the thumb**
seen by left eye   seen by right eye
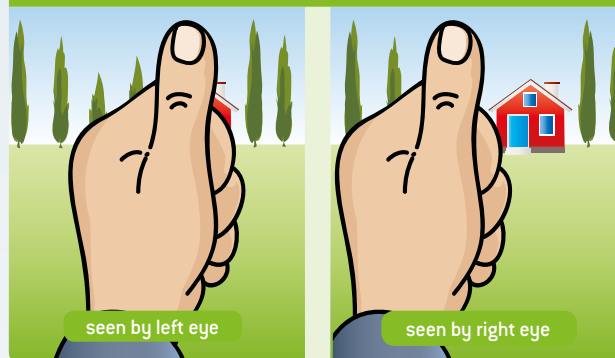
3 | 1 | 1 Experiencing the parallax effect with the thumb

You can see the parallax effect in action by simply stretching out your arm in front of your face, sticking up your thumb, and selecting an object within the room. Close your left eye and position your thumb in line with the object you have selected. Now open your left eye and shut your right eye without moving your thumb, and look at your thumb again. Even though you have not moved your thumb, you will notice that it has appeared to change its position. This shift in the position of your thumb in relation to the object in the background is called the parallax effect. It happens because each of your eyes is looking at your thumb from a different position in space. This is the parallax shift. The distance between the two points is the baseline.

FIG.2 **Simple parallax observation**
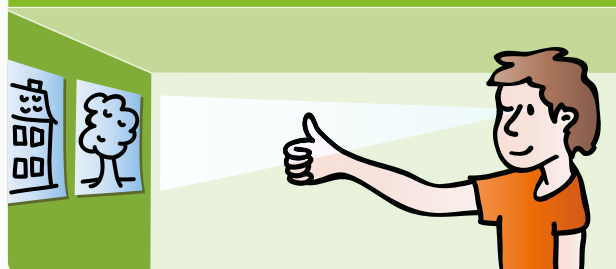
You can estimate the distance to an object by using the parallax shift and applying the following formula:

FIG.3

$$L = \frac{E/2}{\tan(\alpha/2)}$$

FIG.4 E: distance from the eyes, L: arm length, t: thumb position

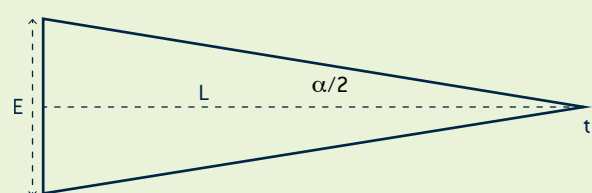It is important to emphasise that the distance is inversely proportional to the parallax angle. If the distance between the Earth and a star is long, the parallax angle is small; if the distance is short, the parallax angle is large.

3|1|2 Using a handmade angular measurement device

How can we easily determine the distance to close objects, e.g. in the classroom or in the school garden?

We were inspired by "PARALLAX – IT'S SIMPLE!". In this paper the authors created a cardboard device to measure the parallax effect.

As shown in FIG. 5, we developed a device to measure the parallax angle. It consists of a direction-finding part (which is turnable and moveable) and a rack (baseline = 1 metre).

FIG.5 Measurement on school campus

EXPERIMENT 1 Learn how to measure distances in the classroom by using the parallax method

Materials used
- Protractor (or smartphone with a compass app)
- Measuring device
- Object

For short distances you would not need this method, but you can learn how it works and how to be accurate.

Place the object (e.g. a bottle) somewhere on a table. Put the rack a few metres away, at a right angle to the viewing direction (rack–object). Move the turnable part to the other end, focus on the object (by eye or using a laser) and measure the angle between the two lines of sight. You can calculate the distance L by using the formula (FIG. 3).

EXPERIMENT 2 Use the parallax method to measure distances on the school campus

Materials used
- Measuring device
- Protractor (or smartphone with a compass app)
- Streetlight on the school campus

Place the measurement rack at a distance from the object. Point to the object from both ends of the rack and determine the angle between the two lines of sight. Instead of a classic protractor you can use a smartphone (with a compass app). It is rather tricky to measure the angle using a magnetic compass; make sure no iron objects are near the measurement device.

Instead of this device you can use a scale or the border of a table with a known length. The measurement will become more exact if you use a longer scale, e.g. 3 metres.

3|1|3 Practice and think about the parallax method using apps

There are a lot of apps you can use to measure (short) distances, e.g. Smart Measure. They use the phone's camera. Measure some distances within the school building and compare them with the results of measuring tapes.

Using the picture, explain how the measurement works. (The camera is used to locate the object. The phone uses its g-sensor to determine the slope. It calculates the distance by using the known height h (input) and the angle of 90° at the bottom.)

Smart Measure is an appropriate tool for measuring the height of an object and its distance from you. This telemeter measures the distance, height, width and area of an object by using trigonometry with your smartphone. It's simple to use: you only have to stand up, push the button and aim the camera at the ground, not the object, to find out the distance instantly.
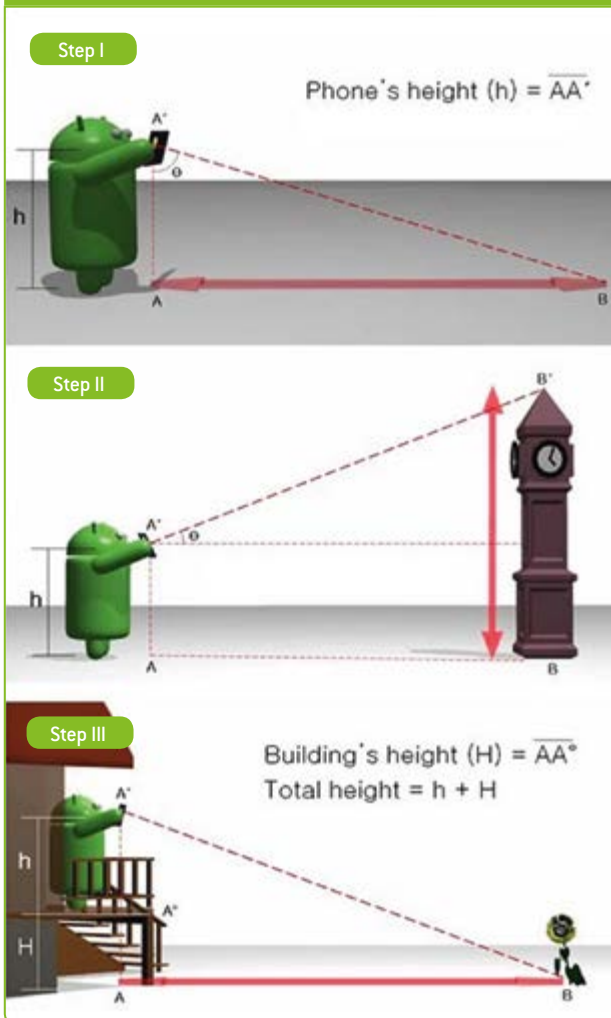
The Distance and Parallax app works with our eyes and a pencil. Although it is a simple calculation tool, it convincingly shows the principle of parallax measurement.

3|2 Determine the distance to the moon (simulation)

The students have to simulate a parallax measurement by using data they get from apps. **Principle:** A virtual observation.

FIG.6 Smart Measure screenshot

Step I

Phone's height (h) = $\overline{AA'}$

Step II

Step III

Building's height (H) = $\overline{AA'}$
Total height = h + H

We need two locations on Earth on the same meridian (i.e. at the same geographical longitude), but far away — e.g. in Europe and South Africa. Then we have to measure the altitude of the moon (the angle between it and the horizon) when it passes the meridian, simultaneously from both locations.

To make the calculation easy, we choose two locations: 60° North and 60° South, both at the longitude of 15° East. Here they are shown for the Stellarium app.

FIG.7 Moon in the northern sky (upper figure) and in the southern sky (lower figure)

We have to find out the time when the moon passes the meridian. For 9 February 2014 this was 8:20 p.m. Stellarium shows the moon's altitude above the horizon. (Note that in the northern hemisphere the meridian is in the south, and in the southern hemisphere it is in the north.)

FIG.8 Moon data, northern sky

We can see that: h (north): 48°41' = 48.68°;
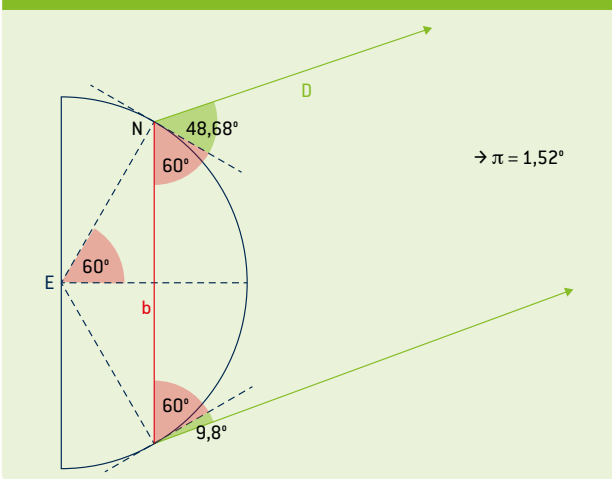h (south): 9°48' = 9.8°

FIG.9 Moon data, southern sky

This gives us the following situation:

FIG.10 E: Earth; D: distance to the moon

The baseline b(N−S) can be calculated with:
$\sin 60° = b/2 : 6{,}370 \text{ km} \rightarrow b = 11{,}033 \text{ km}$

Adding 60° to each of the altitudes, we get for the parallax angle π:
$180° − 60° − 60° − 48.68° − 9.8° = 1.52°$.

Simplification: We calculate with a right angle → $\tan π = b/D$, which gives us D = 415,786 km. Compared with the real distance of 398,733 km, this is 4 % too far.

4 | Cooperation option
The altitude of the ISS—an international collaboration project

The International Space Station is a very bright object that is fascinating to observe. Because it is very close to the Earth (300-400 km high), it is possible to use the parallax method to calculate the altitude of a real astronomical object.

We can estimate the altitude of the International Space Station by using angle measurements taken from two locations at the same time.

▸ 1. Using the app ISS Detector: Find a possible observation point at each location. Agree on the measurement time. This moment should be as exact as possible (within seconds), because the ISS is moving very fast.
▸ 2. Determine the air-line distance and the aberration of this line in a northerly direction.
▸ 3. You have to measure two angles at the same time: the altitude and the compass point (angle to the north). You can use two apps for this purpose: Smart Protractor (altitude) and the compass. Alternatively, try the Theodolite app, which gives both angles at the same time.
▸ 4. Share the data.
▸ 5. Calculate the altitude, then analyse and discuss the results. How can you calculate the altitude?

FIG.11 Calculation
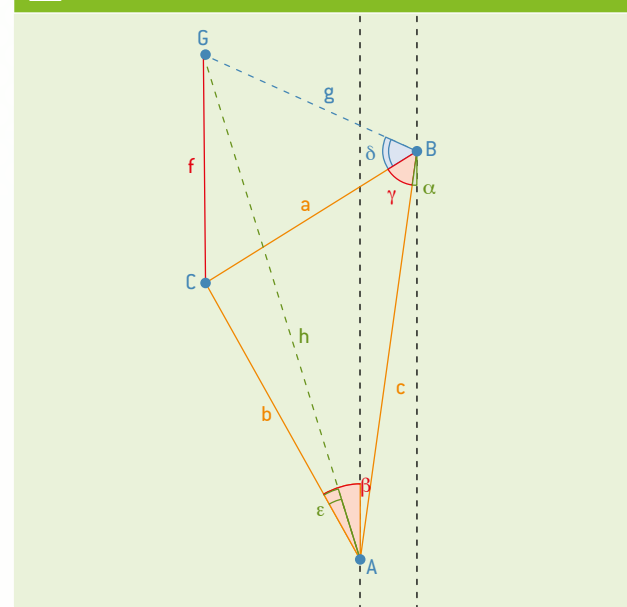
In this figure the two locations are A and B. c represents the air-line distance, α the aberration.

β and γ are the directions to the ISS (here at G), pointing to the virtual base point C. So the red triangle is located on the Earth, connecting the observation points with the base point of ISS.

Using this triangle, we can calculate the ground distances a and b by using the law of sines:
$π = 180° − α − β$
$c/\sin π = a/\sin (β + α) = b/\sin (γ − α)$

Then we calculate the altitude of the ISS (f). Here it is shown for location B. We have the ground distance a and have measured the altitude δ. So we get f: $\tan \delta = f/a$

Example:
▸ Locations: Graz (A) and Naples (I). Air-line distance: 700 km, aberration to the meridian: 8°.
▸ Date: 20 February 2014. The ISS Detector shows us what we can expect.

In Graz we will see the ISS moving from west to southwest, in Naples from northwest to north.

📱 **FIG.12 ISS seen from Graz (left) and seen from Naples (right)**
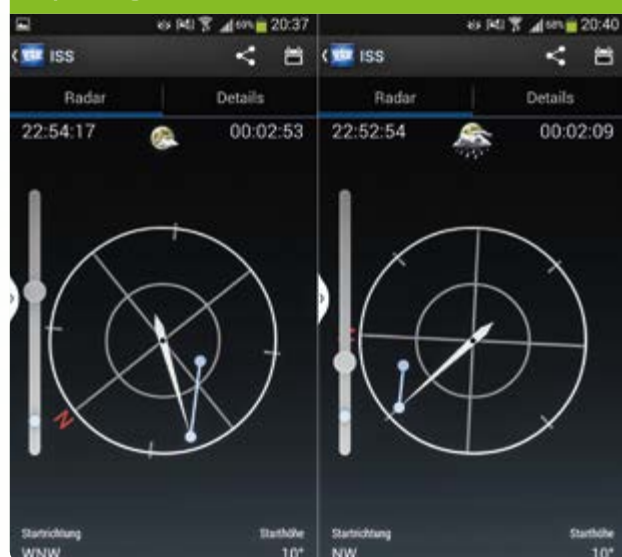
At 7:35 p.m. we measured the angles seen in **FIG. 13**. The red triangle shows the ground point of the ISS at this time near Verona. Using the formula above, we determine that a is 450 km and b is 540 km.
▸ Altitude measurements: Graz: 56°, Naples: 31°

Using the formula above, we calculated that the altitude f is about 320 km.

5 | Conclusion

What the students are expected to gain from this experiment:
▸ An understanding of how to measure and calculate astronomical distances (up to a hundred light years from the Earth)
▸ Skills in using mobile devices to make angular measurements and calculations
▸ An understanding of the relationship between the variability of their measurements and the accuracy of astronomic measurements

📈 **FIG.13 Triangle with measured angles**
(Map source: OpenStreetMap)

At the end of the experiments, the students should be able to calculate the effective distance between two objects thanks to very simple instruments, such as the parallax measuring device and a smartphone app. Hands-on activities can effectively involve students in the learning process and help them gain skills in the handling of scientific tools.

Students have participated with real enthusiasm and been emotionally involved in this experimental activity. Our students also learned that in the real world trigonometry functions are used not only during maths lessons but also in GPS navigation and in surveying. Astronomers use parallax angles and other techniques for finding the distances to the stars every day. This article also suggests ways in which parallax and trigonometry functions are used in real-world applications, such as surveying, celestial navigation, and even 3D movies. It also discusses how parallax angles to stars are measured, as well as other techniques for finding the distances to the moon.

6 | References

▸ "Parallax – it's simple!", Ilgonis Vilks and Alexandre Costa, EAAE Summer School Working Group Latvia – Portugal, link: eaae-astronomy.org/WG3-SS/WorkShops/pdf/ ws7_2007.pdf (29.08.2014)
▸ OpenStreetMap: www.openstreetmap.org

iSky: Smart Measurements of the Heavens

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1 | Summary

How can mobile phones be used for astronomy? Starting with planetarium apps, we can go on to take measurements of objects in the sky by day and night. By determining the altitude of stars or of the sun, we can learn about orientation, our position on the Earth and the size of our planet.

- **Keywords:** measuring altitude, latitude, longitude
- **Disciplines:** ICT, mathematics, geography, astronomy
- **Age level of students:** 14-18 years
- **Android apps:** Angle Meter, Google Maps, Planetarium, Smart Protractor, Star Chart, Theodolite droid
- **iOS apps:** Angle Meter, Solar Walk, Star Chart, GPS Essentials, Theodolite

2 | Conceptual introduction

Is it possible to find a geographic location by reference to the stars? We live on a big sphere that rotates and moves around the sun. This gives us changing perspectives and patterns in the sky and makes it difficult for us to orientate ourselves and determine our location in space.

Throughout history, the use of the stars has been an important tool for determining the position of individuals and places on the Earth. From the viewpoint of European history, the astrolabe could be considered the first mechanism that was used to locate a star in space. During the great voyages in the fifteenth century, it was used to determine positions at sea by measuring the altitude of Polaris—its height above the horizon—which gives the local latitude. In this context we have to note that an error of only 1° in the altitude causes an error of more than 100 km in the position.

The precision was increased by using a Davis sextant, mainly to measure the altitude of the sun at noon. But it was not until Harrison's invention of the marine chronometer that it was also possible to determine the local longitude.

Nowadays we can determine positions by using electronic methods, but the use of classic astronomical techniques still allows us to compare and evaluate the degrees of accuracy of the different methods. We can also combine traditional and modern methods in order to learn about historical measurements such as the famous experiment of Eratosthenes to determine the size of the Earth.

In most countries, the treatment of this subject in the school curriculum is rather theoretical. Students are not given any examples of how to apply the methods of calculation or any opportunities to compare classic methods with the use of mobile devices. Therefore, this will be the focus of our work. The objectives to be achieved are:

- Gaining basic orientation regarding the night sky by using smartphone apps.
- Reconciling the use of ICT (apps for mobiles and tablets) with traditional techniques for obtaining results in the area of astronomy.
- Measuring the altitude of two stars (Polaris and the sun) by using a smartphone and the associated applications.
- Calculating the circumference of the Earth by means of an experiment similar to that of Eratosthenes.

3 | What the students do

3 | 1 Introduction: Planetarium—the sky above

📱 **FIG.1 Screenshot Star Chart app**
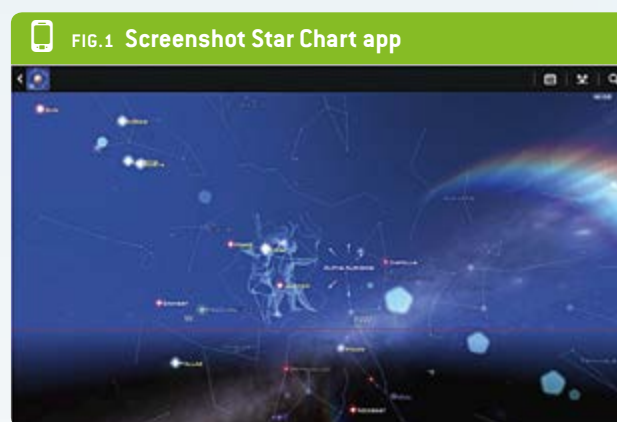
We use Planetarium apps such as Google Sky Map or Star Chart to orientate ourselves in the sky and to learn astronomy.

Basics: horizon, zenith; the constellations and their movements; the sun, the moon and the planets; coordinates.

EXERCISES
Star Chart

- Use the fixed mode (AR mode off).
- Search for the horizon. Turn around virtually one time (360°), and "look" in every direction.
- Go up vertically — what can you observe? How far can you go?
- Search for the planet Saturn and zoom in until you can see its moons. Tap on one of them and note the information about it. What do you notice during the very close zooms?
- Change to 3D Explore mode and make a virtual journey around the poles of the Earth.
- Activate the time/date mode and look toward the southern horizon. Try taking different time steps and note your observations.

3|2 Measurement: Altitude of Polaris

Determine the local latitude by measuring the altitude of Polaris. Of course the "altitude" of an astronomical object is not a distance, but the angle from the horizon straight up to the object. FIG. 2 shows that the altitude of Polaris is the same as the local latitude.

📈 FIG.2 **Altitude of Polaris; altitude of Polaris = latitude**
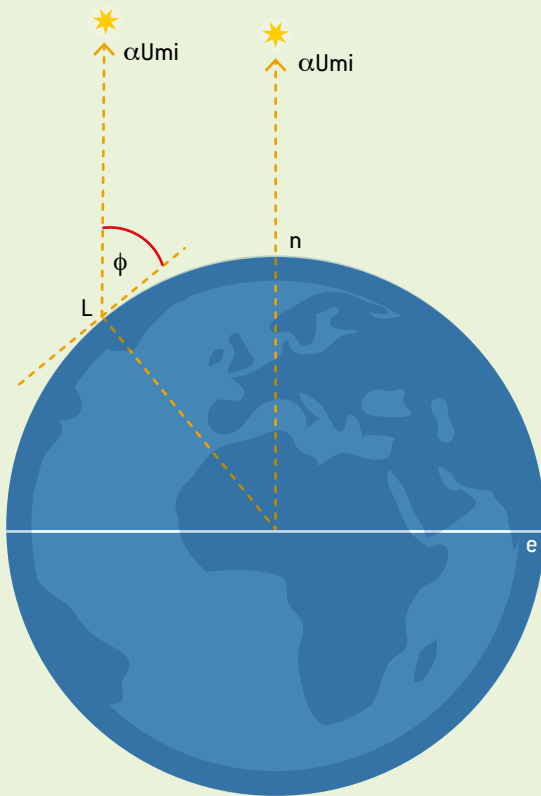
latitude = Φ | horizon = n | equator = e
altitude of Polaris: αUmi

How can you measure the altitude of a star using your smartphone? Try using angle measurement apps. It will be important to adjust the phone properly and to look along the edge. How accurate are the measurements? You can compare the results with GPS data in order to estimate the accuracy of your experiment.

A hint: Locating this star is tricky, because it is not very bright. You may be able to train your measurement skills by starting with brighter objects such as planets or the moon.

FIGS. 6-8 show a tool that enables you to support the measurement by stabilizing the phone and positioning it using a tripod.

3|3 Measurement: Altitude of the sun

Throughout history, it was important for navigators to be able to determine the altitude of the sun at noon. For a long time, this was the only way to determine the position of a ship at sea (latitude).

Determine the altitude of the sun at noon at your location by using a mobile device. DANGER: Do not look directly at the sun! When you located Polaris you may have looked along an edge of your phone, but this is not possible with the sun! However, you can use a shadow cast by the sun to make your measurement.

Suggestion: Attach a straw to one edge of the phone with adhesive tape. Search for the minimised shadow at noon and measure the slope of the phone with an angle measurement app.

📷 FIG.3 **Easy measurement of the altitude of the sun**

Use the Planetarium app to get the relevant data (e.g. the time of real noon, the declination) and compare the data with your measurement. How accurate was your measurement?

📱 FIG.4 **Planetarium app**

FIG. 5 shows the angles involved. If you know the declination, you can determine the latitude:

FIG.5

latitude = Φ | declination = δ | altitude = α
horizon = n | equator = e
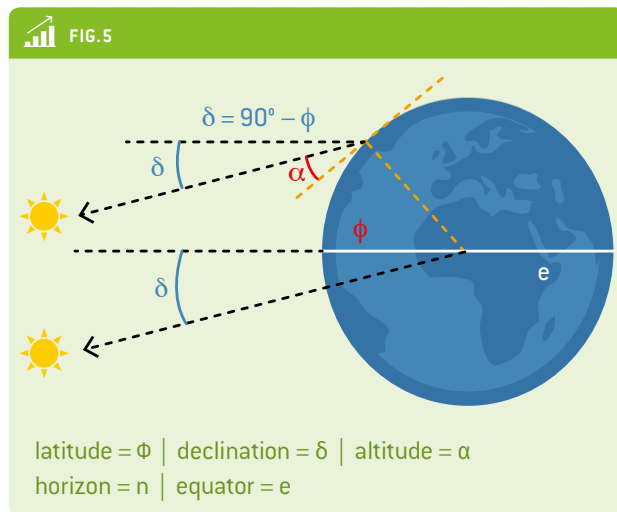
Alternative suggestion: For a more stable positioning of the mobile phone, we suggest that you build a device that can be placed on a tripod. This way it will be easier to point precisely to the sun's position from anywhere.

Equipment needed:
- Tripod
- Smartphone
- Medium-density fibreboard (MDF) 3 mm
- Wood strip 1 × 2 cm
- PVC pipe 13/16 mm
- ¼" BSW (British Standard Whitworth) full nut
- Elastic string
- Glue

You can see the assembly process at www.science-on-stage.de/iStage2-downloads.

4 | Cooperation option

Eratosthenes experiment

Measure the altitude of the sun at real noon at different locations. By using Google Maps, we can get the air-line distances and calculate the radius of the Earth.

Step by step for two locations: Decide on a day X to perform the experiment. Note the weather forecast—clear skies are necessary at noon at both locations. Find out the time of real noon and the air-line distance for each location.

Day X: Determine the altitude of the sun at real noon at the two locations. Share the data and determine the difference between the two altitudes. Calculate the circumference of the Earth using Eratosthenes' method.

FIG.9 **Example of measurement: Tarragona — Lyon 495 km** map source: OpenStreetMap
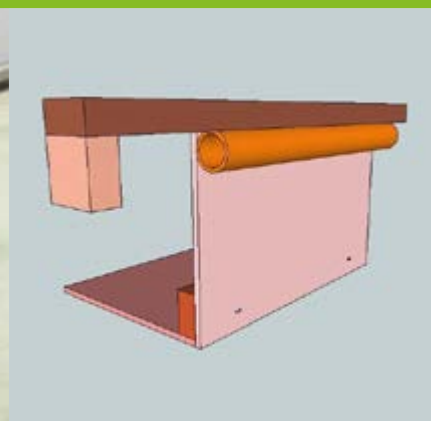

FIG.6 · 7 · 8

FIG.10 **Tarragona: real noon: 13:56**

Planetarium

Valls (ES) / 41,28544° N / 1,24946° E

Juny 21 2014

13:56 Europe/Madrid (UTC+02:00) CEST

Sun

Rise 06:21   Transit 13:56   Set 21:31
Civil dawn 05:48   Civil dusk 22:05
Azimuth 359,4° S   Altitude 72,2°
Distance 152.026.702 km
Constellation ♉ Taurus, ♊ Gemini (21:22)

FIG.11 **Lyon: real noon: 13:42**

Planetarium

Lyon (FR) / 45,7654° N / 4,83659° E

Juny 21 2014

13:42 Europe/Paris (UTC+02:00) CEST

Sun

Rise 05:50   Transit 13:42   Set 21:34
Civil dawn 05:12   Civil dusk 22:12
Azimuth 359,7° S   Altitude 67,7°
Distance 152.026.598 km
Constellation ♉ Taurus, ♊ Gemini (21:22)

- Day X: 21 June. Planetarium app (**FIGS. 10** and **11**).
- Altitude of the sun (should be measured): 72.2°
- Altitude of the sun: 67.7°
- The angular difference is: 72.2° - 67.7° = 4.5°
- Calculation: 4.5° corresponds to 495 km.
  Circumference c = ?
- $4.5° : 360° = 495 \text{ km} : c$
- $c = 495 \cdot 360 : 4.5 = 39{,}600 \text{ km}$

How accurate is the measurement?
- We can measure the angle with an accuracy of 0.1°, e.g.
  Tarragona: 72.3°, Lyon: 67.7°. Difference: 4.7°.
- We calculate c = 37,914 km. So we can expect an accuracy of about +/- 2,000 km.
- If the angular difference is bigger, the error will be smaller.

5 | Conclusion

Smartphones are powerful and multifunctional tools. We can learn a lot of basic astronomy not only from simulations such as planetarium apps, but also by using smartphones as measurement tools. The built-in acceleration sensors permit a precision of 0.1° in slope angles. This enables us not only to locate our own position on the Earth using the North Star or the sun, but also to estimate the circumference of the Earth according to Eratosthenes' method. The charm of this experiment lies in the fact that we are performing historical experiments using modern devices, comparing the methods and evaluating the accuracy of the measurements.

We can see that the use of smartphones does not mean we can work less carefully. We have to learn how to use them correctly, and we will have to repeat our experiments in order to increase our accuracy. Even when we use new technologies, we still need old virtues too; this remains the case when we do real science.
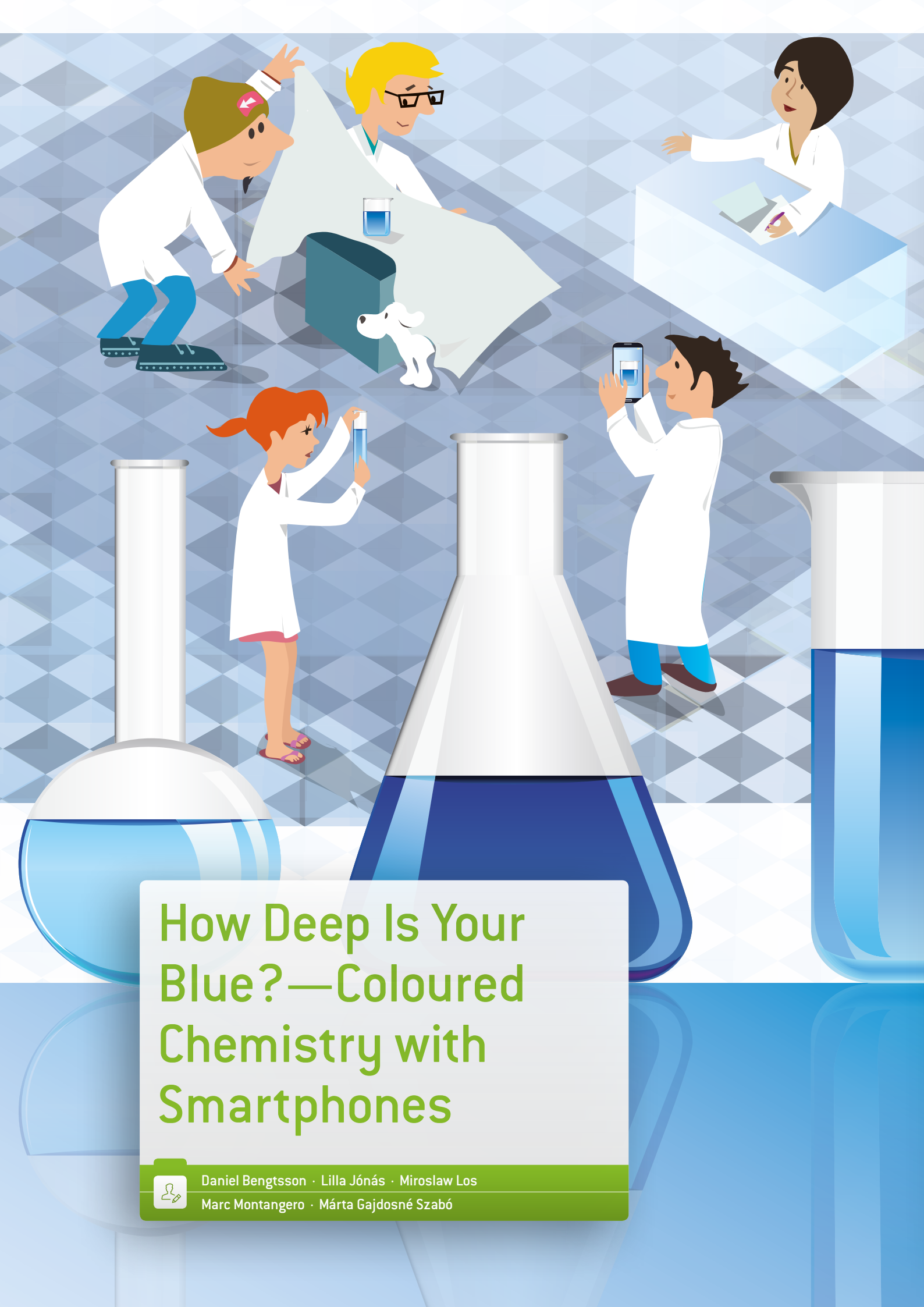
How Deep Is Your Blue?—Coloured Chemistry with Smartphones

Daniel Bengtsson · Lilla Jónás · Miroslaw Los
Marc Montangero · Márta Gajdosné Szabó

1 | Summary

Copper dissolved in water yields a blue solution. The more copper is dissolved, the more blue the solution becomes. Students can use a smartphone to determine how much copper is dissolved in an aqueous solution of nitric acid. To do this, they must prepare three solutions in which known amounts of copper have been dissolved and make measurements.

▸ **Keywords:** copper solution, Lambert-Beer Law, scientific method protocols
▸ **Disciplines:** chemistry, mathematics
▸ **Age level of students:** 13-16 and 16-18 years
▸ **Android app:** Color Grab
▸ **iOS app:** ColorAssist Free Edition

2 | Conceptual introduction

People know that when you dilute syrup, it turns a lighter colour. This is because the absorption of light, which gives the colour, is proportional to the concentration of the dissolved colorant (Lambert-Beer Law). In this activity, the students will test this law by carrying out measurements of copper solutions using their smartphones.
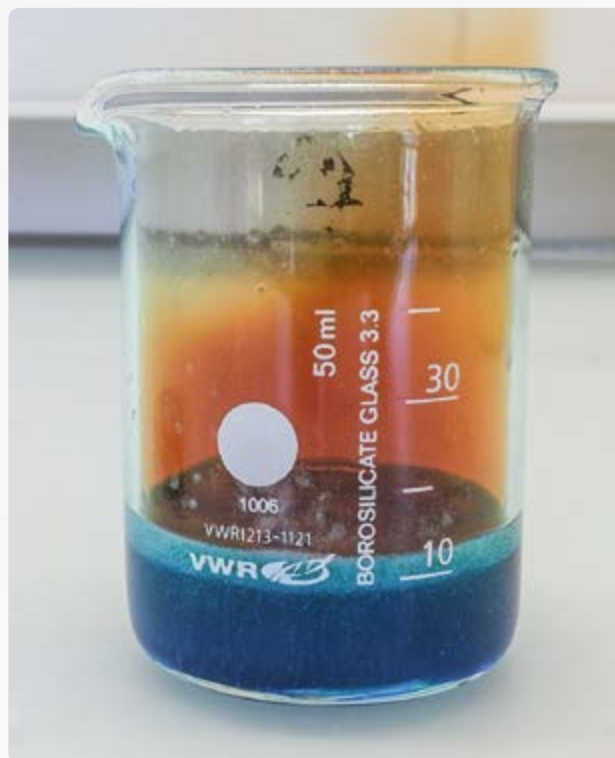
This activity is of course intended for a chemistry lab, but it is also suitable for a mathematics class (the students can use solutions prepared by the teacher and just make the measurements on them). In the chemistry lab, students will prepare three different solutions containing known amounts of copper (using a copper salt). The teacher dissolves an unknown amount of pure copper (unknown to the students) in nitric acid.

Students use the smartphone to collect data on the four solutions. They organise the collected data on a graph in order to determine the unknown amount of copper that has been dissolved by the teacher.

This activity gives the students an opportunity to practice the scientific method. They have a question to answer (how much copper did my teacher dissolve?). They must choose (in challenge mode) the way they will make the measurements. The students then make measurements, collect data, organise the data in a table and make a graph. The graph is used to estimate the amount of copper.

3 | What the students do

Here we suggest three different protocols. The first one is the "classic" cookbook protocol, which provides all of the details on how to carry it out. The second one is a protocol for a math-

ematics class, in which all the solutions have been prepared in advance; the students only make the measurements and carry out the analysis during the class. The third protocol is an open protocol: the students only get a little information and a question to answer.

3 | 1 Cookbook protocol

3 | 1 | 1 Part A: The teacher prepares the unknown copper solution

Hazards: HNO_3 is corrosive! Use gloves, glasses and a fume hood!!

Take between 1.5 g and 3.5 g of pure copper (note the exact mass m (Cu)!). In a 50 cm³ beaker, pour 5 times m (Cu) cm³ of 65% HNO_3 (work under a fume hood! If you took 2 g of copper, use 5 times 2 = 10 cm³ of nitric acid). Pour in the copper (little by little if the copper is in powder form), close the fume hood and wait until all the copper has been dissolved. Add water to about 30 cm³, then transfer it to a 100 cm³ flask, dilute with water to 100 cm³ and close the flask; stir well.

3 | 1 | 2 Part B: The students make the scale

In three 100 cm³ flasks, dissolve about 5, 10 and 15 g of $Cu(NO_3)_2 \cdot 3H_2O$ (note the exact masses m1, m2 and m3!) and dilute with water to 100 cm³; close the flask and stir well. This makes the scale with numbers 1, 2 and 3.

You can also replace $Cu(NO_3)_2 \cdot 3H_2O$ with $CuSO_4 \cdot 5H_2O$ (do not change the quantities) or with anhydrous $CuSO_4$ (use about 3.3 g, 6.6 g and 10 g in this case).

3|1|3 Part C: The students measure the H-values with their smartphones

Put the flask on a white paper (bottom and background) and make some lines on the bottom to note the exact position of the flask. Fix your smartphone on the table so that the centre of the camera points at the larger part of the flask (the viewing angle is horizontal).

FIG.1 Students measuring the H-value with the smartphone

The distance between the background and the flask is about 4 cm, and between the smartphone and the flask it is about 14 cm. Just read the H-value (of the HSV or HSL colour model) with the app and note it; repeat this with all the flasks.

3|1|4 Part D: The students use their results

First transform the masses of scale (m1, m2 and m3) into the equivalent masses of pure copper. Make a graph of the H-value as a function of the mass of copper for the three values of the scale. Record the H-value of the sample on the graph and determine the mass of copper in the unknown copper solution.

FIG.2 Relationship between the H-value (°) and the mass of copper (g). The blue dots are the three points of the scale; the red dot is the unknown copper solution
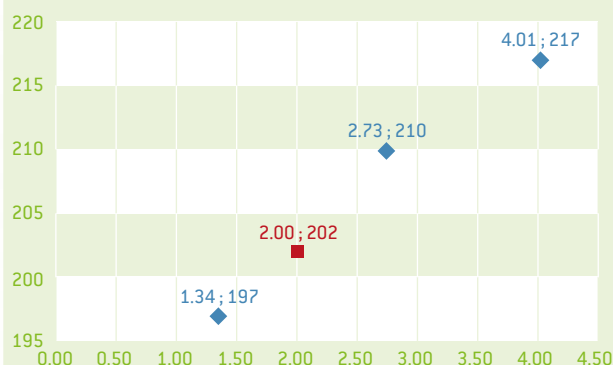
3|2 Mathematics class protocol

The teacher has to make the four solutions in advance and write the equivalent mass of pure copper on the flasks. Prepare the equipment the students will probably need or ask for in order to carry out a fair test.

▸ 1. Install the application and figure out the best way to measure the colour. Try to learn how to pause the measurement and how to use the flash.
▸ 2. The three flasks contain different masses of copper. Look at the labels. Your assignment is to measure the H-values of the solutions in the three flasks and to draw a graph (see above). Record the relationship between the H-value and the mass of copper. The more copper, the darker the solution.
▸ 3. From another group (or your teacher) you will be given a flask with an unknown mass of copper.
▸ 4. Measure the H-value of the fourth solution exactly the same way you have done before. With the graph you should be able to find the mass of the copper in this flask.

3|3 Challenge protocol

The teacher asks the students to install the app, shows them how to use it and asks them to carry out a fair test using the H-value. He gives them the three flasks with the masses of copper written on them and asks them to determine the mass of copper in the fourth flask.

4| Cooperation option

The students in one class carry out the experiment and make a movie that explains how to do the experiment by means of a smartphone. The movie is sent to another class (international or in the same school), who will use it as a protocol.

5 | Conclusion

In this experiment, students will learn:

▸ that the higher the concentration of copper ions, the more blue the solution.
▸ how to follow a precise protocol and how to identify an unknown solution using their own scale.
▸ how to use a smartphone colour identification app.

Students face several difficulties in this experiment. In particular, when they use the app the viewing angle should be perfectly horizontal in order to yield reproducible measurements.

All of the measurements (scale and sample) should be done simultaneously in order to avoid different lighting conditions.

5 | 1 Feedback

Students:

▸ "Different from other labs."
▸ "Mix of chemistry and technology. WOW!"
▸ "The protocol is easy to understand and to follow."
▸ "It was interesting to have to use our smartphones in the chemistry lab."
▸ "We loved using our smartphones during the lab. Combining technology and chemistry was great!"

A teacher's experience:

"Yes, I think it's a good idea to practise making our own investigations. I try as often as I can to let my students investigate a phenomenon and try to understand it. Instead of a protocol, I give them a question or a problem they should find an answer to. I call it an open experiment. They should try something out and try to keep as many variables as possible unchanged. A fair test.

In this case I show them the three flasks and tell them that you can measure the colour with a smartphone. This value or code can be used in a shop when you buy paint. Then I ask them to plan the experiment as precisely and fairly as they can! I exaggerate and show them really bad ways of doing it. I also show them how to hold the device in front of the solution, in a light or dark place, and how to keep the way they measure the value as equal and fair as possible.

They install the app and I help them to make it work. I show them how to pause the app and how to get the H-value. Then they plan how to measure and I give them the equipment they ask for—for example, a lamp, a ruler or a white sheet of paper.

Then they measure the three flasks and find out the mass of pure copper from me. If you have older pupils you tell them the mass of $CuNO_3/CuSO_4$ and they have to calculate how much pure copper they have. They make a table with the values they have. They receive millimetre graph paper so they can plot the graph. Then they can see how much copper the unknown flask contains by plotting the line connecting the three known values in the graph.

My pupils put a certain amount of copper in a flask without telling me the mass. Then I pour nitric acid into the flask and

dilute the solution to 100 cm³ after the metal has been totally dissolved.

Now they can measure the H-value in the fourth flask. From their value I can tell how much copper it contains."

5|2 What does the app do?

It measures a colour and expresses its values in terms of a colour model (RGB, HSV, LAB etc.). This can be useful when you want to buy paint of a particular colour; you can measure the colour with your smartphone and ask the paint shop for the same colour.

5|3 Why use the HSV or HSL colour model?

The RGB system is the most commonly used colour model, but these values are not related to the wavelength of the colour. This system uses only one wavelength of each primary colour. The hue value (H) of the HSV or HSL colour model distinguishes between the different blues (navy blue, deep sky blue, pacific blue etc.). This value can be used instead of absorption in a certain range of concentration (it doesn't work if the solution is too dilute or too concentrated).

5|4 Can this app be used for other experiments?

Although we did not try it, we think the same procedure could be used with other coloured solutions (potassium permanganate, food colouring solutions etc.). You just have to identify the range of concentrations for which the H-value is proportional to the concentration of each coloured substance.

We have tried to use it with a well-known colour experiment: red cabbage. Unfortunately, this was not possible, because the different colours of red cabbage do not show any linear variation of the pH in terms of wavelength. Therefore there is no way to model the whole pH range. We also tried to differentiate the hues between pH 3 and 10, but the app was not able to do so. The app can therefore only give us the "basic" colour of red cabbage (pink, purple, green, yellow) and we can then deduce a range of possible pH values, but we usually do that by using our eyes. So it makes no sense to use the smartphone for this purpose.

How to use the app

How to plot the measurements

Ears

Over the past few years smartphones have become a part of everyday life, to the point where most people can't imagine life without them. Go out on the street and look around you; everybody has a smartphone in his or her hands. People don't even look at each other anymore, and students are no exception. Smartphones open the door to the world and all its distractions, yet they have been banned in most European schools. However, this is not the solution; ignoring modern technology and the way our habits are changing will not "preserve" the school system; it will merely increase the gap between teachers and students.

These little slabs of glass, metal and plastic should not be mistaken for "toys". They are very powerful computers with processing power that nerds of the 1980s would have thought impossible in such a small device. By 2010, the best smartphone was already as powerful as the Cray 1 (one of the mythical supercomputers of 1979 used at the Los Alamos laboratory to develop nuclear bombs for the USA and at various meteorological agencies to calculate weather forecasts). And that's just the beginning, because our smartphones have a lot of sensors to find out where they are in space (GPS, accelerometer, compass, magnetometer etc.), communication links (3G, 4G, Wi-Fi, NFC, Bluetooth etc.), data recorders for sound and images (most of the time with two cameras), pressure sensors, proximity sensors, temperature sensors … and the list goes on!

Because they are cheap, compact and easily portable, smartphones are perfect scientific tools that could replace regular computers for a wide range of applications in science. You don't have to buy expensive external sensors, as we used to do in schools a few years ago.

Of course smartphone sensors are not as sensitive and precise as the professional-grade ones used in universities and research centres. But this is not a problem for schools, because we only want students to understand physics, chemistry or biology by doing experiments. Smartphones can be calibrated to solve precision problems, as explained in the unit about noise pollution.

Instead of fighting this technology, which has been so widely adopted by our students, we should use it wisely and accept the fact that our schools have no money to spend, because almost all of our pupils have their "scientific tools" in their pockets! From a teacher's point of view, the challenge is to find out how to best use this tool, and the aim of this booklet is to help teachers do just that.

In the "Ears" section, we introduce four different projects involving sound. Our teachers from all over Europe will explain how to compare the frequencies and harmonics of musical instruments, how to make a noise map of your school to reduce noise pollution, how to study the effects of noise pollution on birdsong, and how to measure the speed of a car by means of the Doppler effect. These teaching units are laid out as step-by-step recipes, so you can use them as they are or adapt them to your curriculum, student age or current mood.

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Coordinator

Spectral Sounds

Marco Nicolini

Emmanuel Thibault

1 | Summary

Young pupils are often fascinated by music, not only because they listen to music on dozens of devices, but also because a number of them play musical instruments at different levels. For this reason music is a good way to explore wave phenomena and behaviour. And since waves are found in different areas of physics and science, music can be used to investigate a concept that is widespread in science. This activity is focused on studying what is called the spectrum of a sound, and in particular the entire range of frequencies produced by an instrument. It is this range which characterises any musical instrument.

- **Keywords:** sound, frequency, power, pressure, amplitude, note, pitch, timbre, graphs, logarithms
- **Disciplines involved:** physics, music, mathematics
- **Age level of students:** 16-18 years
- **Android apps:** Sound Spectrum Analyzer; n-Track Tuner
- **iOS apps:** iAnalyzer Lite
- **Further computer software:** freeware sound card oscilloscope SW, Scope 1.41

2 | Conceptual introduction

2 | 1 The science involved

Sound is a great way to study waves. Waves are common to different themes in science: sound, light, radio transmission and electromagnetic fields, plus any periodic phenomena—events repeating themselves at regular time intervals. Waves provide a good mathematical model for studying the behaviour of periodic dependencies. Laptops, tablets and smartphones are able to convert sound into a digital form, which means numbers, with the onboard microphone and an analogue-to-digital converter. And with the numbers on electronic devices, graphs can be plotted to show the waveforms and characteristics of the sound. Many oscilloscope apps based on smartphones' onboard microphones can be found for any operating system. Most of them offer the features that are necessary for a good study of waves. This is the reason why sound and smartphones offer quick access to an effective class activity focusing on waves. Many interesting characteristics of waves can be visualised using an oscilloscope app. As we conduct this activity, we will be studying and visualising waves in a time domain and, above all, in a frequency domain. Showing waves in a time domain means that we will basically see the sinusoidal graph of a wave, detecting its period, frequency and wavelength. Studying waves in a frequency domain is what in scientific language is known as studying the spectrum of a wave. This is what we will be most concerned with in this unit.

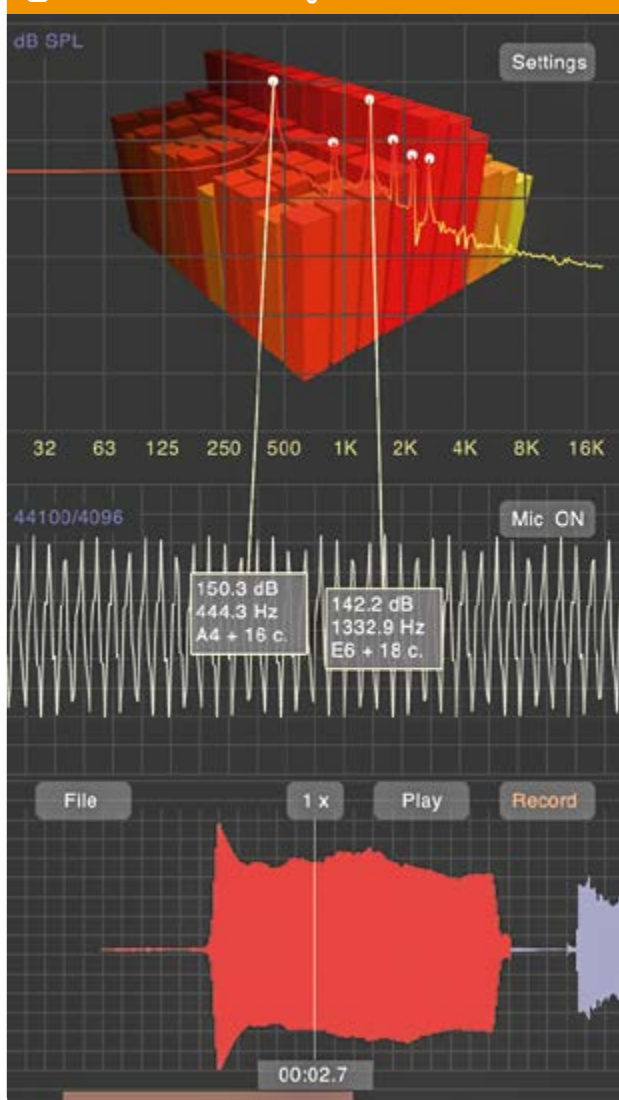

2 | 2 Relation to the curriculum

We assembled and conducted this project in Italy and France. Waves, as a general way of studying acoustics and optics, are studied in Italy in upper secondary schools with pupils aged 17-18. In France, acoustic music is taught in disciplines chosen by the students during the last year before the Baccalauréat (exams in secondary school in France). The concepts of intensity, pitch and timbre of a sound are studied by all students during the physics course in a topic called "Properties of waves" during the same year.

3 | What the students do

- The students download an app. They can choose amongst the apps mentioned above or find another one if they prefer.
- A set of instruments to be sampled is established. The students should preferably make the spectrum measurements on a set of instruments that includes string, woodwind, brass and percussion instruments. This is because the spectra they will get are slightly different, and different families of instruments produce different harmonic series.

FIG.1 Screenshot: iAnalyzer Lite

FIG.2 Screenshot: Sound Spectrum Analyzer

▸ The students should be sure to save every recorded spectrum in a file with a meaningful name that will allow them to recognise the note and the instrument later.

▸ Since the students are likely to use different apps and smartphones, it could be useful to have a common reference for every spectrum, independent of the smartphone microphone's sensitivity and the app's time resolution. We used the freeware sound card oscilloscope SW, Scope 1.41. Amongst its features, it has a good spectrum analysis window that is fantastic for educational purposes.

FIG.3 Harmonics of a flute

One nice idea is also to register and analyse the spectra of a tuning fork, a tone produced by an electronic source and the human voice, for comparison with the instruments.
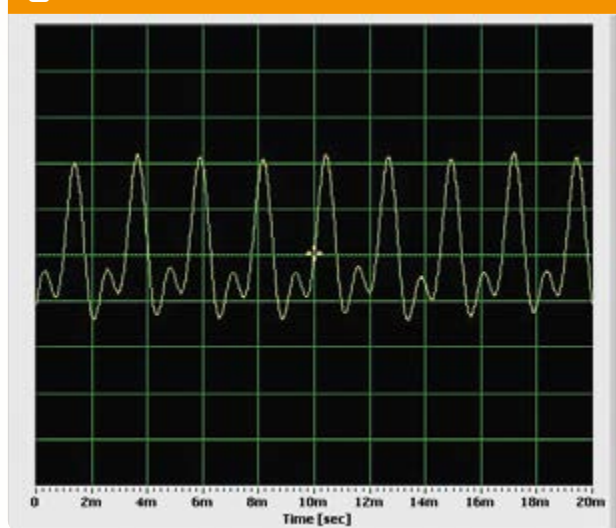
▸ A set of sampled frequencies must be chosen. These frequencies will be played by all the instruments. For instance, we agreed on C4, F4, G4 and A4, played by a violin, a guitar, a clarinet, an electronic keyboard (it can produce hundreds of sounds and timbres), an electric guitar and an oboe.

▸ The students can now start the recording phase. The pupil acting as the "musician" starts to play a note, and another pupil starts the app acquisition, putting the smartphone about one metre from the source of the music. After a few seconds, he or she stops the recording and saves the file or takes a screenshot.

▸ After recording the spectra for every note and every single instrument, the students analyse the graphs they have obtained, comparing each frequency spectrum obtained from every instrument. A table similar to FIG. 4 can help them analyse differences and analogies.

▸ Before ending the recording session, the students can also record the spectrum of a tuning fork, the notes produced electronically (a wealth of software to produce tones is available for PCs or smartphones), and the voice

FIG.4 A table can help to analyse differences and analogies. Write down your observations

Instrument	Note			
	C4	F4	G4	A4/440
Guitar (Acoustic)				
Guitar (Electric)				
Violin				
Clarinet				

of the best singer amongst the students, all singing the same notes.
▸ Now they are ready to examine the spectra produced by the orchestra. It is very interesting to examine the graphs of the strings (guitar, violin), the woodwinds (clarinet, flute), the brass instruments (trumpet, horn), and the percussion instruments, and to try to spot the analogies and the differences.

At first glance, for every recorded instrument you will notice a number of prominent peaks in its spectrum. These are the amplitudes (y-axis) of the frequencies (x-axis) that make up the harmonic series of the played note. The lower frequency is usually the fundamental note, the one that was actually played. You will also observe that a tuning fork produces a perfect line in the graphs, while the human voice, no matter how clear it is, produces a more complex line. This line is the result of the sum of all of the frequencies produced by the student's voice.

We would suggest that at this point you introduce some good inquiry-based learning (IBL) activity with the students in order to guide them toward spectrum analysis. This would be based on a form including questions such as the following:
▸ Describe what you see in the picture.
▸ Why do you think that some frequencies are more prominent than the others?
▸ Can you infer a dependency or a relationship amongst the prominent frequencies?
▸ Can you explain the dependence?

Further activities could include:
1. Inspect the mathematical construction of the tempered scale and deduce the pitch of the sound of an instrument.
▸ The students could propose a protocol to verify the relationship between the different notes of the 4th tempered scale. They can find the proper formula in several documents.

▸ They are then asked to find a linear relationship expressing the height of one of four notes of the scale and the number n of this note in the range. For this, a table giving the number of the note can be provided.
▸ Then, after downloading the mobile application, they record different sounds provided by a pitch pipe. They can deduce the pitch from the spectrum they obtain.
▸ Finally, they draw a graph on a spreadsheet showing the relationship between $\log(f_n)$ and the number n of the notes in the tempered scale. They must obtain an affine function whose leading coefficient is $\log(a)$. They can then return the value and compare it with the theoretical value.

2. Discover that the pitch of the sound of a pan pipe is inversely proportional to the length of the tubing.
▸ The students find the theoretical relation between the pitch of the sound emitted and the length of the pan pipe.
▸ Then they propose a protocol to verify this relation using the pan pipes, the spectrum analyser of their smartphone and a spreadsheet to plot a graph. Finally they implement their protocol.

3. Highlight the fact that the pitch of a note on a xylophone is proportional to the length of the respective bar.
▸ The students suggest an experimental protocol that can verify the influence of the small bar's length on the sound's frequency. This protocol must include the plan of a graph with a modelling.
▸ Then the students have to implement their protocol.

4 | Cooperation option
Students from different schools can work together to analyse the spectra of different instruments. They can also analyse the same instruments and compare their results. Another idea is that the different schools could focus on different kinds of instruments, i.e. one school could analyse woodwinds, while another could analyse brass instruments, and

then a spectral comparison can be performed, underlining differences and analogies.

If a musical instrument workshop is located in your area, you might want to measure the spectra of the instruments directly where they are assembled. For example, in Italy there is a centre of violin production in and around Cremona, thanks to the Stradivari tradition. Samples of spectra can be acquired at different stages of instrument assembly, so that the students can understand how the components influence the spectrum and the harmonics produced.

5 | Conclusion

Students can learn to understand the complex world of periodic events and wave phenomena by exploring the easiest and most visible part of it: acoustics. In particular, the activity shows them how a sound is composed of several frequencies, and how different frequencies can be assembled to produce a sound. They acquire the know-how that is required to analyse a sound spectrum, recognise the harmonics of a note, and understand how the amplitude depends on the frequency. They then will be able to analyse a light spectrum and an electromagnetic spectrum. This activity is also meant to motivate young students to study the production of sound in different instruments—the different harmonic formation in wind, string and brass instruments, and the waves and resonance in strings compared to pipes.

Personal experience

If you start examining a wave in the time domain together with students, you will show them a plain sinusoidal wave. In the frequency domain they may meet with some difficulties, because they see only lines. You might want the students to be able to understand logarithms: the amplitude (pressure or energy) is always measured on the Y-axis in decibels, so they should know how to read the decibel scale. Students have to

practice the use of apps in order to be able to spot harmonics and understand them as multiples of the fundamental frequency. Usually a background noise is recorded together with the notes unless you are in a very professional musical studio, so the students have got to recognise the background level and be able to get rid of it. Moreover, the premium apps usually offer the ability to save a spectrum as a file, but in a free app version the pupils have to take a screenshot of the graph, and this could lead to some logistical difficulties.

Since not all the apps shown in the list offer the option of saving the spectrum as a file, at least in the free versions, the pupil playing the instrument needs help from another pupil in order to take a screenshot of the recorded data. The graphs obtained are usually examined as pictures.

The spectrum of the oscilloscope running on a PC is always useful as a common reference for all the apps.

You might also want to explain to the students what the harmonics, pitch, loudness and timbre of a note are.

If you use an amplifier (i.e. for a guitar or an electronic keyboard), you have to consider that it can act as a filter, taking away some of the harmonics, volume or bass elements.

Please note that your spectrum might contain some unwanted noise. In particular, if some important electric activity is going on close to the location where you are carrying out this activity, you might notice that a 50Hz frequency is present in your spectrum. This is the (European) main electricity frequency, which might also cause some acoustic interference.

We started this project after introducing the topics of waves and sound. It received a good response from students who were able to play musical instruments.
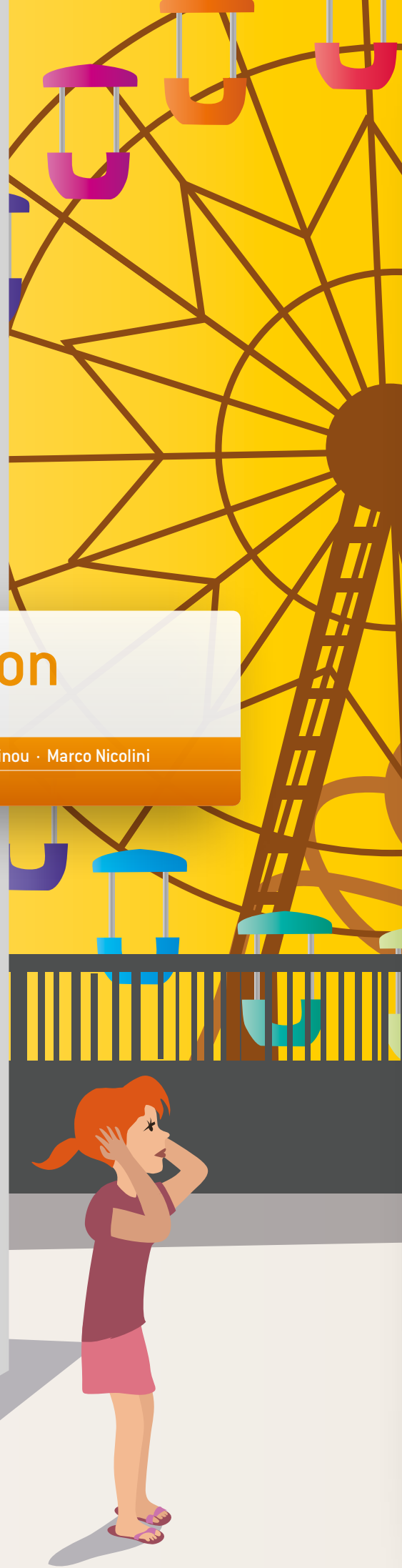
Noise Pollution

Maria Dobkowska · Dionysis Konstantinou · Marco Nicolini

Anna Maria Pavlou · Volker Smit

1 | Summary

Creating a noise map of the school's surroundings based on the students' measurements and exchanging the results between students of different countries[1].

- **Keywords:** noise pollution, acoustics, decibel, sound, power, pressure, energy and sound pressure, amplitude, oscillation, resonance, waves, equation graphs, decibel scale, logarithms, file management, spreadsheet, graphs, health, ear and hearing, physiology of stress, resonance on the human body, small-scale maps, using GPS points for mapping
- **Disciplines:** environmental studies, physics, maths, ICT, biology, geography
- **Age level of students:** 12-19 years
- **Ages 12-14:** survey, measurement of sound levels, qualitative analysis, preparing graphs in relation to the health issue
- **Ages 15-19:** survey, measurement of sound levels, qualitative and quantitative analysis, preparing graphs, discussion of noise in relation to physiological stress and well-being (health issue)
- **Android apps:** Decibel Meter, Sound Meter
- **iOS apps:** Decibel Ultra

2 | Conceptual introduction

This project forms part of environmental studies, because it deals with characteristics of the environment—noise levels and noise pollution. The main objective is to sensitise students to the quality of their school environment regarding the noise level. It is meant to be experimental, giving the students opportunities to use different approaches, including Inquiry Based Learning[2] (IBL). The students will have to design the process of their research and specify the methodology they will follow in order to establish a geographic map of the noise levels in their school area. They will have to understand how noise is measured and how simple it is to measure noise by using a microphone and an app. During the working process some concepts from the fields of physics, biology, maths, geography and ICT will automatically surface in the students' minds and be discussed, depending on the students' approach and their own tasks and questions. If results are to be compared between schools, the methodology of the measurements has to be identical or at least very similar.

2 | 1 The science involved: Noise pollution and its impacts

Noise pollution is a big issue in modern society, and it has a major impact on the health of almost everybody. Nowadays we can no longer experience perfect silence unless we are in a soundproof room or in a desert (without any wind). If you live in a city, you cannot avoid hearing background noise 24 hours a day. Our ears are used to this. But our ears are also

FIG.1-3 Screenshots: Decibel Meter, Decibel Ultra, Sound Meter

delicate, and we must be aware of how noise can damage them. Young people tend to disregard the dangers of unhealthy behaviour with respect to their acoustic apparatus. Music concerts, amusement parks and parties are places and events where noise can reach dangerous levels. Moreover, in these situations the sounds do not peak—they are constantly at high levels.

On top of this, our schools, as working and living environments, deliver many more acoustic impacts that can strongly increase both short-term and long-term chronic damage to the health of teachers and students alike.

Our aim for this project is to finally sensitise the whole school community to this noise problem. Since the students are the major factor contributing to this noise pollution, they could be the solution to this problem as well.

Students attend school at least five days a week and spend a lot of time in schoolrooms and recreation areas within the school. This means that the noise level should be monitored in school environments in particular. The activity described here encourages students to measure noise and sound levels at school and shows them some simple and cost-free tools for checking acoustic environments. Last but not least, health issues at schools have become more and more important during the past 20 years, ever since a common set of European laws was proposed by the EU (http://ec.europa.eu/environment/noise/home.htm, last updated: 8/22/2014). Noise is among the parameters that must be assessed in order to guarantee a healthy school environment. In order to make such an assessment, the people who are responsible for health and safety at a school should consider supporting the activities described in this project.

2 | 2   Relation to the curriculum

Generally speaking, there are many different ways to incorporate this project into the different subjects of any given curriculum in any country. A teacher of any given country will easily find connections to his or her subject and others, and may even open up doors to inter-subject activities. Below you will find some ideas concerning how our international group would approach this task and how they would link it to their particular curriculum.

3 | What the students do

At the beginning there should be a short introduction to noise (e.g. showing an image of a worker wearing ear protection) to help students to create a connection between noise pollution and health issues. The amount of guidance provided to the students should depend on the group and the age level, leaving enough space for real inquiry. The students' activities could be supported by introducing the following questions:

▶ What do you see in your smartphone during the sampling time?
▶ Is there a difference between the samples recorded in the same place at different times?
▶ Can you infer a dependence or link between the noise level and what happened around you?
▶ Can you explain the dependence?
▶ Can you average the recorded values?
▶ How can you explain the value of the average? Is it close to the peak? Is it close to the minimum? Why?
▶ How could you create a Web-based map that incorporates your data?
▶ Could you expect any negative health effects for the people who are exposed to such noise? What do you find in other studies (literature)?
▶ What could be the short-term and long-term impacts to the human body? Could you measure such impacts?
▶ How could you present your findings to the school council?

Of course there are many more questions that could be asked. What are yours?

Steps in the practical process:
▶ Download and install the required app
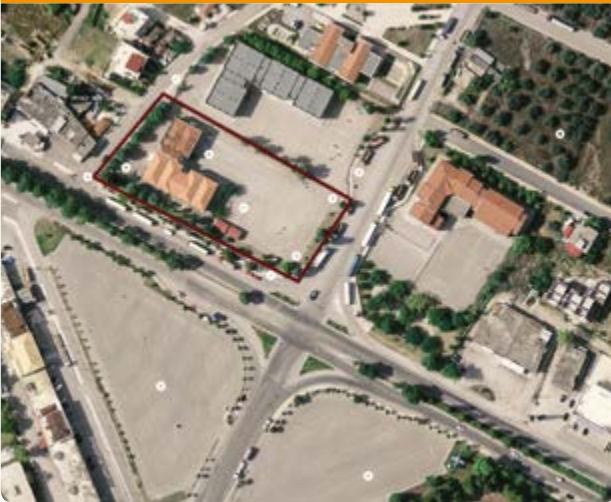▶ Calibrate the app on all the smart devices being used

In order to be able to compare the measurements within your group or between different groups in different countries, you have to calibrate the app (iOS or Android) of all the smartphones involved to the same standard. This calibration is a crucial requirement and needs some extra preliminary attention. You should consider broaching the issue of calibration in a short unit in order to explain the problems and the impor-

FIG.4 **Students calibrating their smartphones**

FIG.5 **Example of school map**
Source: Hellenic Cadastre and Mapping Agency s.a.; http://www.ktimatologio.gr/sites/en/Pages/Default.aspx

FIG.6 **Students taking measurements outside the school area**

FIG.7 **Students taking measurements within a school classroom**

tance of this issue—once again, depending on the age group. The Web-based calibration process we suggest here has the great advantage of being independent of the place where you do your survey. It was suggested by the experts at the Institute of Environmental Protection of the National Research Institute in Warsaw, Poland. To guide you through the calibration process, please take the following steps:

▸ Find a quiet and peaceful spot (this could be the most difficult bit).
▸ Find the YouTube video "pink noise" and use this noise as a reference to calibrate all the smartphones; https://www.youtube.com/watch?v=fguGuABgm-Q.
▸ Turn on your computer's external speakers to the maximum level (speaker power 2-3 W).
▸ Find out where the microphone is fitted in your device.
▸ Start to measure this noise with your app, keeping a distance of 1 m between the smartphone and the loud-

speaker and pointing the microphone toward the speaker. You should then see on your smartphone screen the value of about 86 dB (if it is less or more, use the +/− function of the app to calibrate the microphone of your device).

FIG.8 **Sound level diagram (x-axis: measurement point; y-axis: dB)**

— 14.11.2013
— 19.11.2013
— 21.11.2013
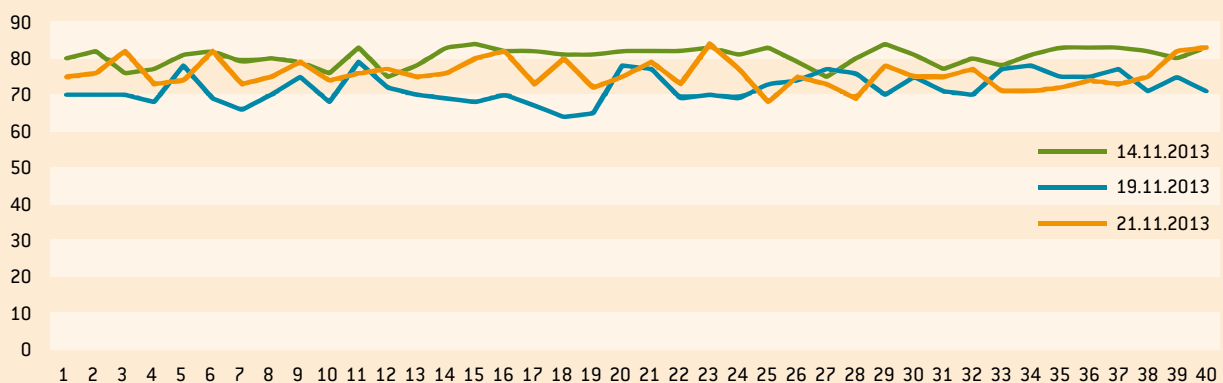
- Select the measurement points within the school and/or the surrounding area[3].
- Design and use a recording sheet for reporting the measurements.
- Within the same class or project, agree that everyone will use the same sampling procedures, e.g. sampling intervals, continuous recording with average values etc.
- Process the data for presentation in graphs and/or statistical analysis.
- Review and compare the findings with the literature.
- Draw conclusions and make suggestions concerning changes in the school environment.

4 | Cooperation option

An international flash mob could be staged on the same day at the same time in order to draw people's attention to the issue of noise pollution and ensure a healthier work atmosphere in the school. The students could start the noise detection app together, sampling the noise levels and holding their phones high in order to make people aware of the high levels of background noise and the related health topics. With some precautions, media coverage could also be provided.

A comparison of the results obtained in the different countries would be possible if the participants have comparable teaching situations prior to the project.

It would be feasible to compare the noise levels within the context of the different legislation in place in the respective countries. What average sound levels can one be legally exposed to?

Students from different schools could discuss project ideas and share data via moodle, eTwinning or other social media. There are also apps that link sound levels to online maps such as noise watch or geovibes.

Finally, the participants could conduct a discussion of the consequences of their project and make suggestions about further activities. It would be especially interesting to discuss ways to lower the students' exposure to noise in the school environment.

5 | Conclusion

5 | 1 What are the students expected to gain from the project?

- Participating in a school survey
- Cooperating with each other in a group
- Sensitising the school community about noise pollution
- Applying and using a smartphone application in an authentic school project (not only for fun but in a way that reflects on our daily life)

- Understanding the connection of noise pollution to our health
- Possibly even getting an idea about how to initiate political changes within a community

5 | 2 Personal experience

The teacher should present some sort of introduction, depending on the subject and the age group. For example, you could introduce the basics of the physics of sound and sound processing in the human ear. Using an image of a person wearing ear protection and working with a jackhammer on the road could start a discussion. This could become controversial, e.g. the students might start to discuss whether one should wear ear protection or not. Some students might argue that ear protection is not necessary, since some workers do this job without any ear protection at all. However, once students know about the sensitiveness of the human ear they could conclude that wearing the protection would make sense. The questions below can be helpful as means of linking the image previously mentioned to the school situation as a working environment for students and teachers.

- What does the picture of the road worker tell us about our life in the school environment?
- Have you ever had a headache? When did this happen?
- What do you think was the reason for your headache?
- Could you imagine that noise can be a cause of headaches?

Before starting the measurements, a major issue was the calibration. There are different methods of calibration. In addition to the calibration procedure mentioned above, one can use a digital sound level meter to calibrate each of the students' smartphones. We believe our results should resemble reality quite well.

Another aspect to be mentioned is the processing of the noise. Any device will have a threshold in terms of reaction time. In addition, this processing time (probably processor-dependent) will be different for different smartphones. We strongly recommend lowering this threshold by closing all unnecessary applications prior to the start of any measurement.

We furthermore recommend that a project group should stick to the same sampling and measuring protocol (e.g. take a screenshot every 15 seconds; measure at exactly the same spot; point all the smartphones in the same manner). In some apps it is possible to send the whole measurement as a data file, e. g. per e-mail or social media after the measurement is done, usually leaving behind a csv file for further processing.

In order to establish comparable studies between our schools, of course we had to direct the students to use comparable approaches, thus narrowing down their idea-generating process.

The project was very well accepted by the students. During the working process all of them were very eager to do all sorts of measurements. They felt especially important because they received personal permits with the teacher's signature that allowed them to use their smartphones to make measurements within the school and the classrooms.

If you start examining noise in an upper secondary school, you might want to introduce logarithms in order to enable the students to understand the decibel scale and the dependence of the perceived noise on the produced noise. It is also useful to explain to the students the concept of zero noise and the way they are constantly subjected to background noise 24 hours a day.

An introduction to the human hearing range and human sound perception and how these are affected by background noise could be a good starting point for discussion. These topics could then be linked to other disciplines such as medicine and law. An introduction to the logarithmic Weber-Fechner law of human perception could also be a good starting point.

Footnotes

1 Keeping in mind that the sound source is producing a higher intensity of sound, we focus here on the receiver of the noise, using the SI unit dB for our recordings.

2 Inquiry-based learning emphasises constructivist ideas of learning, where knowledge, especially socially based knowledge, is built from experience and process. On the basis of this premise, learning develops best in group situations. The progress and outcomes are generally assessed according to how well people develop experimental and analytic skills, and often according to how well they work in groups [http://en.wikipedia.org/wiki/Inquiry-based learning].

3 Some places to study:
- The school's main hall during the break
- The corridor and staircases during the break
- A classroom during a lesson / during the break
- The gym hall
- The school canteen
- The library
- The schoolyard during exercises / games
- The streets in the neighbourhood around the school
- The swimming hall.

Going for a Song (Cheap & Cheep)

A low-cost protocol for studying birdsong

Maria Dobkowska · Anna Maria Pavlou

Richard Spencer

1 | Summary

This project shows how students can develop a wide range of research skills by using smartphones and free apps to investigate whether noise pollution alters the amplitude or frequency of birdsong.

- **Keywords:** birdsong, amplitude, frequency, house sparrow *(Passer domesticus)*, noise pollution, urban, rural
- **Disciplines:** biology, physics
- **Age level of students:** 16-18 years (also suitable for the 14-16 age group)
- **Android apps:** iRig Recorder, FreequenSee, Sound Meter, UK Birds Sounds
- **iOS apps:** iRig Recorder, Decibel Meter, British Birds Lite
- **Further software:** Audacity® freeware

2 | Conceptual introduction

Birds sing to communicate. In particular, male songbirds sing to attract females and to deter male competitors. Each songbird species has its own signature tune.

Several research studies, including studies on blackbirds, great tits, song sparrows and nightingales, have concluded that songbirds in urban areas are challenged by noise pollution. These studies indicate that songbirds compensate to get themselves heard above urban noise pollution by singing at either a higher amplitude (louder) or at a higher frequency (higher pitch) than members of the same species in rural areas where noise pollution is lower.

In the Going for a Song project, students carry out their own investigations of the effect of noise pollution on birdsong using smartphones and free apps.

3 | What the students do

Present the students with a challenge: to investigate whether noise pollution alters the amplitude or the frequency of birdsong.

Introduce the conceptual background and the available Android/iOS apps, and explain how free software (Audacity®) can be used to analyse birdsong. Audacity® is an open-source, cross-platform software for recording and editing sounds.

The students make preliminary recordings using their smartphones and apps at two locations (one urban, one rural) to help them choose one bird species suitable for the study and the length of recording. Bird species can be identified by their songs with the UK Birds Sounds (Android) or the British Birds Lite (iOS) apps. The Sound Meter app (Android) or the Decibel Meter app (iOS) can be used to record the noise level in decibels. iRig Recorder (Android/iOS) can be used to record bird songs for later analysis using Audacity®. FreequenSee is an alternative recording app (Android).

During preliminary investigations, the students are reminded that they must consider how they can make valid comparisons between the urban and rural sites. The variable under investigation is the level of noise pollution. All other variables must be controlled as far as possible to ensure fair testing. Sufficient recordings must be made at each site to ensure data reliability. The students report their preliminary findings to the supervising teacher, including variables which they have identified as requiring control and the importance of controlling these variables.

The students are encouraged to consider any other variables they have not considered, using the following list as a guide: Species of bird, time of year, time of day, weather conditions, type of habitat, recording distance from birds, number of birds recorded at one time (for species, which flock), presence of other songbird species during recording.

The students adjust their methods accordingly. They carry out twenty final recordings at each site over a period of two weeks and analyse the collected data using Audacity®.

The students evaluate their data and draw conclusions regarding the effect of noise pollution on the amplitude and frequency of the birdsong.

📱 **FIG.1** **Male house sparrows *(Passer domesticus)* chirp to attract mates** Source: wikipedia CCA, Adamo

What the students did (as an example project)

The students used Android apps. Preliminary investigations were carried out to help identify a suitable songbird for study (using UK Birds Sounds) and to help find two contrasting

FIG.2 **Students used Android apps to record noise pollution and birdsong**

FIG.3 **A hawthorn hedgerow provides cover for house sparrows**

locations with significantly different levels of noise pollution (using Sound Meter). The bird species chosen for investigation must be present in approximately equal numbers at both sites.

The students chose to investigate the songs of house sparrows. They worked in pairs to record male house sparrows (FIG. 1) at two different locations — an urban hawthorn hedgerow beside a busy main road (FIG. 2) and a rural hawthorn hedgerow in a country lane (FIG. 3). Recordings were made 1.5 metres away from the hedgerow. One student recorded the background noise level amplitude (in decibels) using Sound Meter, and the second student recorded the birdsong using iRig Recorder.

Twenty iRig and Sound Meter recordings were made at each location (rural and urban) at approximately the same time of day (14.00−16.00 hours) at the same time of year (first two weeks in March 2014) on days with similar weather conditions. Only flocks with similar bird numbers were recorded

(approximately ten birds). Each recording lasted one minute. The mean noise level recorded using Sound Meter was 43 dB at the rural sites and 70 dB at the urban sites. The iRig recordings were downloaded into Audacity® and viewed as spectrograms (FIG. 4 and 5).

The students noted that the highest-frequency recordings at the urban sites were caused by road traffic. Choosing to focus on ten recordings, students questioned whether the average number of house sparrow chirps differed between the two sites. They used the Audacity® recordings to count the number of chirps of the house sparrows within ten-second intervals, from 20 to 30-second intervals for rural recordings and for ten-second intervals in between road traffic for urban recordings (FIG. 6). They found that the average number of house sparrow chirps varied considerably at both sites (between five and 20 chirps) but that the mean number of chirps per ten seconds taken over ten sites from each location was remarkably similar (approximately 13 chirps per ten seconds).

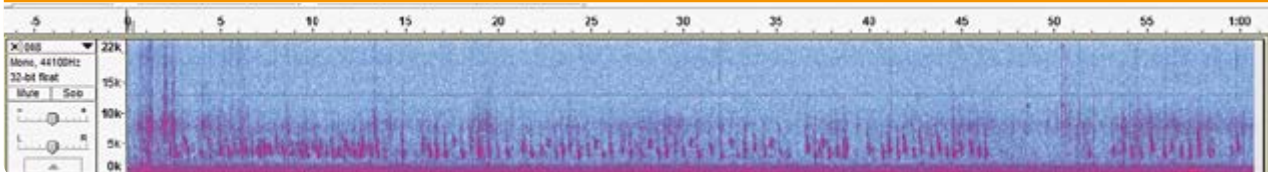FIG.4 **An example of an iRig app recording at a rural site, imported into Audacity®**

FIG.5 **An example of an iRig app recording at an urban site, imported into Audacity®**
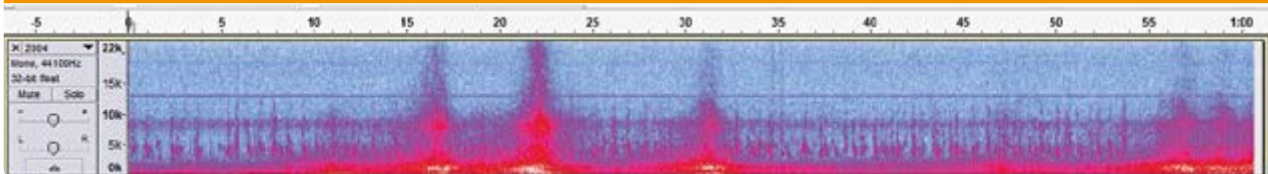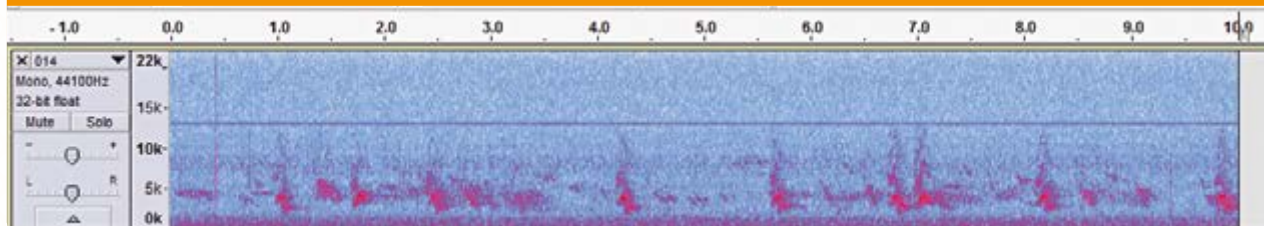
FIG.6 House sparrow *(Passer domesticus)* chirps over ten seconds (typical recording)

The students concluded that there was no evidence that house sparrows chirp at a different frequency (in Hertz), amplitude (in decibels) or recurrence (chirps per second) at urban sites compared to rural sites. They concluded that the intermittent noise pollution caused by road traffic occurs at a much higher frequency and amplitude than the chirps of house sparrows. Any attempt by birds to compete would not only be futile, but also would waste the birds' energy.

4 | Cooperation option

Passer domesticus (the house sparrow) is the most widely distributed species of wild bird. This species is native to Europe and most of Asia. Human activities have introduced this species into Australia, Africa, North America and South America, whether deliberately or accidentally. Consequently, it is an ideal subject for studies to compare data on the same species in different countries, opening up exciting possibilities for international comparisons and project extension. Alternatively, the general protocol could be adapted to study any songbird species.

5 | Conclusion

Presenting students with a simple challenge (to investigate the effect of noise pollution on the amplitude or frequency of birdsong) helped students to develop a wide range of research skills using smartphones and freely available apps. The students gained the following skills from participating in this project:
- Experience of gathering "real" data in the field using smartphones as a tool.
- Appreciation of the importance of controlling variables for fair testing when gathering data to compare two different situations (in this case, for valid comparison of house sparrow birdsong in urban versus rural areas).
- Decision-making skills in planning experimental design and in gathering data.
- Decision-making skills in analysing and evaluating data.
- An understanding of the tentative nature of science (see under "Personal experience").
- Knowledge of how to identify birds from their songs.
- Increased familiarity with the local environment and its wildlife.

- A broader interest in the species of bird being studied and environmental issues. In studying the birdsong of house sparrows, the students wanted to find out more about why birds sing, why males sing more than females, why house sparrows are in decline in the UK (an estimated 71% decline in UK numbers between 1977 and 2008), whether this is a universal phenomenon and what they can do as individuals to encourage house sparrows in their own gardens.

Personal experience

An appropriate risk assessment must be completed before students carry out fieldwork (an exemplar is available at www.science-on-stage.de/istage2-downloads).

Having been introduced to background research on the effect of noise pollution on birdsong, students may be disappointed if their results do not fit in with the findings of other researchers. However, this is an excellent opportunity to discuss the tentative nature of science and opens up debate on why students' results may be different from published studies. For example, students may consider the effects of different forms of noise pollution (in terms of both amplitude and frequency) and the fact that the published research applied to one species of bird may not necessarily apply to another species. They can find out how the data gathering in published studies may be more sophisticated.

Colleagues from Cyprus (Anna Maria Pavlou) and Poland (Maria Dobkowska) trialled preliminary recordings and have made several helpful suggestions for future investigations. The bird species under investigation must be chosen carefully, as some species are wary of humans and will fly off unless the students making the recordings approach them quietly or under cover. The sound quality could be improved by fixing a cheap directional microphone to the smartphone with a boom attached.

Fast and Curious

Pere Compte · Immacolata Ercolino · Philippe Jeanjacquot
Dionysis Konstantinou · Emmanuel Thibault

1 | Summary

The pupils measure the speed of an object using the Doppler effect of the sound. In this activity they use the audio (or video) file of the sound of a car.

- **Keywords:** Doppler effect, vehicle, speed, smartphones, sound
- **Disciplines:** physics, maths
- **Age level of students:** 17-18 years
- **Android apps:** Sound spectrum analyzer (SSA)
- **iOS apps:** iAnalyzer lite
- **Further functions needed:** camera for recording a video file, voice memo or sound recorder to record an audio file, signal generator for the extra activity

2 | Conceptual introduction

The objective is to measure the speed of a vehicle by recording the sound emitted by the vehicle when it passes a microphone (e.g. that of a smartphone). Measurements are made using smartphone spectrum analysis applications.

Required skills:
- Setting up an experiment to measure speed by using the Doppler effect.
- Using the expression describing the relative changes in frequency at low speeds.
- Using spectral data and image processing software to illustrate the applications of the Doppler effect as a method of investigation in astrophysics

Implied knowledge:
- The Doppler effect: The change of the observed frequency as the source moves towards and away from the observer.

3 | What the students do

This activity is divided into three parts:
- **As homework:** The students record the sound of a car or another vehicle by using their smartphones. (3.1.)
- **In class:** They explain what the Doppler effect is. (3.2)
- **Using their smartphones:** They measure and analyse the sound and determine the velocity of the car. (3.3)

3 | 1 Record the sound of a vehicle

In the first phase, the vehicle has to move towards the microphone; in the second phase it has to move away from it. It is better if the vehicle sounds its horn during the measurement. While the sound is being recorded, the vehicle is travelling in a straight line at a constant velocity (value: v).

For the recording, use either (i) the camera application for a video or (ii) the voice memo or sound recorder application for recording only the sound.

During the recording, the best method is to stand still and just turn the smartphone in the direction of the car. Be careful to record the car in a quiet place, without other noises.

3 | 2 What is the Doppler effect?

Listen to the recording and explain what characteristic of the sound is altered. In your explanation, make sure you distinguish between the two phases of the recording. The alteration is a result of the Doppler effect.

If the vehicle sounds its horn, the sound spectrum has peaks of frequency. Choose one peak with a very clear shift.
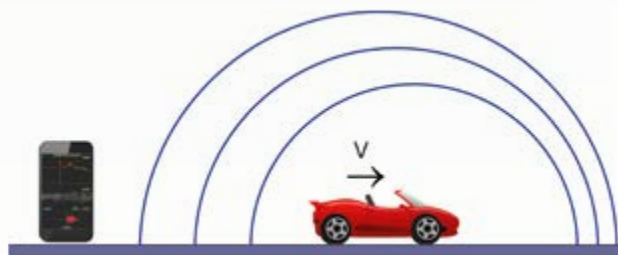
If the vehicle is at a standstill the frequency will be $f_{(0)}$.
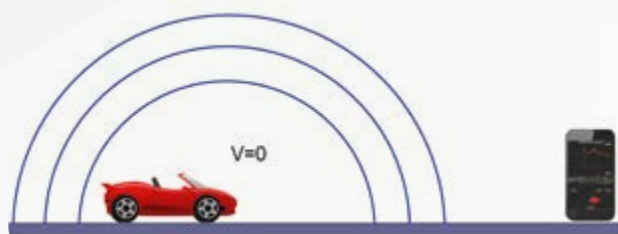
If the vehicle is approaching the microphone, the pitch of the sound will be higher; the frequency increases to $f_{(1)}$.
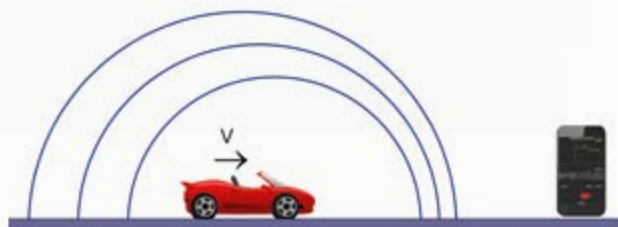
If the vehicle is moving away from the microphone, the pitch of the sound will be lower; the frequency decreases to $f_{(2)}$.

The same phenomenon occurs if the vehicle is standing still and the microphone is moving.

The formulas are:

$$f_{(1)} = f_{(0)} \frac{V_{sound}}{V_{sound} - V_{vehicle}}$$

$$f_{(2)} = f_{(0)} \frac{V_{sound}}{V_{sound} + V_{vehicle}}$$

3|3 Measure and analyse the frequency of the sound

This activity requires two smartphones. One will play back the sound emitted by the vehicle, and the other will determine the spectrum of the sound. In the first part of the recorded audio file, the vehicle is moving towards the microphone; in the second part it is moving away from it. While the sound was being recorded, the vehicle was travelling in a straight line at constant velocity (value: v).

FIG.1 Screenshot of Sound Spectrum Analyzer

3|3|1 With Android (FIG. 1)

▸ Stand in front of the playback smartphone speaker.
▸ Start the Sound Spectrum Analyzer on the other smartphone.
▸ Open the menu of the app.
▸ Start to play back the file.
▸ After one or two seconds, quickly start the analysis in Sound Spectrum Analyzer (in the menu).
▸ In the Sound Spectrum Analyzer menu, go to the x-axis and choose log Scale. Do the same with the y-axis.
▸ With your finger, move the cursor to the first peak (1 in the screenshot).
▸ Read the frequency from the top right of the screen (2 in the screenshot).
▸ After you have obtained the first frequency, measure the second frequency.
▸ To determine the second frequency, follow the same procedure as for the first frequency. The only difference is that you start the SSA analysis just before the end of the recorded audio file.
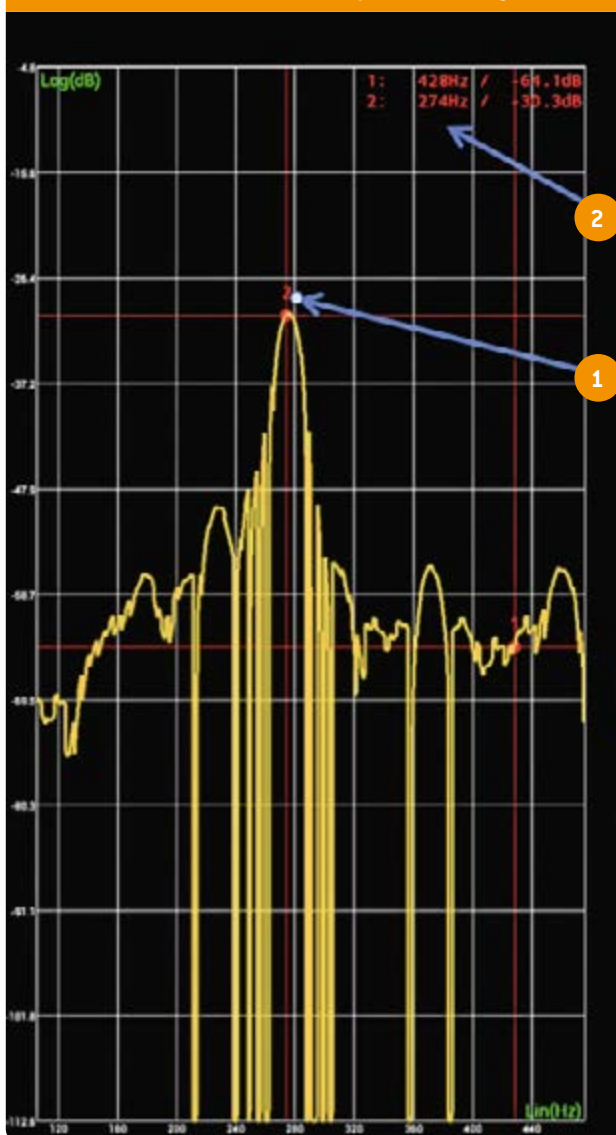
3|3|2 With iOS (FIG. 2)

▸ Stand in front of the speaker.
▸ Start iAnalyzer lite on iOS.
▸ Start to record.
▸ Start to read the audio file.
▸ When the audio file is finished, stop the recording.
▸ The recording of the sound is displayed in the lower part of the screen.
▸ With your finger, scroll along the audio file (1 in the screenshot).
▸ The spectrum is displayed in the top part of the screen.
▸ Touch the screen and scroll to measure the frequency of the sound (2 in the screenshot).
▸ Choose one frequency peak.
▸ Measure the frequency (3 in the screenshot) of this peak at the beginning (frequency 1) and at the end (frequency 2) of the recording.

3|3|3 To obtain this speed of the vehicle, use the following formula:

$$V_{vehicle} = V_{sound} \cdot \frac{f_{(1)} - f_{(2)}}{f_{(1)} + f_{(2)}}$$

FIG.2 Screenshot of iAnalyzer lite

v=340 m/s is the speed of sound; $f_{(1)}$ is the first frequency; $f_{(2)}$ is the second frequency.

3|3|4 To go further

This formula can be deduced by dividing the formulas of $f_{(1)}$ and $f_{(2)}$

$$\frac{f_{(1)}}{f_{(2)}} = \frac{V_{sound} + V_{vehicle}}{V_{sound} - V_{vehicle}}$$

$$f_{(1)} \cdot \left(V_{sound} - V_{vehicle}\right) = f_{(2)} \cdot \left(V_{sound} + V_{vehicle}\right)$$

$$f_{(1)} \cdot V_{sound} - f_{(1)} \cdot V_{vehicle} = f_{(2)} \cdot V_{sound} + f_{(2)} \cdot V_{vehicle}$$

$$V_{sound} \cdot \left(f_{(1)} - f_{(2)}\right) = V_{vehicle} \cdot \left(f_{(1)} + f_{(2)}\right)$$

$$V_{vehicle} = V_{sound} \cdot \frac{f_{(1)} - f_{(2)}}{f_{(1)} + f_{(2)}}$$

3|3|5 Results

$f_{(1)} = 431.2$ Hz; $f_{(2)} = 395.8$ Hz

$$V_{vehicle} = 340 \cdot \frac{431{,}2 - 395{,}8}{431{,}2 + 395{,}8}$$

$v_{vehicle} = 13.1$ m/s; $v_{vehicle} = 47$ km/h; the speed on the speedometer is 50 km/h.

4| Cooperation option

▸ Share different files with different velocities and different vehicles and Doppler effect measurements. Make a database of these measurements.

▸ One school can record its files and send them to another school. The students have to estimate the speed of the vehicle from the other school's recordings.

5| Conclusion

In this teaching unit, the students can follow the described procedure or create their own procedure.

There are other possibilities, for example:

▸ Come back and find the real frequency $f_{(0)}$ when the vehicle is standing still. For this activity, use the speed of the vehicle, $f_{(1)}$ or $f_{(2)}$.

▸ Put a buzzer or a smartphone in a fabric bag. For the smartphone, the students first have to start the signal generator app and set it to produce a sinusoidal sound. The maximum sound level should be between 500 Hz and 1 kHz. One student takes the bag and makes vertical circles with the noisy smartphone (be careful not to smash the phone while whirling it around!). Another student records the spectrum of the sound and calculates the radial velocity of the phone using the Doppler effect. This activity can be linked with an activity in which the students search for exoplanets by using the radial velocity method.

▸ Put a buzzer or a smartphone in front of the pupils. Use the signal generator app to make a sinusoidal sound. The maximum sound level should be between 500 Hz and 1 kHz. One pupil runs with the noisy smartphone and another records the spectrum using another smartphone. You can use the Doppler effect to find the speed of the runner.

6| Further information

▸ For more information about exoplanets, see http://exoplanets.org/

▸ Hands-on universe Europe: exercise about exoplanets at euhou.obspm.fr.

Hands

Hands are very versatile tools for humans at every stage of growth and development. Infants use their hands to explore the world around them by grabbing, and adults use them for all sorts of sophisticated work ranging from hard manual labour to fine arts.

Nowadays people use their hands to interact with modern personal devices such as smartphones. These devices are so common today that almost every student in a European secondary school will always have one at hand. When students come to school they might forget their textbooks, but never their smartphones.

Our hands are a very important interface to the digital world of the smartphone, as well as to the real world. "Hands-on" also describes a style of teaching in which the students do something by themselves, rather than consuming something. The four teaching units described here combine these aspects: students do something in the real world and they also use their smartphones.

Classic measurements of distance and height are compared to measurements made with smartphones in the teaching unit "Measuring the World around us". Students use their hands to make measurements with a ruler or a set square and with a smartphone. Is it really smart to use the phone, or is it even better to go for the old-fashioned way? Either way, they will need hands-on geometry to make the measurements.

In the next teaching unit, "Smart Accelerometer", the students get their hands on an old record player and have fun on a merry-go-round. In order to study circular motion, they must always have their smartphones with them. They measure centripetal acceleration and locate the position of the acceleration sensor within their own smartphones.

"Spot the Physics" would probably also qualify for our Eyes section, but here the students need to use their hands as well. This teaching unit is about video analysis with smartphones. There is a wide range of possibilities for using video analysis in class, especially to analyse any kind of motion. The smartphone comes in here because it has a high-resolution camera, so that every student can make his or her own video. This advantage cannot be overestimated. In many cases the video can then be analysed on a computer, which has a bigger screen, but the analysis can also be done directly on the smartphone if mobility is an important factor.

The last teaching unit in this section is "The Earth's Magnetic Field". In this unit the students compare classic measurements with the results from their smartphone sensors. For the classic hands-on part, the students build their own pair of Helmholtz coils and then use them to generate a magnetic field that compensates for the magnetic field of the Earth.

These four teaching units are good examples, but probably the reader will have many more ideas while going through them. They show how hands-on natural science can be combined with modern technology that is always at hand.

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Measuring the World around us

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Corina Toma

1 | Summary

Measuring the world around us implies being able to understand it. Answering the questions of a curious mind, this teaching unit shows how to measure distances and towering heights by means of simple reasoning. How often do we ask ourselves, how tall is that skyscraper, that mountain or that TV tower? Why not use the ubiquitous smartphone to find out? In this unit the students will make their measurements by using the appropriate apps, and they will compare their results with the measurement data gathered by using classic, well-established tools.

▸ **Keywords:** distance, height, altitude, parallax, pressure
▸ **Disciplines:** physics, mathematics, ICT
▸ **Age level of students:** 12-19 years
▸ **Android apps:** Distance and Parallax, Smart Distance, Distance and Height, Height and Pressure
▸ **iOS apps:** Easy Measure, Height and Distance, My Altitude

2 | Conceptual introduction

At the beginning of physics classes, the students are taught to measure lengths and distances. The well-known method of measuring distance or height is to use a ruler or measuring tape. In this teaching unit we propose that the students use other modern tools: various applications and a smartphone. They can decide on their own which way to go: to measure in the classic way, to use pen and paper to do the calculation or, alternatively, to use applications and a smartphone. The students will compare these methods and discover the advantages of each one.

The students can use different kinds of applications to make their measurements, but in this unit we have carefully chosen some examples for our purpose. These applications require some knowledge of mathematics (especially geometry) and physics formulas.

First, the students will become acquainted with the principle of parallax and then employ the Distance and Parallax Android application (as far as we know there is no corresponding iOS application) to determine the distance to a remote object.

Secondly, the students will determine the distance to the target object and also its height by using a ruler and the Distance and Height Android application or the Height and Distance iOS application.

Both activities will require the students to revise their basic knowledge of geometry, specifically the theorems about similar triangles, such as Thales' theorem.

Thirdly, the height of a hill or a mountain can be derived by measuring the temperature and the air pressure both at the base and at the top. In this case the students will use the Height and Pressure Android application, which was created for this teaching unit, or the My Altitude iOS application.

These smartphone apps enable the students to use various methods of investigation to reach their goals, such as mathematical computation, physics formulas, comparisons and checks with data that is available online, in order to find various geographic altitudes or distances.

This unit fits in well with European curricula.

3 | What the students do

3 | 1 How to use the Android application Distance and Parallax in order to find the terrestrial distance to a remote object

The students can find a complete explanation of the parallax effect and the use of the parallax method in terrestrial measurements in the teaching unit "Smartastronomers: From the Classroom to the Sky". The new method is described in paragraph 3.1 (page 9).

The observer must first measure the distance between his eyes and his thumb d (or pencil) and the distance between his eyes LR. With the help of these values, the observer can

FIG.1 Screenshot: Distance and Parallax
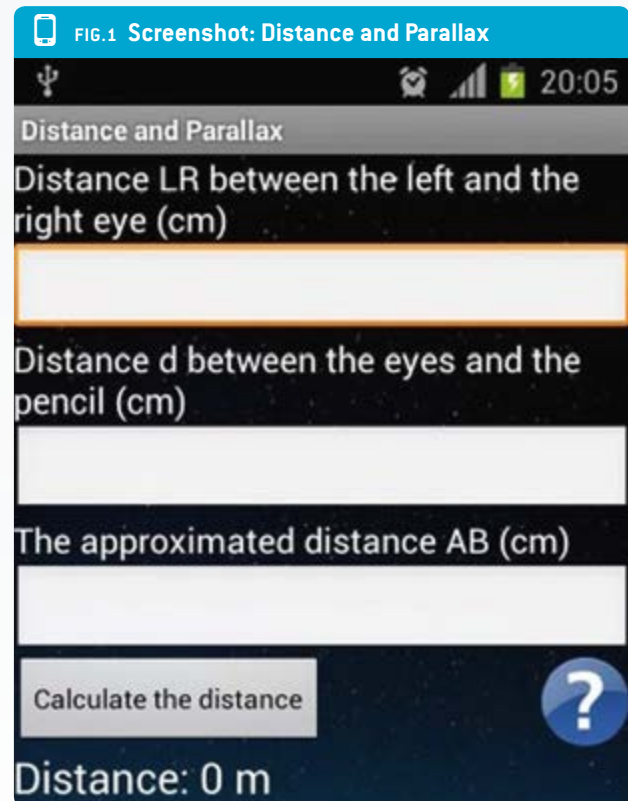
then estimate the distance AB (the approximate distance between the perceived locations of the targeted object). The students have to insert the data into the respective fields of the application (**FIG. 1**) and then push the button <CALCULATE THE DISTANCE> to obtain the distance.

In this case, with the following data: d = 55 cm, AB = 3 m and LR = 6.5 cm, the result for the length of the school's sport field was D = 25.9 m.

To be sure that the measurement above was good, the students measured the same distance with a classic method using a measuring tape. They found that D = 25 m.

The students can compare the results and decide which measurement is easier to do.

The students can use various other applications, such as Smart Distance for Android and Easy Measure for iOS, to determine the distance to an object. Such applications become essential when students cannot use a measuring tape to determine the direct distance to the target object (when the distances are too long). With this telemeter application, the measurement is made by using the smartphone's camera perspective. The students have to estimate the height of the target, enter this data into the respective field and then touch the screen and align the target between two horizontal lines. The smartphone will provide the distance value.

3 | 2   How to use the Distance and Height app for Android or the Height and Distance app for iOS to simultaneously determine the distance to the target object and its height

The students start by using a ruler to measure the apparent height h of the target object. The target object is situated at an unknown distance D.

They move several steps toward the target object. The distance d can be measured by using a measuring tape or estimated by using the approximate length of one's stride.
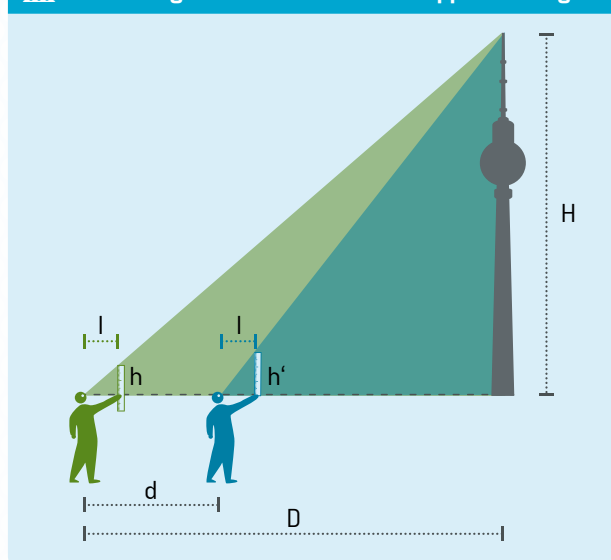
Once again, the students measure the apparent height of the target object h'. This time the measured apparent height will appear larger than the initial measurement.

The two trinangles are both right-angled triangles.

Distance D can be calculated by using the formula
$$D = d \; \frac{h'}{h'-h}$$

📈 **FIG.2 Using a ruler to measure the apparent height**

The target object height H can be calculated by using the formula
$$H = \frac{d \cdot h \cdot h'}{l(h'-h)}$$
where
▸ l — distance from the eyes to the ruler
▸ D — distance to the target object
▸ H — height of the target object
▸ d — distance between the two observation points
▸ h and h' — apparent heights of the target object, measured with a ruler.

Obviously it is much easier to input the data into a ready-made application that will instantly return the results (**FIG. 3**).

The students will observe that if the target is at a distance of about 50 m they can use a distance d of about 10 m between the two observation points. If the target is far away, about 2 km, then the distance d has to grow to 50 m and so on. The difference between the two apparent heights h and h' (found with the ruler) has to be at least 0.5 cm, because the human eye cannot accurately distinguish distances below this threshold.

FIG.3 **Screenshot: Distance and Height**

⏰ 📶 🔋 5:56

Distance and Height

Distance mesurement

Height measurement

3 | 3 How to use the Height and Pressure application for Android or My Altitude for iOS to determine the height of a mountain or the altitude of a school with a smartphone that incorporates temperature and barometric sensors

First of all the students have to see whether their smartphones are suitable. They can find out how many sensors their smartphones have by using the Sensor Box application for Android or the Sensor Monitor for IOS.

3 | 3 | 1 Height measurement with four parameters

The temperature and the pressure of the atmosphere vary with the altitude. If the students are measuring the atmospheric parameters at different altitudes, namely points A and B (FIG. 4), the temperature and the altitude can be considered to have a linear dependence within the troposphere.

At each kilometre from the sea level, there will be a temperature drop of 6.5 Kelvin. In this case the following equation can be used:

$$T = T_0 + \alpha(h - h_0)$$

FIG.4 **Measurements of atmospheric parameters at different altitudes**

$B(h, T, p)$

$A(h_0, T_0, p_0)$

sea level
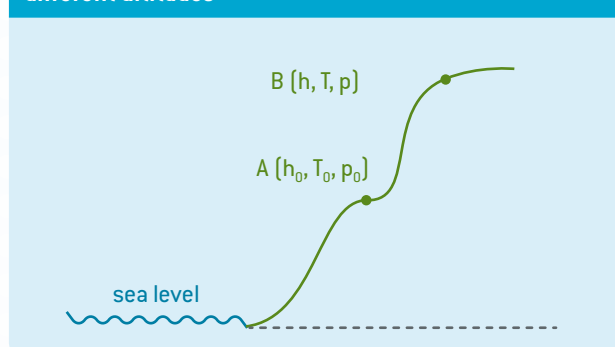
where
- T – temperature at altitude h (point B)
- T_0 – starting temperature at the starting altitude h_0 (point A)
- α – temperature gradient = −0.0065 K/m.

The relationship between pressure and temperature is expressed as follows:

$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{-\frac{g\mu}{\alpha R}}$$

where
- p – pressure (in mbar) at altitude h
- p_0 – pressure (in mbar) at altitude h_0
- g – gravitational acceleration at sea level = 9.81 m/s2
- R – universal gas constant = 8.310 J/(kmol · K)
- μ – molar mass for the air = 29 kg/kmol.

By combining these two formulas, the students will obtain the final equation, which they can use to calculate the altitude:

$$h = \frac{T_0}{\alpha}\left[\left(\frac{p}{p_0}\right)^{-\frac{\alpha R}{\mu g}} - 1\right] + h_0$$

To recap: The students have to use their smartphones to measure the temperature T_0 and the pressure p_0 at the starting point A, find the altitude h_0 on the Internet (or to consider $h_0 = 0$) and then measure the pressure p at the final point B. They have to insert all of these data into the respective fields of the application and then push the button <CALCULATE THE HEIGHT>.

FIG.5 Screenshot: Height Measurement

3|3|2 Measuring height with five parameters

By using the same application, the students can also calculate the height or the altitude using the barometric **formula 6**

$$p = p_{sl} \cdot e^{-\mu g h/(RT)}$$

where p_{sl} = pressure at sea level.

We obtain the following results for the parameters of both points A and B:

$$\frac{p}{p_0} = e^{-\frac{\mu g}{R}\left[\frac{h_0}{T_0} - \frac{h}{T}\right]}$$

In this case the students can calculate the altitude h by means of the following **formula 8**:

$$h = \frac{RT}{\mu g} \ln \frac{p_0}{p} + \frac{T}{T_0} h_0$$

Why use two formulas for the same measurement?

The students have to observe the similarities and the differences between these two methods.

First of all, if they use the second part of the application, they have to insert one more parameter: the temperature T at the point B.

Then they can complete a table (**FIG. 6**) with the data from the Internet and the data calculated with the Height and Pressure application.

Further experiments

It is advised that students use two or three different smartphone apps for measuring:
▸ Distances to the target objects
▸ Heights of target buildings
▸ Distances to geographic features (hills or mountains) and their heights

During their investigations they will notice that some applications are better suited for objects that are closer to the observer, while others are better for more distant objects.

They will be able to compare their results with reference data and then to identify the errors in their measurements.

The students could form teams to answer a number of simple questions:
▸ Which are the best applications for measuring small distances or large distances?
▸ Which application is best suited for measuring the height of the school building?

FIG.6 Table of comparision of data

T_0 (K)	T (K)	p (mbar)	h_0 (m)	$h_{(formula\ 6)}$ (m)	$h_{(formula\ 8)}$ (m)	$h_{internet}$ (m)

Each student measures the height of the building or the height from a window of the building by using a piece of string that has a weight tied to one end and then measuring the length of the string. The string is hung from the top of the building or out of the window to its base. Afterwards the same height will be determined by using the apps presented in this teaching unit. In addition, the students can use a third application such as Smart Distance.

For the applications that employ geometric theorems, it will be useful to note that the final result will depend on the distance between the observer and the target object.

When measuring the height or altitude by using the pressure sensor, it is interesting to compare the pressure measurements with the values measured by a classic barometer.

▸ Which application is suitable for determining your height?
▸ Which application is suitable for determining the height of a mountain?

3 | 4 Another interesting problem/exercise

Today almost every smartphone has a built-in accelerometer sensor. The students could potentially measure the gravitational acceleration on the ground and during an airplane flight. By using the formula for gravitational acceleration, which depends on altitude, the students can derive the altitude of the plane. Can this method be employed successfully? Provide arguments for and against its successful use.

4 | Cooperation option

Students from different countries can compare their results and initiate a common project with a title such as "Measuring the height of your school with a smartphone".

5 | Conclusion

Even though this teaching unit may appear relatively easy at first glance, the investigations require the students to refresh their knowledge of basic geometry, mechanics and hydrostatics, while recording and processing a fair amount of data.

The students have to know the mathematical formulas and the physical laws that form the foundation of the smartphone apps.

It is important for the students to choose the right smartphone application to use for a given range of heights or distances so that they can achieve the most accurate measurements. They will realise that the smartphone is an invaluable tool for this purpose.

Last but not least, we would like to emphasise that the three Android applications used in this teaching unit (Distance and Parallax, Distance and Height, and Height and Pressure) were developed by Alex Toma, a Romanian student. It's a challenge for students to try to develop corresponding iOS applications or others that could be used in experiments. This means that physics, mathematics and computer science would have to work together to develop interesting new methods for studying the natural sciences.

A Smart
Accelerometer

Lorenza Resta

Zbigniew Trzmiel

1 | Summary

The motion sensors inside a smartphone allow students to measure the acceleration X in three perpendicular directions and thus can be useful for explaining how to resolve a vector into its components and their combination. Acceleration on a small scale can be demonstrated in the classroom using a record player (30 cm in diameter). It is very important to find the position of the accelerometer and take it into consideration when we investigate movements along a non-linear trajectory. Acceleration on a large scale can be seen outdoors on a rotating ride in an amusement park or a fairground (7.20 m in diameter).

▸ **Keywords:** acceleration
▸ **Disciplines:** physics, mathematics, computer science
▸ **Age of students:** 15-18 years
▸ **Android and iOS apps:** SensorKinetics, SensorKinetics Pro
▸ **Android apps:** Physics Toolbox Accelerometer, Accelerometer Monitor, Physics Toolbox Roller Coaster, Regression Calculator
▸ **iOS apps:** Sparkvue, Regression Calculator
▸ **Further software for computers:** Tracker

2 | Conceptual introduction

The students examine uniform circular motion in real contexts. They investigate the motion on a small scale using a record player. The sensor of the smartphone provides the values of acceleration along the three axes. Measuring the acceleration of the smartphone in different positions on the record player makes it possible to localise the sensor's position within the smartphone.

We present two measurement methods. Students can better understand the influence of the sensor's position by using an application for dynamic geometry.

The students can investigate circular motion on a large scale on board a rotating ride. They measure the acceleration with smartphones placed at different positions on the platform of the ride. They study the effect of the acceleration along the three axes. In particular, they focus their attention on the radial direction in order to better understand the centripetal acceleration.

Then they analyse the values obtained and insert them into a specific app on their smartphones. Using this app, the students trace the graph of acceleration versus radius, and they carry out a regression on the data. They find the equation of the linear fit, with slope and intercept, and evaluate the quality of this fit.

3 | What the students do

3 | 1 On a small scale (a record player or other small rotation device in the classroom)

3 | 1 | 1 Methods of measuring

The experiment could be set up as in **FIG. 1**. We record the videos and the acceleration using apps while spinning a smartphone on a record player.

The interpretation of the data and the calculation become easier when either pair of the smartphone's sides is aligned perpendicularly to the radius of the disk.

📷 **FIG.1 The disk with a transparent sheet simplifies the positioning of the smartphone**
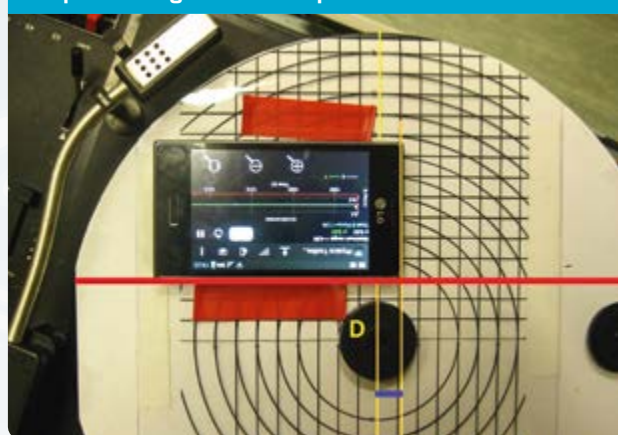
We can attach the smartphone to a transparent sheet with a piece of double-sided adhesive tape. This enables the accurate location of the smartphone in different positions along the chosen chord (the red coloured line in **FIG. 1**).

3 | 1 | 2 Simulation of movement with dynamic geometry

As seen in **FIGS. 1** and **2**, the smartphone revolves in the horizontal plane (the x-y plane) and therefore there is no Z component of acceleration. However, when the smartphone is placed vertically the X or Y acceleration can be omitted.

The application for dynamic geometry, i.e. Geogebra, makes it possible to change the positions of both the smartphone and the sensor within the smartphone and to plot the values of the acceleration components.

3 | 1 | 3 Collection and analysis of the data

[A] Students determine the position of the smartphone sensor during uniform circular motion. They move their smartphone along a fixed chord (the red coloured line in **FIG. 1**) and measure the acceleration for different positions (the blue coloured segment in **FIG. 1**).

The segment represents the distance between the diameter D and one side of the smartphone. When the students find the position where the tangential component of the acceleration is near zero, they have found the Y-coordinate of the sensor position.

In our experiments we measure the tangential, i.e. the Y-component of the acceleration, in ten different positions. Here we present three examples of the results.

The graphs and tables in FIGS. 2, 3 and 4 show examples of results and calculations of average acceleration components vs. time.

The declared uncertainty of our sensor ("smallest scale division") is equal to 0.038 m/s^2 and in FIG. 3 the measured Y-acceleration is smaller than this value, so we can consider it as the zero value and we can say that we have found the position of the sensor on the y-axis.

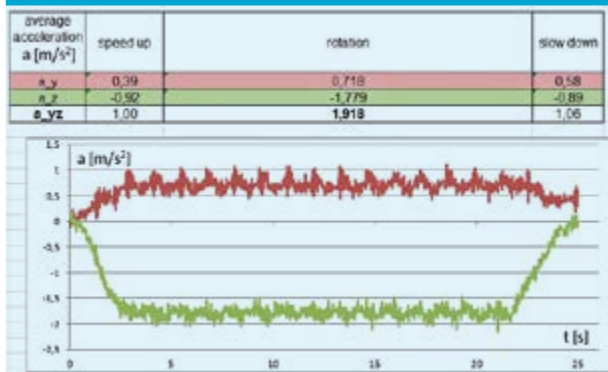FIG.2 **The side of the smartphone is 1 cm from the diameter D (*)**

average acceleration a [m/s^2]	speed up	rotation	slow down
a_y	0,39	0,718	0,58
a_z	-0,92	-1,779	-0,89
a_yz	1,00	1,918	1,06

FIG.3 **The side of the smartphone is 4 cm from the diameter D**

average acceleration a [m/s^2]	speed up	rotation	slow down
a_y	0,02	-0,030	0,05
a_z	-0,72	-1,830	-0,67
a_yz	0,72	1,830	0,67
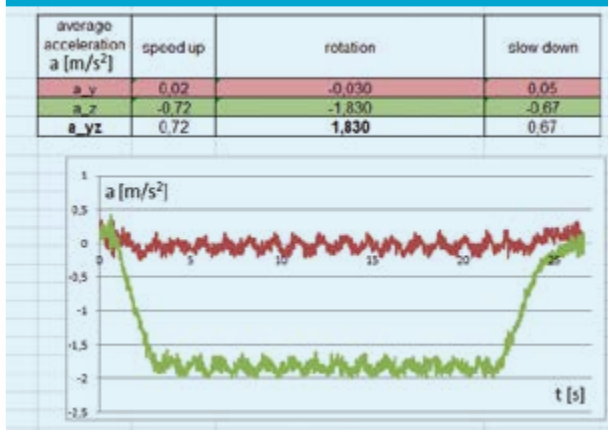
FIG.4 **The side of the smartphone is 11 cm from the diameter D**

average acceleration a [m/s^2]	speed up	rotation	slow down
a_y	-0,89	-1,673	-0,67
a_z	-0,77	-1,773	-0,89
a_yz	1,17	2,438	1,12
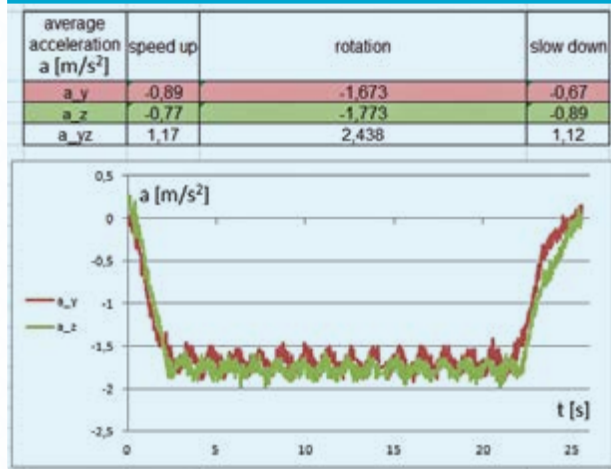
Similar measurements made when the second pair of the smartphone sides is perpendicular to the radius enable the students to find the second sensor coordinate. Thus the sensor position is localised.

[B] Another method of finding a sensor position does not require getting zero for a chord tangential component of the acceleration. The distance R of the revolving sensor from a central axis can be calculated as follows:
$R = a / \omega^2$
where the acceleration "a" is derived from Pythagoras' theorem on the basis of the acceleration components measured

FIG.5 **The centres of rotation C' and C" are the frames of reference for two positions of the smartphone on the record player**

FIG.6 **Setup of the experiment**

FIG.7 **Attach the smartphone accurately**

by the sensor. We can estimate the angular speed ω from the frequency of the disk rotation or from video measurements, e.g. with the Tracker software. See also the "Spot the Physics" teaching unit in this brochure.

An example:
The acceleration components for the first setup are equal to $a_x=0.128$ m/s^2 and $a_y=-2.435$ m/s^2 and the circular motion period is T=1.31.s.

$a_x=0.128$ m/s^2

$a_y=-2.435$ m/s^2

$a=\sqrt{a_x^2+a_y^2} = 2.438$ m/s^2

We calculate "a" from the formula above and finally R = 0.106 m.

We calculate the second radius for another position of the smartphone in the same way. **FIG. 6** portrays the position of the sensor as the intersection of the two circles whose radii were traced as above.

On a large scale (rotation ride in an amusement park or fun fair.)
3|2|1 **Setup and measurements**
Find a rotating ride and look for a radial "corridor" on the platform, then fix and mark different points (P1, P2, P3, P4, etc.) with coloured tape along this radius. Measure the distance of each point from the ride's centre using a metric tape. If there are obstacles to direct measurement from the centre, measure the distance of each point from the external edge of the platform and calculate the difference from the platform radius.

Measure the period of the ride with the stopwatch of your smartphone, repeat the measurement and calculate the average value.

Run the app for the acceleration measurement and place the smartphone on one of the marked points, taking care to align the smartphone along the radial direction.

At the same time, other students could put their smartphones in other positions along the radius so that they can obtain more data simultaneously and record the data. They should align the y-direction of their smartphones with the radius of the ride.

FIG.8 **Coordinate system of a smartphone**
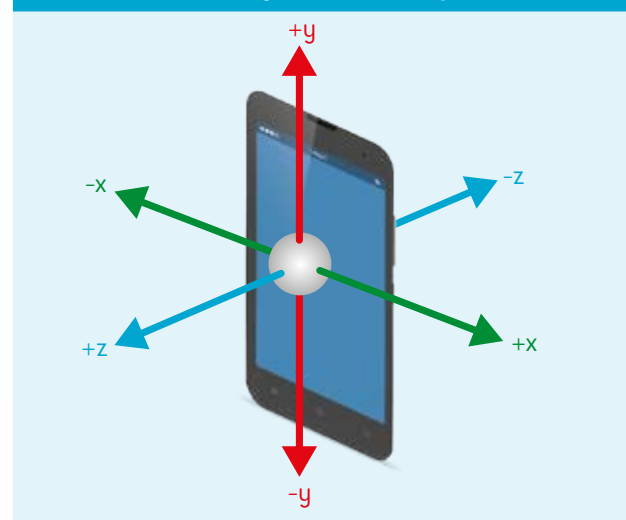
After the ride has stopped, the students should take a look at the graphs of the accelerations along the three axes x, y, z and observe the differences in detail.

FIG.9 Acceleration vs. time in the x-direction
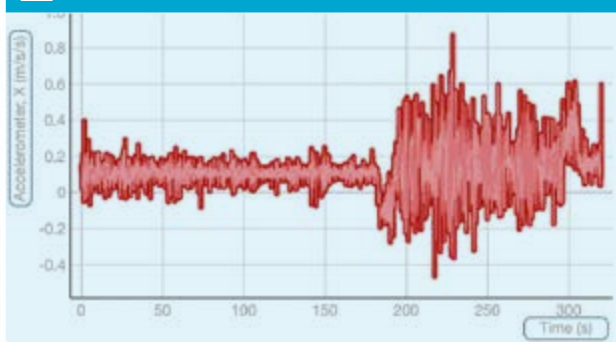
FIG.10 Acceleration vs. time in the z-direction
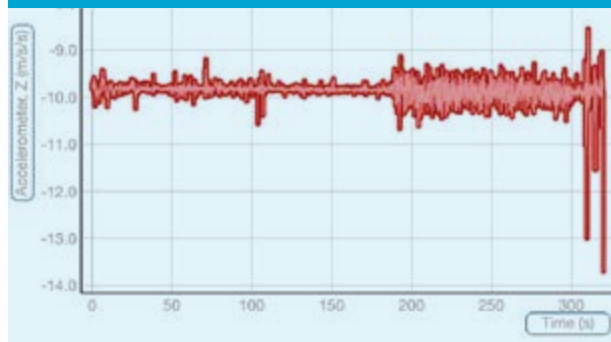
FIG.11 Acceleration vs. time in the y-direction with initialised offset, equal to -0.20 m/s/s
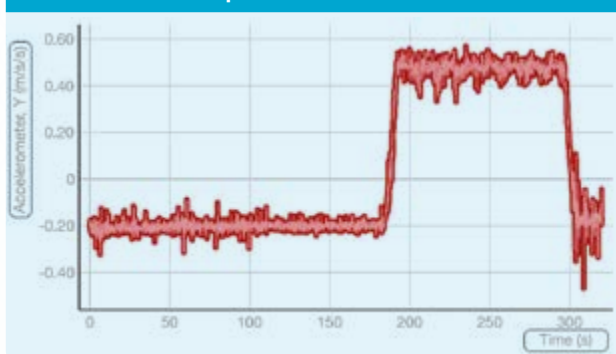
FIG.12 Acceleration vs. time in the y-direction without initialised offset

3|2|2 Analysis

The acceleration vs. time in the x-direction and in the z-direction is quite constant, but there is more fluctuation of the data in the state of motion than in the state of rest.

The charts show a typical measurement: when the ride begins to move, the acceleration along the y-axis increases (in a positive direction with respect to the positive y-direction of the smartphone (see the coordinate system of a smartphone above). After that, the acceleration is quite constant (the rotation speed is constant) and then, after the acceleration along the y-axis decreases, it returns to zero when the ride stops.

In one of the charts the initial value of acceleration, before the rotation, is not zero and the students have to subtract this value from the measured acceleration in order to obtain the real value.

The students can try a manual regression of the data. They must plot the points (radius, acceleration) on a graph and trace the best-fit line of data (linear regression) and find its equation: y = mx+q, with the slope and intercept.

The students can also use an app for regression on the smartphone to carry out the linear regression. In this case they must find the parameters of the equation and plot the data with the line.

The students can observe the value of R2 to decide the quality of the data fit. In the example shown, the result is excellent. At the end of the project, the students take the values of the acceleration they obtained with their smartphones, compare them with the theory (see the formula for centripetal acceleration) and check the level of agreement.

4|Cooperation option

Students from different schools and countries can share and compare their results and activities.

In order to encourage teachers and students to apply the smart accelerometers, we also organise a competition involving physics measurements in amusement parks in collaboration with Science on Stage Europe and eTwinning France.

5|Conclusion

The proposed activity is a good example for the students from the perspective of method. Since the physics of circular motion are always the same, the students have to deal with two situations that are subject to the same laws, but on different scales.

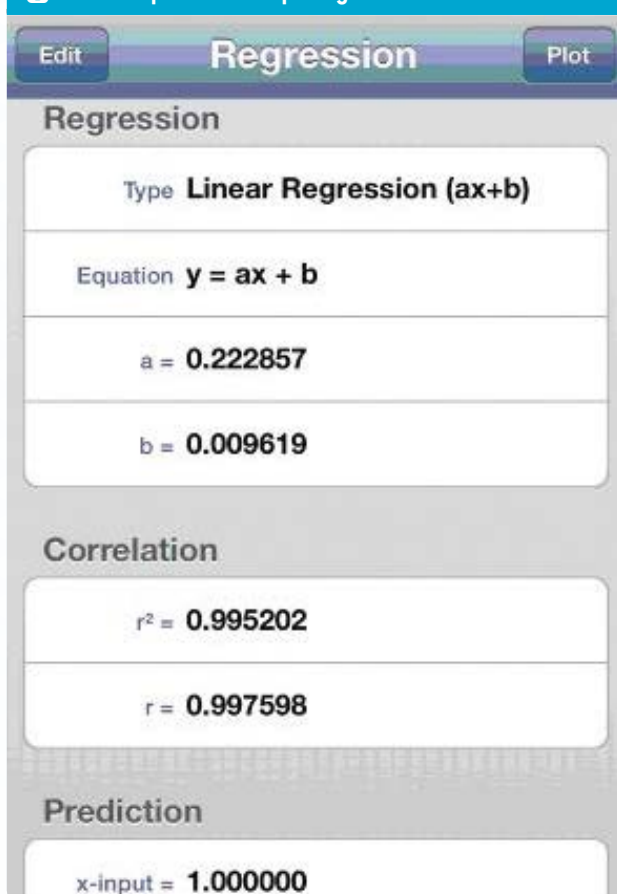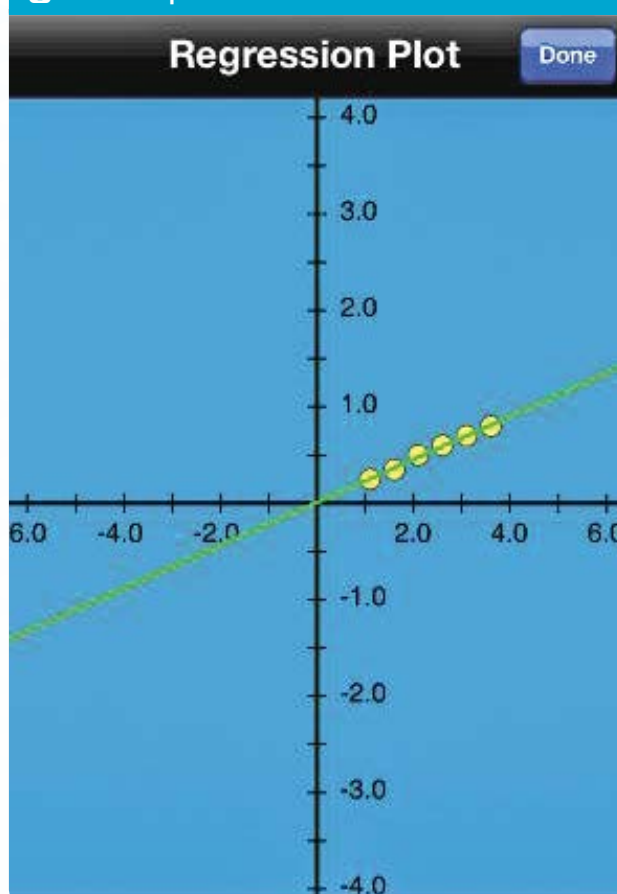**FIG.13 Equation and quality of the linear fit**

FIG.14 Graph acceleration versus radius

After highlighting the similarities, it is also important to highlight the differences between the two situations, for example the different degrees of importance of the accelerometer's uncertain position within the smartphone. This uncertainty, even if it involves several centimetres, is negligible when the dimensions are on the order of a few hundred centimetres (as in the radius of the ride), but it has a greater importance when the dimensions are comparable (as in the radius of the record player, about ten centimetres). There are many more situations in which students deal with circular motion in their lives, so they can also apply this experience to a merry-go-round, centrifuge, spin dryer, turntable, car/bike/train on a circular road, wheel, etc.

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FIG.15 Comparison of experimental and theoretical acceleration

R (m)	a measured (m/s²)	a theoretical (m/s²)
3.60	0.80 ± 0.05	0.83
3.10	0.70 ± 0.05	0.71
2.60	0.60 ± 0.05	0.60
2.10	0.50 ± 0.05	0.48
1.60	0.35 ± 0.05	0.37
1.10	0.25 ± 0.05	0.25
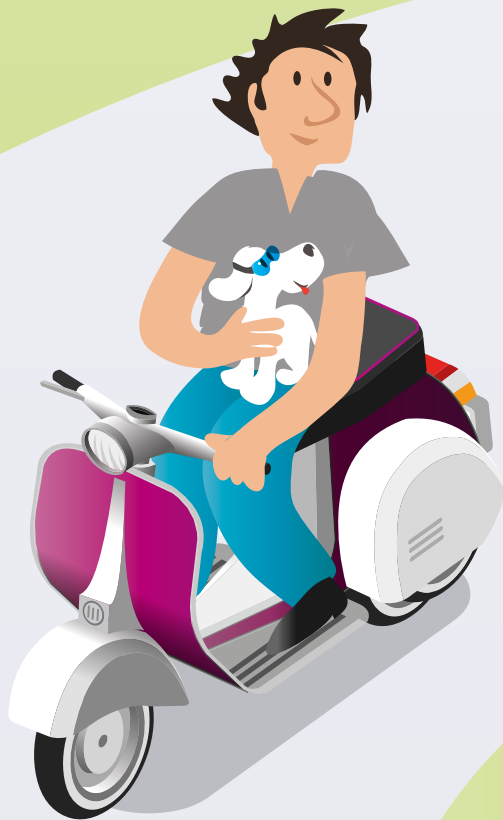
Spot the Physics

Dionysis Konstantinou

Damjan Štrus

1 | Summary

In this unit we present a few examples of how students can use smartphones to conduct physical video analysis of different physical events (movements). It is possible to use the smartphone for the whole analysis, but students can also combine the use of their smartphones with a freeware program named Tracker (or something similar).

- **Keywords:** Tracker, physics, video analysis
- **Discipline:** physics (linear and curved motions, oscillations, collisions)
- **Age level of students:** 15-19 years
- **Android apps:** VidAnalysis (will be released in December 2014)
- **iOS apps:** Adidas Snapshot, Video Physics from Vernier
- **Further computer software:** Tracker

2 | Conceptual introduction

The students prepare an experiment or observe an event (see examples below), record a video and import the video into an application that can make a physical analysis of the selected phenomenon (a smartphone application or Tracker).

The aim is to have the students:
- Compare their theoretical knowledge with their own data, which they have obtained from a real-time experiment or event, and/or
- Derive a physical law.

This activity is very suitable for learning outside the classroom (on an excursion, a trip, at summer camp etc.) in situations where the students have only their smartphones with them. They can learn even while they are riding along the highway on a bus instead of just playing games.

3 | What the students do

The students first have to decide whether they want to record a new video, choose an existing video from their smartphones or borrow a free video from Sample Videos (e-Book, samples from Tracker or a similar program) and import it into their smartphones. Below we offer a few examples of physical experiments or events that students can record with their smartphones:
- An inclined throw of a basketball
- A horizontal throw of a basketball
- A free fall and vertical throw of a basketball
- Acceleration of a cyclist on a horizontal surface (using different gears)
- Downhill free acceleration of a cyclist (or a tennis ball)
- Harmonic and damped oscillations of a spring
- Circulation of the tip of the second hand of a watch
- Circulation of a car on a roundabout
- Elastic and inelastic collisions on the air slide

You can find some examples of videos recorded by our students during their project work in school in the iBook.

When the students are recording movements, they must pay attention to several very important factors. We will explain our tips using the example of an inclined throw of a basketball.

FIG.1 Screenshot from the video of an inclined throw of a basketball

- During the recording, the students must hold their smartphones steady. They should not move the camera, because the analysis assumes the camera is in a fixed position. They also have to keep the plane of motion parallel to the plane of the camera lens.
- The object in motion should remain approximately in a plane perpendicular to the viewing direction.
- The video must be taken from the smallest possible distance, but it is necessary to record the entire motion. In our example, this means that the basketball should not disappear from the video at the top of the parabola.
- The students need to measure a real dimension of the moving object in order to scale the video. In our example we measured the diameter of the basketball.
- During the recording process, the students should consider the lighting conditions in order to have as clear a video as possible.

After recording the video and importing it into the application, the students should make a physical analysis of the selected phenomenon. To conduct the video analysis, the students can use one of the apps mentioned above, i.e. Tracker or a similar program. You can find complete instructions for using Tracker in the iStage 1 brochure, which is available at www.science-on-stage.de/iStage1-download.

The main part of the analysis is to obtain graphs such as $x(t)$, $y(t)$, $y(x)$, $v_x(t)$, $v_y(t)$, $v(t)$, $E_{kin}(t)$, $E_{pot}(y)$ etc. The students will use these graphs to derive further experimental data, which they can compare with a theory and use for further calculations.

Below are a few results (graphs) and tips concerning the selected example (an inclined throw of a basketball).

📊 **FIG. 2 Graph x(t) of the inclined throw**
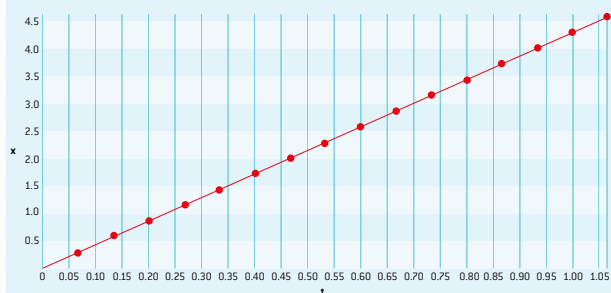
From **FIG. 2** you can see that v_x is constant; on the x-axis the unit is metres, on the t-axis the unit is seconds. Below this graph is the equation of the fit ($x = a \cdot t + b$), and the program gives us the value for the velocity of the ball in the horizontal direction (parameter a): $v_x = 4.3$ m/s.

Further tasks for students:
▸ Convert this value into km/h and mph.
▸ Choose two points from the line, calculate the slope and compare it with the v_x value.

📊 **FIG. 3 Graph y(t) of the inclined throw**
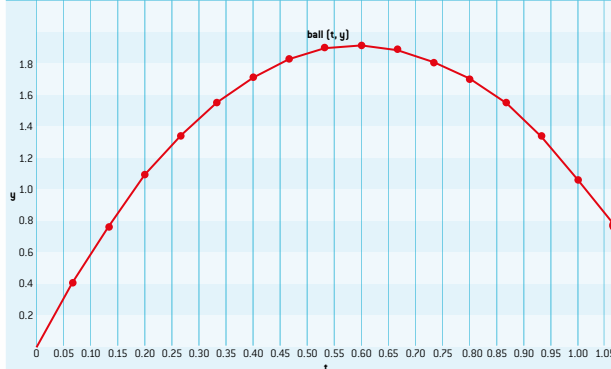
On the y-axis the unit is metres, on the t-axis the unit is seconds. The slope of the tangent of the parabola shows the velocity of our ball. The sign of the slope changes—that is because the direction of the ball in the vertical direction changes. The ball reaches the highest point at the vertex, where the slope of the tangent is zero.

Further tasks for students:
1. Write a mathematical equation for the parabola. Write a physical equation for the path of the ball in an inclined throw. Think about what information you can get from the parameters of the parabola. **FIG. 3** shows the actual path of the ball. The curve is called a parabola, and the smartphone application or Tracker allows you to fit the path and get the parabola's parameters.

2. The students should plot four additional graphs based on Graphs 1 and 2 before they look at the solution:

📊 **FIG. 4 Graph y(x) of the inclined throw**
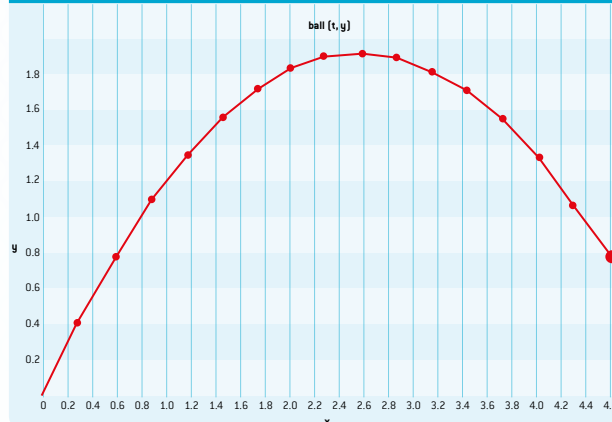
Graphs $v_x(t)$ and $v_y(t)$
Graphs $a_x(t)$ and $a_y(t)$

📊 **FIG. 5 Graph showing the change in the velocity in the vertical dimension during the throw**
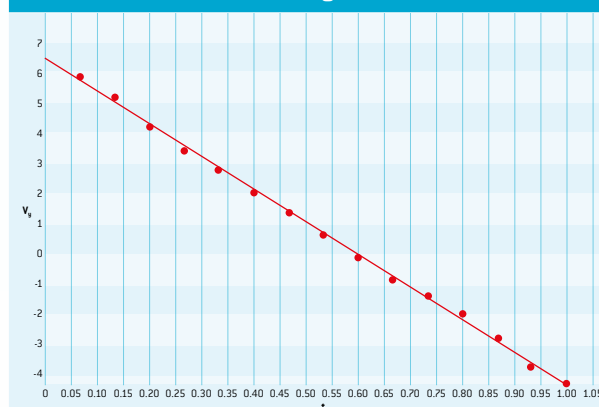

FIG. 5 shows the change in the velocity in the vertical dimension during the throw; on the v_y-axis the unit is metres per second, on the t-axis the unit is seconds.

3. Choose two points from the line and calculate the slope of the line. Do not forget to calculate with units.

Below this graph is the fit equation ($v_y = a \cdot t + b$). Compare the calculated slope with the parameter a. You will get the acceleration of this motion. In this case $a = -10.7$ m/s^2 (it should be $-g$).

Read off the intercept of the line on the vertical axis (v_y). You will get the initial velocity of the ball in the vertical direction (parameter $b = v_{y0} = 6.4$ m/s).

Use the fit equation for calculating the time the ball takes to rise $v_y = a \cdot t + b$. In this case $t = 0.60$ s.

Using the previous data, calculate the highest point that the ball reaches during this inclined throw. In this case, it is $h_{max} = 1.9$ m. You can also check your calculation in **FIG. 3**.

Think about what information you will get if you calculate the area between the line of this graph and the t-axis. Then calculate the size of this area (do not forget the units).

And finally, a few words about VidAnalysis, a mobile application that runs on the Android operating system and was developed by Richard Sadek in 2014 (release in December 2014). The use of this app at an early stage enables the students to learn about the basics of the physical analysis of dynamic phenomena. The operation of the app is quite similar to the previously described tools. At the beginning it is necessary to record a physical phenomenon, import the video into the app and determine the typical length of the phenomenon in the video. The main challenge, once again, is to determine the position of a moving body as accurately as possible. This is a major problem, because it is very difficult to tap precisely with your finger on the moving body on the smartphone's screen. Once this is done, the application immediately presents a graphical analysis of $x(t)$, $y(t)$ and $y(x)$.

4 | Cooperation option

We can organise cooperation between different schools. The students at the first school prepare an experiment, record a video and send it to the second school's students, who analyse it in Tracker and write a report (and vice versa). During the cooperation they can meet through Skype, Viber or any other tool that is appropriate for a video conference and talk about their experiences.

5 | Conclusion

The students can test a physical theory with the help of their own experiments and real-life events. They use their own smartphones as measuring devices, and to conduct the analysis they once again use their smartphones or computers and just click on the mouse—both devices are students' favourite tools/toys nowadays. If the results of their experiment fit the theory, they receive confirmation; if the results do not fit, they can think about the reasons for that (it may be air resistance, or they may have to think about doing the same experiment under different conditions).

By selecting and analysing an appropriate experiment, the students can potentially formulate a physical law.

6 | Personal experience

Students learn or review how to record useful videos, learn to use video analysis tools and think about the reasons why they may end up with differences between theory and practice.

The Earth's Magnetic Field

Stephen Kimbrough · Damjan Štrus
Corina Toma

1 | Summary

Why is it so important to know the values of the Earth's magnetic field? Why is the ESA's three-satellite Swarm mission studying its changes?

The Earth's magnetic field is responsible for the presence of the auroras in the polar regions and the beneficial deflection of the solar winds. We can call this magnetic field the Earth's safeguard against cosmic radiation and charged particles.

The terrestrial magnetic field can be measured using different methods, but in this unit the students can compare their measurements of the magnetic field using two Helmholtz coils and a real compass or a smartphone compass application with a direct measurement using the smartphone's magnetic sensor.

▸ **Keywords:** the Earth's magnetic field, Helmholtz coils, declination
▸ **Disciplines:** physics, mathematics, ICT, geography
▸ **Age level of students:** 12-19 years
▸ **Android apps:** Smart Compass, Sensor Kinetics, Compass
▸ **iOS apps:** Compass, Magnetometer

2 | Conceptual introduction

The Earth's magnetic field is more or less like a bar magnet tilted 11 degrees from the spin axis of the Earth. It seems that the electric currents in the Earth's core and their dynamo effect are responsible for the presence of this magnetic field. The Earth's magnetic field changes continually in terms of both magnitude and direction, and the poles' position changes at the same time. The World Magnetic Model calculated at the National Geophysical Data Center is updated every five years. According to the NGDC, in the year 2010 the magnetic pole co-ordinates of the World Magnetic Model were 84.97°N, 132.35°W for the South magnetic pole and 64.42°S, 137.34°E for North magnetic pole.

The Earth's magnetic field B is measured in the SI units microtesla (μT) or nanotesla (nT), and its value varies from 24μT to 66μT.

The purpose of this experiment is to measure the horizontal component of the Earth's magnetic field using a pair of Helmholtz coils, a compass and a smartphone with a sensor for magnetic fields.

This unit fits in well with the physics curricula in each European country (every physics student learns about the static magnetic field and the DC magnetic effect).

3 | What the students do

The students determine the magnitude of the horizontal component of the Earth's magnetic field. To do this, the students first have to assemble the electric circuit. Note that the power supply has to be far away from the coils due to its own magnetic field. If your school doesn't have a pair of Helmholtz coils, you can easily build them together with your students (see the instructions on how to make a Helmholtz coil in the iBook or at www.science-on-stage.de/iStage2-downloads). The device produces a homogeneous magnetic field in the mid-plane between the two circular coils. For this experiment the coils have to be aligned in a North–South direction and be in a vertical position, so that the Helmholtz coils' magnetic field (B_H) is perpendicular to the horizontal component of the Earth's magnetic field (B_E). A compass or a smartphone (with a compass app) placed in the central position of the device will point in the direction of the vector sum of the two components of the magnetic field, as shown in **FIG. 1**.

Obviously, $\tan \varphi = \dfrac{B_H}{B_E}$

Note: If your smartphone's magnetic sensor is inaccurate, it needs to be recalibrated. Move and twist your smartphone for a few seconds until the correct values can be obtained again. Also make sure that no magnet is near your smartphone.

3 | 1 Level 1

Turn the power supply knob to adjust the current in such a manner that the angle φ becomes 45°.

FIG.1
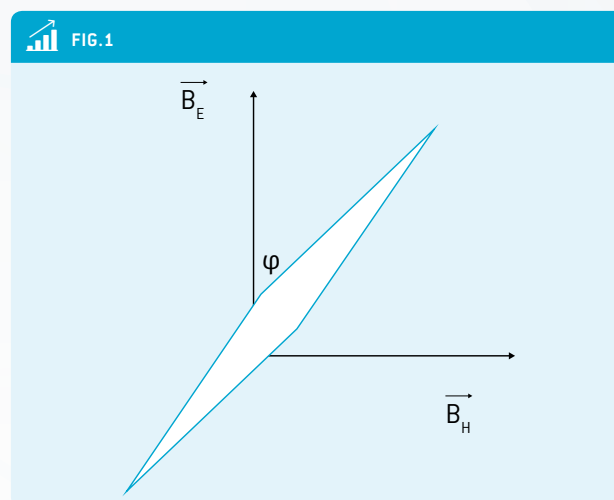
In this case, $\tan \varphi = 1$
and the magnitude of the magnetic field produced by the device equals the horizontal component of the Earth's magnetic field: $B_H = B_E$.

FIG.2 Screenshot Compass app

N
330　　　30
300　　　　　60
270　W　　　O　90
240　　　　　120
210　　　150
180

N
Berlin
Berlin
52°31′33″ N　13°24′12″ O

FIG.3 Screenshot Magnetometer

Magnetometer

45.4

Magnitude

-0.3　　28.4　　-35.4
X µT　　Y µT　　Z µT

Read the value of the current. You can calculate the Helmholtz coils' magnetic field by using the following formula:

$$B_H = \mu_0 \cdot \frac{8 \cdot N \cdot I}{R \cdot 5\sqrt{5}},$$

where N is number of turns in each coil (20 in our case), I is the current through the coils in amperes, R is the radius of the coils in meters (20 cm in our case), and

$$\mu_0 = 4\pi \cdot 10^{-7} \frac{V \cdot s}{A \cdot m}$$

is the magnetic permeability in a vacuum.

To compare the value obtained from the formula, use a smartphone app. Lay your smartphone on a flat surface and align your smartphone parallel to the North–South direction by using the compass app of your smartphone or a magnetic needle (see **FIG. 2**). Use an app to measure the magnetic field in three dimensions. In this case (see **FIG. 3**) one of the components (B_X) should be almost zero. The other one shows the horizontal component (B_Y). B_Z then shows the vertical component of the magnetic field.

3 | 2 **Level 2:**

Turn the power supply knob to produce the suggested values of the electric current through the coils, resistor and ammeter. The values are written as in **FIG. 4**.

FIG.4

I (mA)	φ (°)	tan (φ)
0		
30		
60		
90		
120		
150		
180		
210		
240		
270		
300		

Measure the deflection of the compass and write down these angles. Calculate and fill in the third column.

Plot the two graphs:
▸ $\varphi = f(I)$ $\varphi(I)$
▸ $\text{tg}\,\varphi = f(I)$, which is a linear function $\tan\varphi(I)$

Draw the line that best fits the measurement points of the $\tan\varphi(I)$ graph, choose two points from that line and write down their values. With the slope k of the linear curve, calculate the magnitude of the horizontal component as follows:

$$\tan\varphi = \underbrace{\frac{\mu_0 \cdot N \cdot 8}{B_E \cdot R \cdot 5\sqrt{5}}}_{\text{slope k}} \cdot I \quad\text{and}\quad B_E = \frac{\mu_0 \cdot N \cdot 8}{k \cdot R \cdot 5\sqrt{5}}\,.$$

Compare the values obtained by the measurement with your smartphone measurement shown in Level 1. Also compare your values with the estimated values for the Earth's magnetic field at your location at http://www.ngdc.noaa.gov/geomag-web/. The latitude and longitude can be obtained from your smartphone.

FIGS. 5-7 show examples of our measurements with R = 20 cm and N = 20.

FIG.5

φ (°)	I (mA)	tan (φ)
0	0	0.00
9	28	0.16
17	59	0.31
25	92	0.47
31	120	0.60
37	153	0.57
41	180	0.87
45	210	1.00
49	241	1.15
52	276	1.28
56	320	1.48

The value for the slope is k = 0.00451/mA and therefore $B_E = 19.98\,\mu T$.
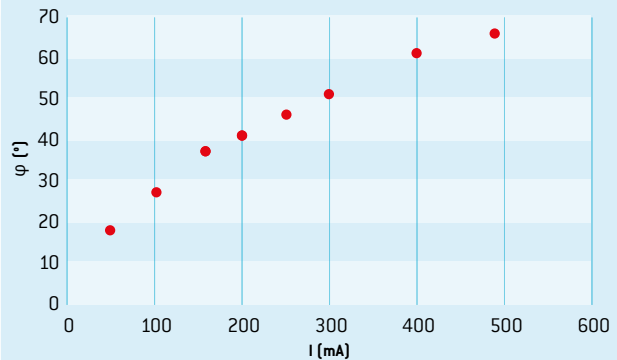
FIG.6

FIG.7

y = 0,0045x
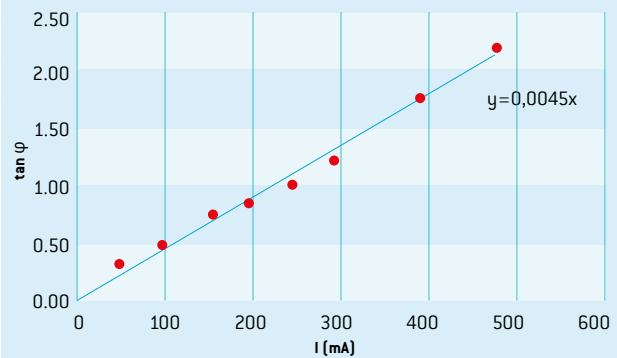
3|3 Further experiments

3|3|1 Observe the change in the Earth's magnetic field over a long period of time (about three months).

Students can measure the horizontal and the total magnitude of the Earth's magnetic field over a period of time. At this stage the students only need to use their smartphones and the Magnetometer app (Sensor Kinetics—Android). The measurement has to be made in the same place every time in order to obtain comparable values. After this the students can record the data in a graph and discuss the fluctuation.

3|3|2 Compare the magnetic field's values with the latitude

Students from different schools can be involved in a common project. For this they have to measure the horizontal magnetic field in their home town and note their latitude. After recording this data the students will realise that the Earth's magnetic field is changing a little every day, and also that there is an important gradient in the horizontal component of the Earth's magnetic field going from the equator to the North Pole (in the northern hemisphere). Data for this experiment can be obtained from the database (Find the link to the moodle database at www.science-on-stage.de/istage2-downloads).

4 | Cooperation option

Take part in a European science project

As part of this teaching unit we have created a database where you can upload your measurements of the horizontal component of the Earth's magnetic field. Please also enter the date of your measurement, your location and your global position coordinates. Link info at www.science-on-stage.de/istage2-downloads. You will have to register to enter data there.

Here you will also have access to the values recorded previously by other participants, both teachers and students.

5 | Conclusion

This unit helps students to understand that the accuracy of the analogue measurement (with a pair of Helmholtz coils and a compass) is just as good as that of the digital measurement (with a smartphone).

The students will observe how modern technology improves scientific research. The duration of the measurement process has changed dramatically. In addition, the smartphone is a multipurpose measuring device.

The students can compare their results to current data and immediately see how accurate they are and share their results.

Hints: How to use smartphones in your lessons

After reading this iStage 2 booklet you might want to use the teaching units together with your students. Here are a few hints that may save you some headaches and alert you to a number of legal and security concerns:

Authorization by your school
Many schools in Europe don't allow students to use their smartphones inside the school and have very strict rules about the use of smartphones inside classrooms. But if you plan to use smartphones in scientific experiments, it is easy to get a limited authorisation for a specific use. Simply bring your iStage 2 booklet to your headmaster and show him the teaching unit you want to use, telling him that you want to conduct experiments with your students and that you will give him a report afterward. This should enable you to receive authorisation to use smartphones together with your students.

Different operating systems and apps
In iStage 2 we have limited the supporting operating systems to Apple iOS and Google Android. Applications for both systems can be found in the teaching units, but you can easily find equivalent applications for Microsoft Windows Phone and BlackBerry.

Not every student has a smartphone
This is why we encourage you to form groups of two or three students who work together on smartphone measurements. The teachers working with us have reported that in Europe's high schools at least a third of the students have an Android or iOS smartphone.

Concerning limited-data phone contracts, let your students know if your activity involves Internet access. If you are in a classroom, you can share a limited period of WiFi access by turning a laptop into a hotspot during the lesson.

Not every student has an unlimited data contract
When you have to transfer the collected data to a computer, don't forget that all smartphones have cable connections and you don't have to use a wireless connection. This is important in schools where wireless connections are forbidden due to health concerns. Of course it is sometimes easier to use dropbox or an equivalent shared online repository for your files, but you always have the possibility of using a direct cable connection to a computer.

Smartphones and social networks
You have to be aware that the temptation to connect to social networks is strong for students who are allowed to use their smartphones in the classroom (or on a school trip). You have two ways to control this:
▸ You can tell them that you trust them to avoid using the phone for anything other than what the lesson requires. It's up to you to be "cool" if they keep unwanted connections to a reasonable level, but most of the time there should be no problems if you trust the students in the first place and have an appealing lesson.
▸ With some students you cannot do otherwise than force them to put their phone in "flight mode". It's easy to check if they have done it by looking at the screen, where you should be able to see a small airplane in one corner. This greatly extends the battery life of the phone and is strongly recommended for measurements that require a long time. But it may prevent you from using some sensors such as GPS on some phones.

Prepare rules and agreements concerning responsibilities
The website at www.science-on-stage.de/istage2-downloads proposes a sample agreement that you can present to your students and their parents to make your responsibilities clear. Because you will be using the students' smartphones, you have to make sure that the students will not demand financial compensation from their teacher if they break their phones by not obeying the security rules that you have presented at the beginning of your lesson.

Smartphone security
These electronic devices are sensitive, and students can become careless if they are enjoying your lesson and carrying it out with too much enthusiasm. Remind them to always hold their devices in a firm grip and to make sure they put their smartphones in a strong holding pouch when they are doing experiments on a roller coaster or measuring their sport performance. If you plan to use the smartphone in a dangerous way, always try out the procedure with your own device first

and build a solid "airbag-like" casing. For experiments involving free fall, you could have your school buy a few Bluetooth sensor devices, which are covered with a solid plastic shell and are available on the Internet for less than €20.

Jean-Luc Richter · Dr Miguel Andrade

App list, Resources and further Material

At our webpage you find the complete list of all smartphone apps and resources used in these teaching units as well as further material:

www.science-on-stage.de/istage2-downloads

Outlook

This publication remains a work in progress. If you are interested in our upcoming teacher trainings, or if you'd like to see how the project continues, please contact us via info@science-on-stage.de — new teachers are welcome to join in!

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Overview of Activities: Project Events

2013

25-28 April 2013
Science on Stage festival in Słubice – Frankfurt (Oder)
Network meeting: Smartphones in Science Teaching

8 July 2013
Coordinators meeting in Dortmund

19-21 October 2013
First workshop in Vienna

2014

3-5 May 2014
Second workshop in Berlin

5-6 December 2014
Presentation of the publication

2015

Throughout the year
Teacher trainings in various European countries

Getting kids excited about technology with the FIRST® LEGO® League (FLL)

The FIRST® LEGO® League (FLL) education programme aims to promote up-and-coming young scientists. The competition in 2014 has been devoted to learning in the digital society.

The worldwide robotics competition is open to schoolchildren between the ages of 10 and 16. It is meant to attract them to science and new technology in a playful way. All of the participants use a comparable system (LEGO Mindstorms) to build and program an autonomous robot that has to solve difficult tasks. All of the teams are also given a predefined project mission, the results of which they present to a panel of expert judges. For the 2014 Challenge, the participants are being asked to develop "the classroom of the future".

The FIRST® LEGO® League education programme was conceived by the non-profit organization FIRST (For Inspiration and Recognition of Science and Technology) in the USA, which also gave the competition its name. The technological basis of the challenge is the robot system from LEGO Mindstorms. In the more than 15 years since the FIRST® LEGO® League was introduced, the programme has spread all over the world. In 2013 the FLL Challenge was organized in more than 70 countries, with almost 23,000 teams competing. In Central Europe, the competition is organized under the auspices of the non-profit association HANDS on TECHNOLOGY.

The FLL competition in Central Europe will continue until mid-February 2015. Registration for the next competition will begin in March 2015. Further information can be found at www.first-lego-league.org.

SAP University Alliances: Inspiration for information technology at schools all over the world

The SAP University Alliances program is providing more than 1,800 universities in over 80 countries all over the world with access to SAP technologies and expertise. The aim of the program is to teach highly qualified high school graduates important skills that they will need in the working world of the future. Thanks to a community consisting of over 8,000 university instructors and an annual program of more than 750 events, students are offered numerous opportunities to experience SAP at first hand. The SAP University Alliances program also offers exciting programs for schools.

erp4school — The interactive learning platform for business management learning content

Today, and even more so companies nowadays will need qualified employees who are trained in the use of computers. That's why it is becoming increasingly important that employees be trained in the use of complex standard industrial programs. This is where erp4school comes into play.

The program is currently being used at 242 schools in Germany, Austria and Africa. It enables schoolchildren and trainees to obtain a management-oriented understanding of companies, business processes, and work procedures. The program does this by taking a holistic approach to providing the students with knowledge about a company's organization and business processes. Sales and procurement play a role, as do accounting and human resources.

The erp4school program employs an educationally structured scenario to give students insights into the process-oriented use of ERP systems in daily business operations. In addition, the participants learn about the latest technology trends, such as SAP HANA®.

A nationwide network of vocational schools, business-focused high schools and other interested academic institutions and associated educational institutions in Africa are helping to successfully offer erp4school and continuously enhance it.

Teachers at the participating schools can take part in introductory courses and further training programmes. The schools then receive a pre-configured SAP ERP system in the cloud. Moreover, students and teachers can use the comprehensive range of supplementary material offered by the continuously expanded online library.

Young Thinkers — getting young people excited about technology and promoting their entrepreneurial spirit

On the basis of its experiences with erp4school, SAP University Alliances launched a new programme in 2014 called "Young Thinkers". It is geared toward students in the first and second stages of secondary education. It gives schools the opportunity to integrate SAP software-assisted courses into the curriculum in a variety of ways. The program offers courses on subjects such as systemic thinking, programming, business processes, data analysis and Web design. The courses are offered at various levels of difficulty and complexity.

Teachers also get access to a wide array of course content, while schoolchildren can take part in competitions, projects and other events with college students. Young Thinkers aims to spark children's interest in STEM subjects and also promote their entrepreneurial spirit. It strives to encourage young people to choose a career in the natural sciences or perhaps even establish their own companies some day.

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