Building a seismograph from scrap

Did you know that you can use old hi-fi speakers to detect earthquakes? And also carry out some simple earthquake experiments in the classroom? Here's how.

By Panteleimon Bazanos

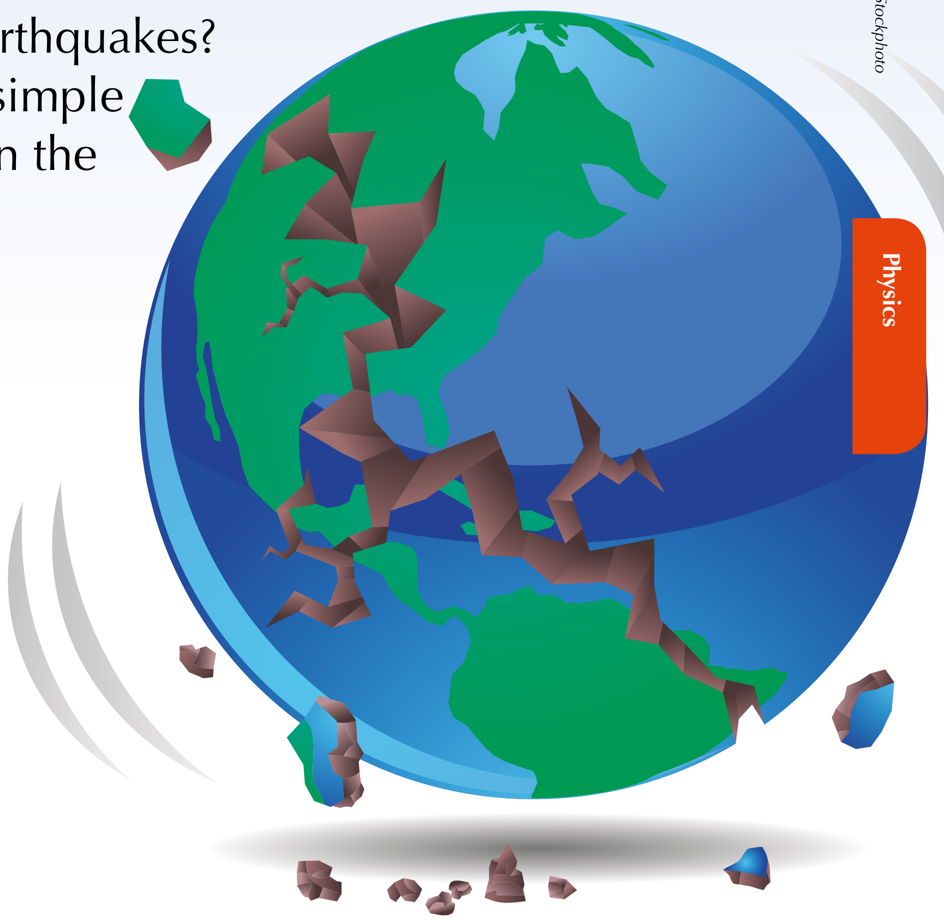

Image courtesy of jeffreyw / iStockphoto

Physics

Earthquakes occur around the world all the time. In 2011, the earthquakes that caused the Fukushima disaster in Japan, killed thousands in Turkey and devastated New Zealand's capital city made the headlines. But did you know that 2011 also saw earthquakes in Finland, Belgium and the Czech Republic?

Some earthquakes may be so slight as to be practically unnoticeable, but they can still be recorded. Each tremor produces different types of vibration, or seismic waves, which travel through Earth's interior with different velocities. These waves can be detected and recorded by instruments called seismographs, which are often sited at great distances from the earthquake. By measuring the time that the seismic waves take to arrive at seismographs, as well as recording the amplitude and duration of the waves, we can calculate the magnitude of the earthquake and determine its epicentre.

Monitoring local earthquakes

Earthquakes are a daily occurrence in Greece (figure 1), sitting as it does at the boundary of two tectonic plates. The district of Messinia, where our school is located, has a history of major earthquakes. In 1886, a severe earthquake of

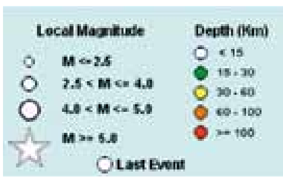

Figure 1: Earthquakes in Greece during the first week of November 2011. Due to its position at the boundary of the African and European tectonic plates, several earthquakes occur in Greece every day

Image courtesy of Panteleimon Bazanos; data source: the automated alert system of the Institute of Geodynamics at the National Observatory of Athens

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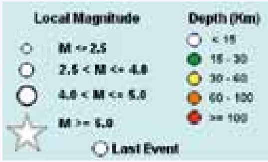


Figure 2: The 1886 earthquake ruined Filiatra, while the 1986 earthquake damaged Kalamata. Sparta is likely to be another victim within the next 100 years

Image courtesy of Nicola Graf

magnitude 7.5 on the Richter scale struck Filiatra[w1] (figure 2). A century later, Kalamata was hit by another strong earthquake[w2], this time of magnitude 6.0. Within the next 100 years, it is predicted that Sparta will be struck by an earthquake[w3] of at least magnitude 7.0.

To encourage my students to learn about earthquakes, I acquired and set up a commercial, educational seismograph in our school (figures 3 and 4), the General Lyceum of Filiatra. The seismograph is based on an array of three geophones – devices that respond to the seismic waves and convert them to electrical signals. Each of the three geophones monitors waves

REVIEW

- **Earth science**
- **Physics**
- **IT**
- **Electrical engineering**
- **Acoustics**
- **Seismology**
- **Ages 16-19**

In 2011, an earthquake caused an environmental disaster by damaging the nuclear power plants in Fukushima, Japan. This article briefly describes the mechanism of earthquakes and especially the propagation of the different waves running through Earth. These waves can be measured with seismographs.

The author describes how you and your students can build your own seismograph using an adapted loudspeaker and audio software. This would be an interesting project in physics (acoustics, acoustic-converter, induction, the mechanical properties of springs), earth science (earthquakes and their classification), or electrical engineering (practical work) lessons. It could also be used in IT lessons (analysing the audio signal and how audio software works; using database software to build a earthquake database).

If you have too little seismic activity in your region to make it worth building your own seismograph, you could visit the suggested websites to download earthquake data to analyse with your students. And of course you could still carry out the earthquake-simulation experiments that the author describes.

The article stimulates questions like:

- What is an earthquake? What can you find out about severe earthquakes in your area?
- How do earthquake waves travel through Earth?
- What is a seismograph and how does it work?
- How do loudspeakers work, and why and how can they be used for earthquake detection?
- What are the basic electrical laws to consider when using a loudspeaker as a microphone or geophone? How do you get a voltage out of them?

Gerd Vogt, Higher Secondary School for Environment and Economics, Yspertal, Austria

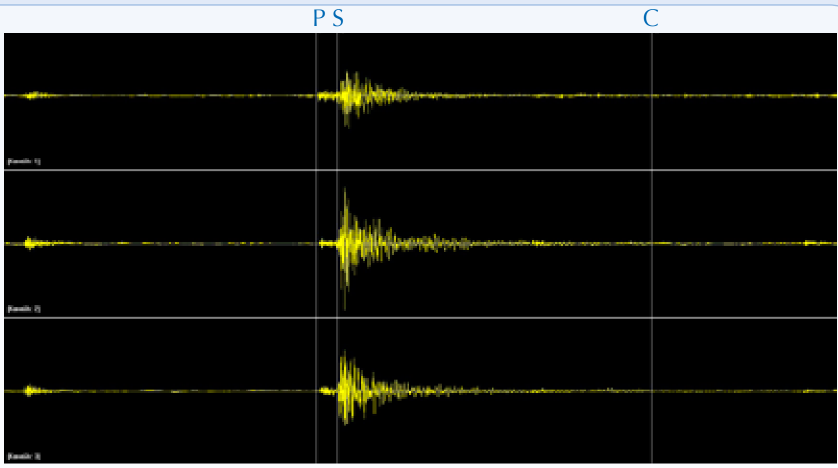


Image courtesy of Panteleimon Bazanos; image source: Seismic Logger, Helicorder and Dataviewer software, Seismology Laboratory of the University of Patras

Figure 3: A three-channel seismogram from our commercial seismograph, showing the start times of the primary (P) and secondary (S) waves and the vibration end time (C).

Primary waves are compressional longitudinal waves[w4] that are the first to arrive at the seismograph. They can travel through solids or fluids – in air they take the form of sound waves, travelling therefore at the speed of sound (340 m/s). In water they travel at about 1450 m/s and in granite at about 5000 m/s. Secondary waves are shear transverse waves, arriving at the seismograph after the primary waves and displacing the ground in a direction perpendicular to the direction of propagation. They do not travel through liquids or gases, travelling through solids at speeds of about 60% of those of primary waves.

The epicentre distance (in km) and the earthquake magnitude (measured on the Richter scale) are calculated according to the formulae

$$\text{distance} = p_1 \cdot (t_s - t_p)$$

and

$$\text{magnitude} = p_2 \cdot \log_{10}(t_c - t_p) + p_3 \cdot \text{distance} - p_4$$

where p_1, p_2, p_3, p_4 are constants that depend on the types of rock that the earthquake passed through. Default values are $p_1 = 7.6$, $p_2 = 2.31$, $p_3 = 0.0012$, $p_4 = 1.0$. Three time measurements (in seconds) are needed: the time that P waves arrive (t_p), the time that S waves arrive (t_s) and the time that vibrations end (t_c)

in the up-down, east-west or north-south directions. The three signals are then processed by computer, allowing the magnitude of the earthquake and the distance from the epicentre to be calculated (figure 3).

Building a seismograph

I also wanted to encourage the students to think about the technology that is used to detect and measure earthquakes and to understand what each component does, rather than viewing a seismograph as a 'black box'. To this end, we build our own seismograph, with which we can detect local earthquakes – up to 100-200 km away, depending on their magnitude.

At the heart of any seismograph are the geophones. They convert the ground vibrations into electrical signals using a coil that moves relative to a magnet, producing an electrical voltage at the end of the coil (Faraday's law; figure 4). To build our seismograph, we used everyday technology as the geophone: a loudspeaker. Normally, loudspeakers operate by converting an electrical signal into the relative movement of a coil and a magnet, which causes the cone to move in and out, thus generating vibrations: sound waves (figure 5). By making them operate the other way round – turning vibrations into electrical signals – they can be made to function as geophones.

To make our geophone, we used a 'woofer' – a speaker for low-pitched sounds – because woofers are designed to work well for low frequencies, and seismic waves are of course low-frequency vibrations. To minimise interference from sound vibrations, we removed the cone of the loudspeaker.

To complete our geophone (figure 6), we also used a weight, a spring and the lid of a spray can. The weight serves to increase the inertia, as the loudspeaker coil itself is very light. Placing a weight directly onto the coil would damage it, so we used the

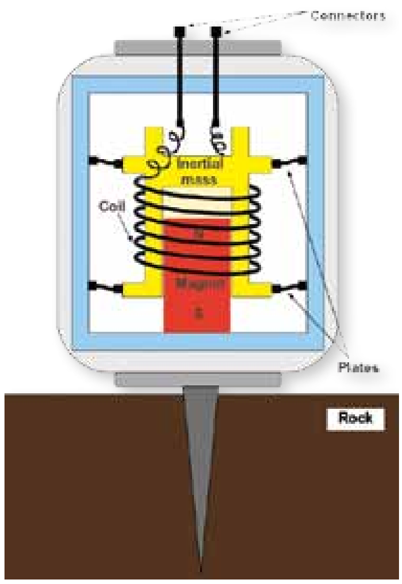


Image courtesy of Panteleimon Bazanos

Figure 4: How a geophone works. When the ground vibrates, the mass with the coil attached to it moves relative to the magnet. The potential difference produced in the connectors depends on the way the ground vibrates

Image courtesy of Iain Fergusson; image source: Wikimedia Commons

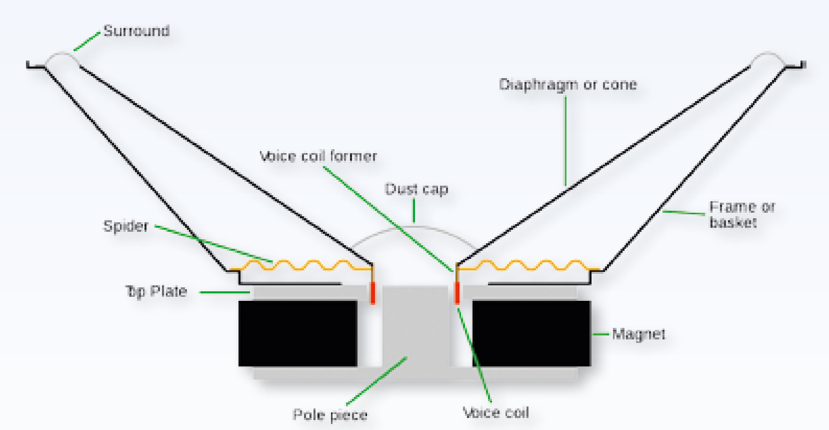


Figure 5: How a loudspeaker works. As the function of loudspeakers is based on the relative movement of coil and magnet, we can use them to detect ground vibrations. These vibrations move the coil relative to the magnet, producing a potential difference between the coil's connectors. This electrical signal is recorded by the computer via the sound card, in the same way as input from a microphone would be[w5]

Image courtesy of Panteleimon Bazanos

Figure 6: Our homemade geophone

spring to hold the weight over the coil, allowing it to oscillate. The lid protected the coil. We then plugged our woofer geophone into the sound-card port of a computer, and recorded the signals using sound-editing software, creating a working seismograph.

Detailed instructions for building our seismograph can be downloaded from the *Science in School* website[w6].

Now it's your turn

If you are interested in monitoring and investigating seismic activity in the classroom, you could:

1. Monitor and analyse data from existing seismographic stations[w7,w8].
2. Use a commercial, educational seismograph.
3. Construct your own seismograph, using the downloadable instructions on the *Science in School* website[w6].
4. Carry out some simple experiments to simulate and investigate the physics of earthquakes (see below).

To record earthquakes with either a commercial or a homemade seismograph, you will need to be relatively close to their epicentres. Our homemade seismograph detected earthquakes up to 100-200 km away[w9], depending on magnitude. With our commercial seismograph[w10], we detected earthquakes of 4.0 on the Richter scale from 500 km away.

Options 1 and 4 have the advantage of being feasible even in regions with very little seismic activity.

Looking for earthquakes

The coil of the homemade seismograph is very sensitive, so the geophone must be handled with great care. For the best measurements, set up the seismograph somewhere quiet and free from vibrations, perhaps in the school cellar. However, to encourage student participation, I set mine up in the classroom.

Once you have set up your seismograph, let it record continuously for one or two days, then save the data in a file. Before you can search for earthquakes in the data, you will need to do some processing. The exact details of the processing will depend on the software you use, but it should be fairly straightforward.

1. Remove any *DC offset*, to remove the contribution of any DC current to the signal.
2. Amplify the low frequencies (below 100 Hz). This is the range in which you will detect earthquakes.
3. Remove background 'noise' (thermal noise, electronic noise, etc.) to make the signal clearer.
4. After that, you can search the data for patterns that indicate an earthquake.

Not all signals recorded by seismographs are earthquakes. Other, more local sources, including traffic, wind, explosions and opening and closing doors, can cause confusion. Earthquakes often have a characteristic pattern: a small waveform followed by a large one (see figure 3). Because this is not always the case, however, you and your students may sometimes be unsure if what you have detected really is an earthquake. The only way to be certain is to do what professional seismologists do and compare your data with the recordings made at other seismographic stations[w7,w8].

When you are confident that you have detected an earthquake, you can calculate its magnitude (on the Richter scale) and your distance (in km) from the epicentre (figure 7). For that, you need only three measurements: the arrival time (in seconds) of the P and S waves, and the time at which the vibrations stop (see figure 3). For more details, download the instructions from the *Science in School* website[w6].

Image courtesy of Panteleimon Bazanos

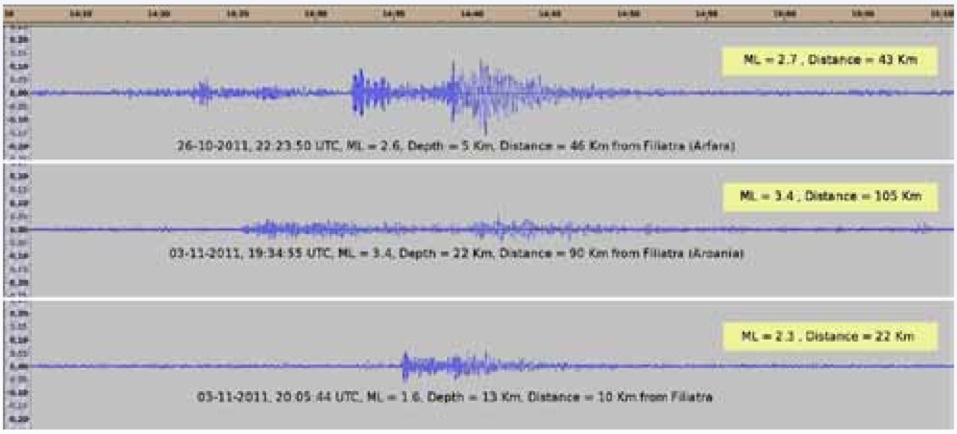


Figure 7: Earthquake signals recorded with our homemade seismograph. The values in the yellow boxes were calculated from the homemade seismograph data, while the values under the signals are from the reports of the Institute of Geodynamics of National Observatory of Athens. ML stands for local magnitude (ML) on the Richter scale

Vibration experiments using computer speakers

I also devised some experiments to simulate some aspects of earthquakes and the signals they produce – for example, how the energy of the earthquake decreases as it passes through different materials.

To do this, we used speakers and a computer equipped with a sound card and audio processing software, as before. But in place of geophones you can use old computer speakers (again with the cone removed), which can be moved around as needed in the experiments (figure 8). You can use 100W / 8Ω woofers, as in the construction of our seismograph, or 3W / 8Ω computer speakers, plus the sound-editing software Audacity[w11]. For more details, see steps 1, 8 and 9 in the downloadable instructions[w6].

The experiments involved dropping balls from different heights (representing different energies) at different distances from the detectors (the speakers), onto surfaces made from various solid materials. When the ball strikes the hard surface, it produces vibrations that travel through the solid – just as an earthquake produces waves that travel through Earth.

Experiment 1: The power of a shake

This activity demonstrates the relationship between earthquake power

Image courtesy of |Chris|; image source: Flickr

and ground movement. We caused vibrations on a piece of marble (or wood, plastic or even the ground) by dropping a mouse ball (from a computer mouse) from different heights, producing different ground-shaking powers. The amplitude of the signal depends on the power of the shake.

1. Set up the equipment as shown in figure 9A.
2. Drop the ball from different heights, recording the signal amplitude (figure 10) in table 1. It is not important exactly what distance from the speaker you drop the ball, but make sure you drop it onto the same spot each time.
3. Plot a graph of amplitude against height.
4. Discuss the graph. Your students should conclude that the more energy is released, the more the ground vibrates.

Experiment 2: Energy attenuation

This activity demonstrates the energy attenuation (decrease) as seismic waves travel through Earth's crust. We produced vibrations by dropping a 4 kg shot put (metal ball) on the ground from the same height but at different distances from the woofer geophone or loudspeaker. As the waves travel, they lose energy and the ground vibrates less. This is reflected in the amplitude of the signals.

Image courtesy of Panteleimon Bazanos

Figure 8: A pair of computer speakers and cable modified for use in the experiments. The plugs on the cable have been replaced by crocodile clips, and the cones have been removed from the speakers to reduce interference from sounds travelling through the air

Image courtesy of Panteleimon Bazanos

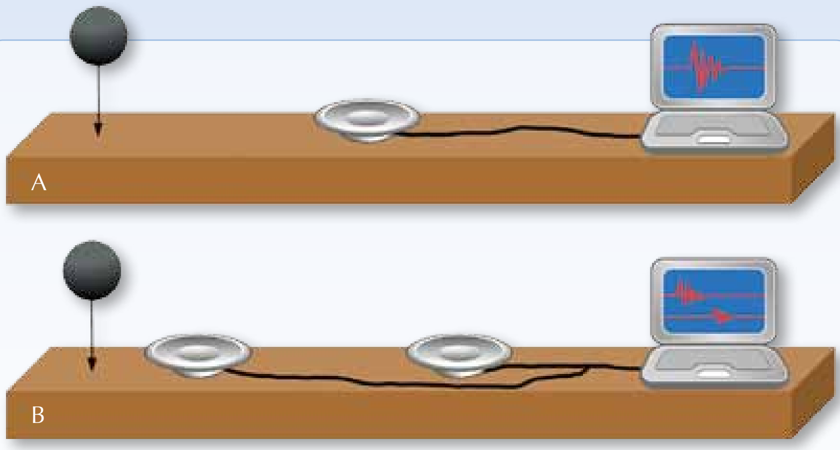


Figure 9: Two set-ups for the experiments, using one (A) or two (B) speakers

Image courtesy of Panteleimon Bazanos

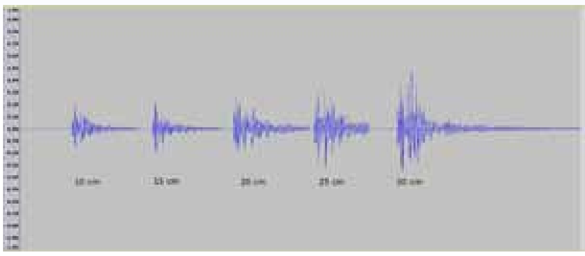


Figure 10: The signals recorded in experiment 1. The signals were amplified by a factor of 10

Table 1: Enter your results for experiment 1

Height (cm)	10	15	20	25	30
Signal amplitude					

Image courtesy of Panteleimon Bazanos

Figure 11: The signals recorded in experiment 2. The signals were amplified by a factor of 4

Table 2: Enter your results for experiment 2

Distance from geophone (m)	1	2	3	4	5
Signal amplitude					

1. Set up the equipment as shown in figure 9A.
2. Mark 5 distances of 1 m intervals from the woofer geophone or loudspeaker along the ground.
3. Let the ball fall from the same height (e.g. 1 m) onto the ground at each marked distance, recording the results (figure 11) in table 2.
4. Plot a graph of amplitude against distance.
5. Discuss the graph. Your students should conclude that the farther away the 'earthquake' is, the less the ground vibrates.

Experiment 3: Wave velocity in different media

In this activity, we investigate wave velocities in different media. As seismic waves travel through Earth, their velocity differs depending on the composition of the rocks they are travelling through. This gives seismologists and geologists important information about Earth's interior. Here, we investigate how fast vibrations travel through different solid materials.

We used wood, iron and marble as the materials, but any hard solid can be used. Just make sure you have the various materials available in a size suitable for the activity.

1. Set up the equipment as shown in figure 9B. We used a distance (x) of 80 cm between the speakers.
2. Drop a mouse ball (or other suitable object) onto the first solid material, close to one speaker, but not between the speakers. Record the times for the signal to reach each speaker (t_1, t_2).
3. Repeat with the other materials, entering each result in table 3. Work out the wave velocities using the formula: $v = x / (t_2 - t_1)$
4. Discuss the results. In which material do the waves travel fastest?

Web references

w1 – To learn more about the 1886 earthquake in Filiatra, see: www.

Table 3: Enter your results for experiment 3

Material	t_1	t_2	t_2-t_1	x	$v = x / (t_2-t_1)$
Wood					
Iron					
Marble					

oasp.gr/node/666 (in Greek, with automated translation into English)

w2 – For more information about the 1986 earthquake in Kalamata, see: www.oasp.gr/node/672 (in Greek, with automated translation into English)

w3 – For an interview (in Greek) with Professor Dimitrios Papanikolaou of the University of Athens, in which he discusses the expected earthquake in Sparta, see: www.youtube.com/watch?v=ukP4KKiblhA

w4 – For an interactive 3D seismic wave simulation, showing primary, secondary and surface waves, see the ForgeFX website: www.forgefx.com (select 'showcase') or use the direct link: http://tinyurl.com/6l6n3gm

w5 – To learn how loudspeakers can act as microphones, see: http://en.wikipedia.org/wiki/Microphone

w6 – Detailed instructions for building your own seismograph can be downloaded from the *Science in School* website: www.scienceinschool.org/2012/issue23/earthquakes#resources

w7 – To monitor the current seismic activity in Greece, see the website of the Institute of Geodynamics: http://bbnet.gein.noa.gr/NOA_HL

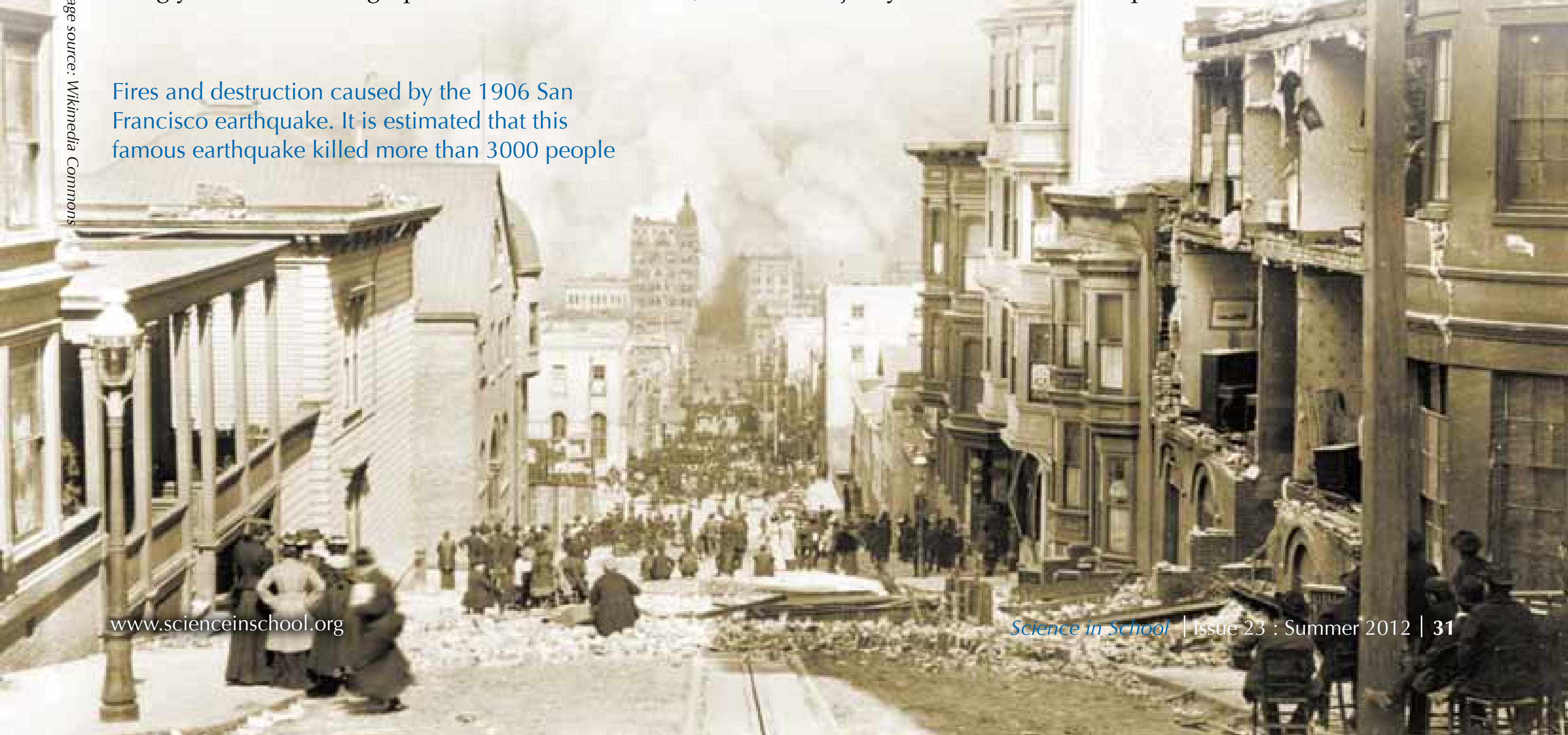
w8 – The Seismographs in Schools programme aims to create an international educational seismic network; already nearly 400 schools have joined. From the website, you can view and (if you have .sac file-viewing software) download seismographic data collected by other schools around the world, searching for specific earthquakes, or for schools or data in particular countries or regions. The website also includes tools to share your own seismic data in real-time, classroom activities. See: www.iris.edu/hq/sis

w9 – For local earthquakes (within 0-100 km), the vast majority of the energy will be in the frequency band 1-50 Hz, but there should still be enough energy to detect vibrations of 50-100 Hz. For more distant earthquakes, the energy content will be much lower: the energy from earthquakes originating in the Pacific rim will be in the frequency range 0.05-1 Hz by the time it reaches Europe. Unfortunately, computer soundcards have filters that limit the frequencies detected to above 40-60 Hz, thus limiting the ability of your homemade seismograph to detect distant earthquakes.

One alternative is to construct a simple mechanical seismometer and then interface it with a specially designed (but relatively affordable) seismic digitiser. For more details, see: www.bgs.ac.uk/schoolSeismology/seismometers.html

w10 – Our commercial seismograph, model GES-24A from the Industrial Systems Institute (ISI), cost around 1000 €; ISI will shortly launch a newer model costing around 600 €. ISI also has a website where schools can exchange their data. See: www.isi.gr/modseism

The Seismographs in Schools website has a useful list of other educational seismographs. See: www.iris.edu/hq/sis



Fires and destruction caused by the 1906 San Francisco earthquake. It is estimated that this famous earthquake killed more than 3000 people

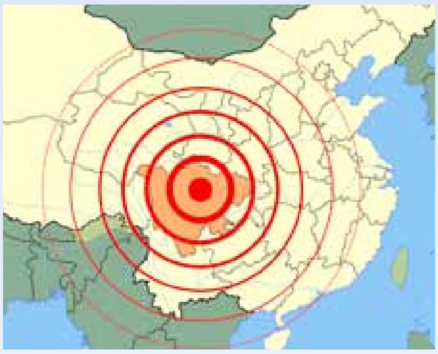
Image courtesy of Durova; image source: Wikimedia Commons

Physics

Image courtesy of Shazster; image source: Flickr

Damage caused by the 2011 earthquake in Christchurch, New Zealand

Image courtesy of Mistman123; image source: Wikimedia Commons



Map showing the epicentre of the 2008 earthquake in China's Sichuan province. The earthquake killed an estimated 68 000 people

Image courtesy of Tubbi; image source: Wikimedia Commons

Earthquake damage to a pavement

w11 – To download Audacity and learn the basics of digital processing, see: http://audacity.sourceforge.net

Resources

On the website of Natural Resources Canada, there is a brief introduction to seismographs and how they function. See: http://earthquakescanada.nrcan.gc.ca/info-gen/smeters-smetres/seismograph-eng.php or use the shorter link http://tinyurl.com/74ql2f7

To learn about earthquake-measuring scales, see About.com (www.about.com; search for 'earthquake magnitudes') or use the direct link http://tinyurl.com/cvwpj9q

For a compact and comprehensive guide for budding seismologists, see the website of Michigan Technological University: www.geo.mtu.edu/UPSeis

For a visual representation of recent earthquakes, see the world seismic monitor: www.iris.edu/seismon/

For another seismograph to build at school, this one based on an ancient Chinese design, see:

Kirschbaum T, Janzen U (2006) Tracing earthquakes: seismology in the classroom. *Science in School* **1**: 41-43. www.scienceinschool.org/2006/issue1/earthquakes

For a collection of teaching ideas for seismology, see the website of the UK's National STEM Centre (www.nationalstemcentre.org.uk) or use the direct link: http://tinyurl.com/ccbbnvm

The materials are free but you need to register on the website to download them.

To learn how to use geographical information systems to analyse earthquakes, see:

Kerski J (2010) GIS: analysing the world in 3D. *Science in School* **15**: 34-38. www.scienceinschool.org/2010/issue15/gis

Marazzi F, Tirelli T (2010) Combating earthquakes: designing and testing anti-seismic buildings. *Science in School* **15**: 55-59. www.scienceinschool.org/2010/issue15/earthquakes

For more teaching ideas about earthquakes, see the education web pages of the Incorporated Research Institutes for Seismology (www.iris.washington.edu; search for 'education outreach') or use the direct link: http://tinyurl.com/y6lq9s4

For further ideas, see 'How to teach natural hazards in school: raising awareness on earthquake hazard' from the EU-funded Eduseis project. The PDF can be downloaded from the European Commission website (http://ec.europa.eu/research/environment/pdf/how_natural_hazards.pdf) or via the shorter link http://tinyurl.com/bqvkpnz

Increasing numbers of schools are becoming involved in recording seismic data themselves. To strengthen the links between such schools in Europe, teachers are invited to apply for the second European summer school in school seismology. To be held in Summer 2013 in France, it is funded by EU Comenius grants to teachers. To find out more, visit www.bgs.ac.uk/schoolseismology/EUworkshop.html

If you found this article inspiring, why not browse all the science education projects in *Science in School*. See: www.scienceinschool.org/projects

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Panteleimon Bazanos has a degree in chemistry and has taught secondary-school science in the private and public education sectors in Greece for around 25 years. For the past five years, he has taught chemistry and physics at the General Lyceum of Filiatra. He has been involved in many school projects on environmental education.

To learn how to use this code, see page 65.