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Simulating Earthquake Early Warning Systems in the Classroom

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One of the first questions students ask about earthquakes is, "can we predict them?" The answer is rather unsatisfying: Yes and No. A prediction includes knowing the location, magnitude, and timing of an earthquake before it happens. Based on our understanding of plate motions that cause earthquakes, we know where on Earth to find locations that will produce large earthquakes and can estimate the maximum energy release at each spot (and therefore magnitude). Earthquake engineers use this information to design buildings so that they can withstand the largest possible earthquake. In areas like California, we even have estimates the likelihood of an earthquake in the next few decades (Working Group on California Earthquake Probabilities, 2007) and even the next few days (Jordan & Jones, 2010). So we actually *can* predict many aspects of an earthquake, but not the exact moment that earthquake will occur.

The Next Generation Science Standards push students to explore engineering solutions that mitigate natural hazards (e.g., MS-ESS3-2; MS-ETS1-2; MS-ETS1-3). While earthquake prediction remains without a solution, an understanding of earthquakes and seismic waves has allowed scientists and engineers to develop early warning systems that can provide vital advance notice of strong shaking, albeit only seconds or minutes (Allen, 2011). We developed a series of classroom and web-based activities to teach basic earthquake processes and this advanced engineering solution.

Introduction to earthquake early warning

While earthquakes strike without warning, their damage is not instantly and simultaneously felt everywhere. The sudden movement of Earth's crust releases seismic waves that quickly move away from the earthquake source like ripples spreading out from a pebble in a pond. Locations close to the source feel the shaking before those further away because the waves reach them sooner. Automated sensors near the source can therefore send warning to distant locations. Even though seismic waves travel faster than the fastest fighter jets (upwards of 6 km/s, or 13,000 mph), digital signals travel through wires and airwaves near the speed of light and can therefore provide seconds to minutes of warning prior to the arrival of strong shaking (Figure 1). The closer the sensor is to the source, the more warning. Intelligently laying out seismic sensors is therefore key to getting the most warning possible, and our web-based activity (described later) introduces students to this design process.

Longer warning times can save lives, and additional knowledge of how shaking happens during earthquakes can help us design an early warning system that gives even longer advance notice. Much like lightning precedes thunder, earthquake waves release energy that travels in two different ways. As the blocks of crust slide past one another, the Earth pops and lurches in different directions. Textbooks and scientists refer to these motions as the familiar P-waves and S-waves, and they carry different amounts of energy at different speeds (Figure 2). P-waves are caused by the sudden pushing or pulling of one section of rock against another. Because rocks are very strong when you push on them, this energy moves easily through rock and P-waves travel fast and arrive first. While they arrive quickly, relatively

Figure 1. Earthquake early warning

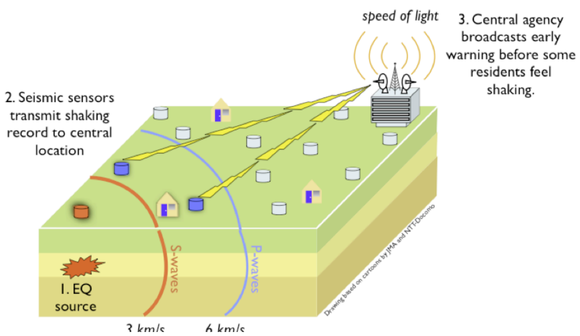


Figure 2. Seismic Waves

Wave	Motion	Speed	Leave source	Arrival	Strength
P-waves	**Push**/**pull**	Faster	*Both leave at the same time	First (“**P**rimary”)	Weaker
S-waves	“**S**ide-to-**S**ide” (from **s**liding)	**S**lower		**S**econd	**S**tronger

little energy is released as pushing/pulling, so P-waves don’t do much damage even in large earthquakes. Earthquakes mostly involve the sliding of two blocks of crust past one another, so they release most of their energy in the side-to-side motion of shear waves, or S-waves. Rock is weaker in shear than it is for pushing/pulling, so S-waves move more slowly through it. S-waves arrive second, but carry the powerful punch that causes great earthquake damage. Continuing the lightning-thunder comparison, you quickly see lightning several seconds before booming thunder rattles your windows. Early warning systems detect P-waves and can determine the earthquake’s magnitude and damage potential before the strongest shaking from the S-wave even hits the first seismic sensor.

These systems are real and are saving lives today. In the 2011 Tohoku, Japan (Magnitude 9.0) earthquake, the nearest major city received 15 seconds advance warning and Tokyo received more than a minute, with 52 million people receiving alerts on their mobile phones throughout the country (Yamasaki, 2011). In addition to Japan, early warning systems exist in Mexico, Taiwan, Romania, and southern California (under development).

Early warning in the classroom

By the end of this activity sequence, students should be able to:

- Describe the kinds of seismic waves (as in Figure 2)
- Explain how early warning systems work
- Design an optimal early warning system

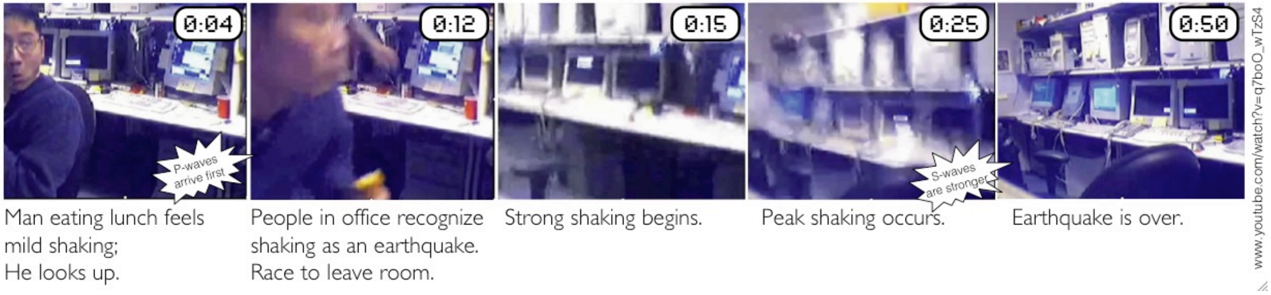
Activity 1: Video Interpretation

The differences between P- and S-waves are so pronounced that they can be seen in serendipitous recordings of everyday life interrupted by earthquakes (such as found on YouTube). In one (Figure 3; http://youtu.be/q7boO_wTzS4), a web camera records a worker eating his lunch. He looks up from his sandwich and his coworkers say "earthquake" even though the viewer sees no evidence of shaking. A few seconds later, the entire camera shakes violently. After watching this video, students can infer that earthquakes seem to have an initial weak pulse followed by a second strong pulse.

Activity 2: Direct instruction.

After students have this framework for understanding different earthquake waves, we use a blank copy of Figure 2 to guide a mini lecture introducing the scientific understanding of these

Figure 3. Video showing two pulses of shaking in an earthquake



Man eating lunch feels mild shaking;
He looks up.

People in office recognize shaking as an earthquake.
Race to leave room.

Strong shaking begins.

Peak shaking occurs.

Earthquake is over.

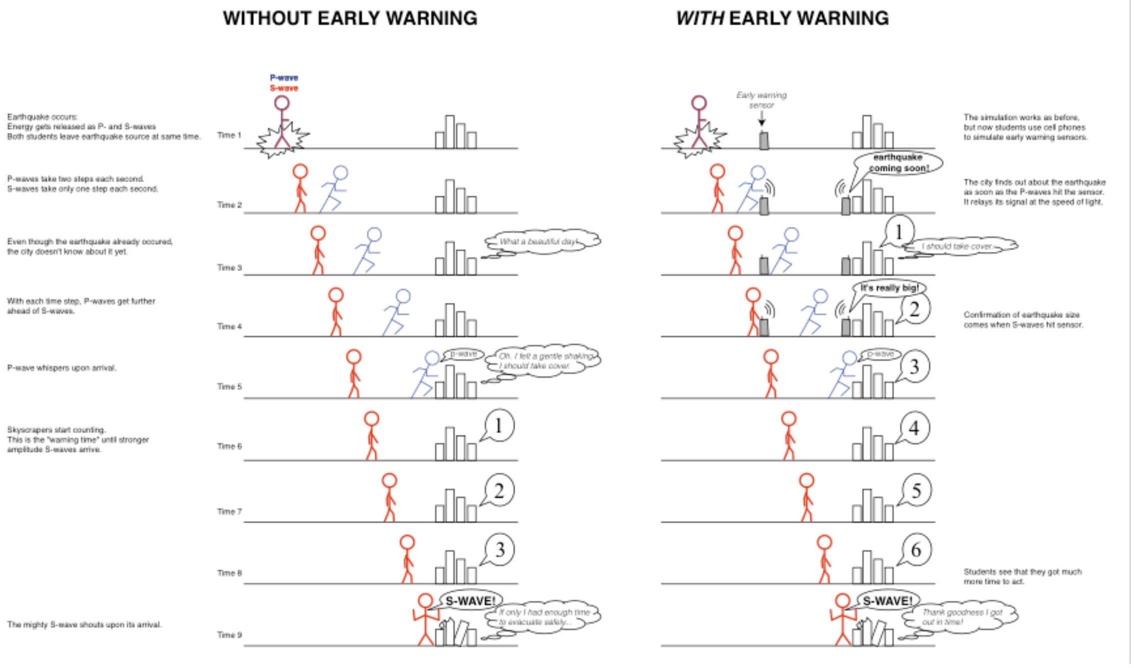
waves. Many lessons on seismic waves use a “Slinky” spring to demonstrate the particle motion of the two types of waves. The particle motion is important, but primarily because it is the cause for the differences in wave speed (push-pull moves faster through rock) and strength (earthquakes are mostly sliding movement).

Activity 3: Kinesthetic early warning.

We designed a kinesthetic activity where students act out the movement of seismic waves (Figure 4) in order to discover how an early warning system works. Best completed outside where there is about 20 meters of space, student volunteers play the part of P- and S-waves or skyscrapers in a city. We start with two volunteers (P- and S- waves) about 2/3 of the total available distance away from the majority of the class (the city). S-waves are slow, so they walk one step each second. P-waves are about twice as fast as S-waves in real life, so they take two steps each second. Skyscrapers are instructed to "feel" the arrival of the first earthquake waves and then count off the “warning time” in seconds until the second pulse of stronger shaking appears. When the instructor gives the signal, the waves start moving away from the earthquake source. Who goes first? Most students mistakenly answer that the P-wave starts moving first. In fact, both types of waves are generated at the same time when the blocks of crust begin to slide. P-waves only arrive first because they are faster, like sprinters in a race that all start at the gun but arrive at the finish in the order of their speed. Repeat the process with earthquakes at three different locations so that students recognize they get less warning time when earthquakes are close to them. For a fourth "mystery earthquake" at an unknown distance, students face away from the earthquake and then the instructor silently signals the P- and S-waves to begin. This situation reflects real life where the city doesn't know an earthquake has occurred until the first P-wave arrives.

We reset to the first earthquake and I have a few volunteers move to a "new city" located close to the earthquake source. One student uses a cell phone to call a student in the distant city. While they are talking, we initiate the earthquake and the student close to the source feels the P-wave almost immediately and informs the distant city of the waves. The skyscrapers in

Figure 4. Kinesthetic earthquake early warning activity

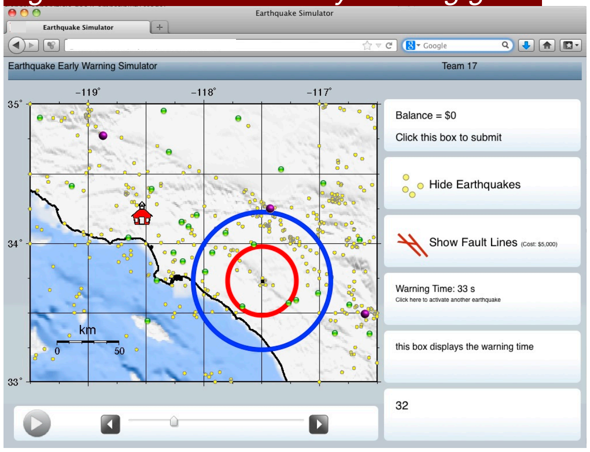


the distant city start counting as soon as they receive the cell phone notification. They get substantially longer warning before the damaging S-waves finally occur than they did without the communications link.

Activity 4 / Assessment: Web-based early warning network design

In real life, we never know exactly where an earthquake will occur, so designing an early warning network is more complex. We developed a web-based activity where teams of students determine where to place seismic sensors to provide the most warning possible to a local school (Figure 5; http://www.csun.edu/quake; login with teacher name *demo* and password *demo*) Students view a map of existing seismic sensors that can be upgraded to include the real-time communication required for the sensor to contribute to an early warning network. They can also build new sensors at any location they choose, but this costs additional money in their limited budget. They can purchase geological data including the location of active faults or previous earthquakes. They can try their network design out on a sample earthquake (for a fee!). After each team submits their network design, the teacher projects a map with the entire class's sensor placements. The teacher activates a random earthquake and students watch as the waves spread out and trigger their sensors. The web page tabulates the warning time provided by each team's network so that the teacher can assign a winner, if desired.

Figure 5. Web-based early warning game



Balance = $0

Warning Time: 33 s

this box displays the warning time

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Extensions

Early warning is well suited to extensions in both English language arts and mathematics. Students can use distance = rate x time equations appropriate for middle school mathematics to calculate actual warning times themselves. While a few seconds of warning does not sound like much, the economic and life-saving applications are countless. Students in classrooms can get under their desks or move to safe areas, airplanes on final approach can be turned back, or surgeons can avoid performing critical incisions. In Japan, more than 16,000 elevators are programmed to automatically respond to the early warning system by stopping at the nearest floor and opening their doors, rather than trapping occupants inside for hours until power is restored (Yamasaki, 2012). Students can write a short essay describing a creative use of early warning that they dream up. Examples have included ceasing activity at the construction site across the street and automatically saving all the open documents on school computers so nobody loses their work.

Conclusion

Compared to many other tactics for mitigating earthquake hazards (like costly earthquake retrofits or advanced building design), early warning provides phenomenal benefits at relatively low cost. In this activity, students see early warning in action, act it out with their bodies, and design it on the computer. Students see how a few simple facts about earthquake waves can be easily used to design systems that make people safer.

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