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# Seismographs for Citizens of Planet Earth:

## *Opportunities and Challenges at the Intersection of Basic Research, Science Education, and the Public Good*

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**Introduction**

Seismographs in classrooms and other public and private citizen settings provide great opportunities for integrating basic research, science education, and citizen science. A variety of terms are used to refer to this type of endeavor, such as "seismographs in schools", "educational seismology", and "citizen seismology." For brevity below, I use the terms "citizen seismographs" and "citizen seismology" to refer to the range of such endeavors, and in this context, I mean citizens of Planet Earth, not citizens of any particular political entity.

This enterprise is beneficial for improving science education and for contributing to basic research in seismology. But, unlike some other citizen science initiatives, such as engaging citizens in measuring atmospheric temperature, rainfall, or wind speed, seismological measurements do not typically reveal direct, intuitive information about the phenomena they are used to explore. Understanding what is recorded by a seismograph requires a level of abstract conceptual reasoning to bridge the gap between what is observed and the phenomena it represents. People have direct experiences of temperature, rainfall, and wind speed, but vibrations associated with most seismic phenomena recorded on citizen seismographs are too weak for people to feel. And large, widely felt, earthquakes do not happen very often.

That makes it difficult to implement citizen seismology programs as “Do-It-Yourself” educational experiences. Rather, it requires a well-trained seismologist partner to guide participants in interpreting what is recorded on their citizen seismograph. And it takes many years of experience for professional seismologists to learn how to interpret, and convey an accurate picture of, what is typically recorded on a seismogram. That level of understanding of seismology is generally more than can be routinely expected of teachers and other citizen scientists. Thus, citizen seismograph initiatives, and their promise of integrating basic research, science education, and citizen science, will only work for a wide audience if professional seismologists are willing to commit time and effort to be active partners in this endeavor.

**Recording Earthquakes with Low-Cost Citizen Seismographs**

Many professional seismologists are engaged in partnering with science educators and citizen scientists to operate seismographs in schools and other public and private venues (e.g., Kafka, et al., 2006; Kafka and Fink, 2019; Bravo, et al., 2020). The science of seismology forms an excellent foundation for engaging people in this type of endeavor because:

- It is an interdisciplinary science that requires understanding a wide range of scientific concepts.
- It teaches students how the natural environment impacts our everyday lives.
- It offers possibilities for introducing students of all ages to the nature of scientific inquiry.

It is fascinating that it is possible to record earthquakes that occur thousands of km away from us using seismographs. Seismographs measure the pulse of the Earth, and provide useful information about earthquakes, plate tectonics, and the structure of the Earth’s interior. Thus, having their own seismograph enables people to collect real-world data and make measurements that provide an understanding of the internal structure of the Earth and of processes by which the Earth changes.

Two common types of low-cost seismographs are the so-called EQ1 seismograph and the more recently introduced “Raspberry Shake” (RS) seismograph, based on the “Raspberry Pi” computer (Figure 1, raspberryshake.org, raspberrypi.org). Both types have pros and cons for educational and research purposes. In many ways, the RS is turning out to be quite ideal for this endeavor. Figure 2 shows seismograms recorded in New England (at Weston Observatory, and at a middle school and a science education center) from a magnitude 7.5 earthquake that occurred in Alaska. The seismographs used for the recordings shown in

Figure 2 are RS devices that cost about $400 (compared with the thousands of dollars cost of research grade seismographs, see upper right of Figure 1). The RS seismograms do not, of course, exhibit all of the signal characteristics as well as those of the expensive instruments. But the RS signals do have many characteristics necessary for monitoring and research, and you can easily put these low-cost instruments in citizen seismology locations.

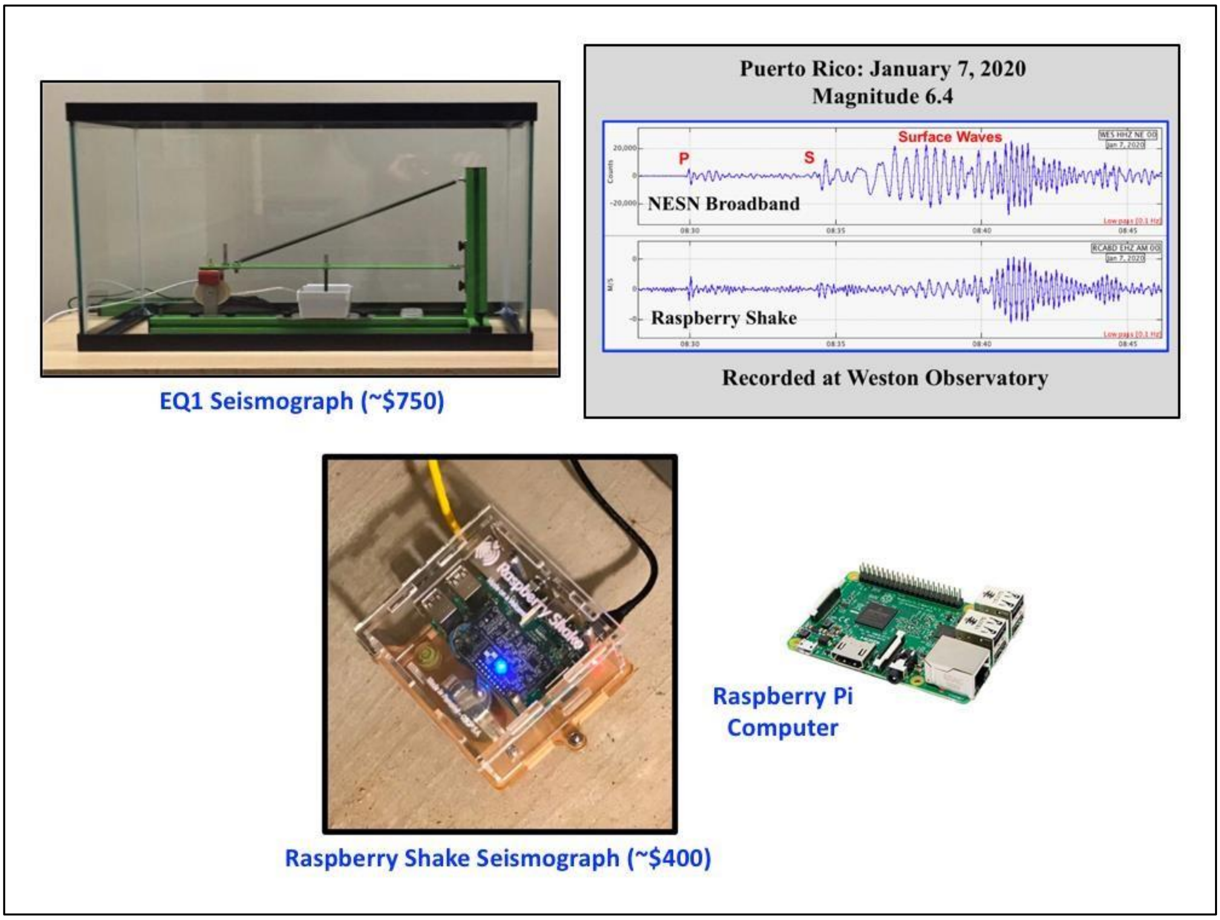


**Figure 1:** Two common types of low-cost seismographs are the so-called EQ1 seismograph and the more recently introduced "Raspberry Shake" (RS) seismograph, based on the "Raspberry Pi" computer (raspberryshake.org, raspberrypi.org).

Once the seismograms are plotted and interpreted (usually requiring the help of a seismologist partner), displays like that of Figure 2 become very useful resources for teachers, students, and other citizen scientists. That, in itself, is a worthwhile outcome of citizen seismology projects. But to complete the picture and bring these endeavors to their full potential, we need to also assess the extent to which these low-cost seismographs can be more than just an educational enhancement: Are citizen seismographs "just for display", and for "Wow, look what we recorded!?", and for some very basic traditional educational purposes. Or can they also offer opportunities for students and other citizen scientists to be research partners in the scientific community? To what extent are affordable seismographs technically capable of recording data at a level of quality that, given the right educational and research circumstances, authentic research is possible based on the recorded seismograms?

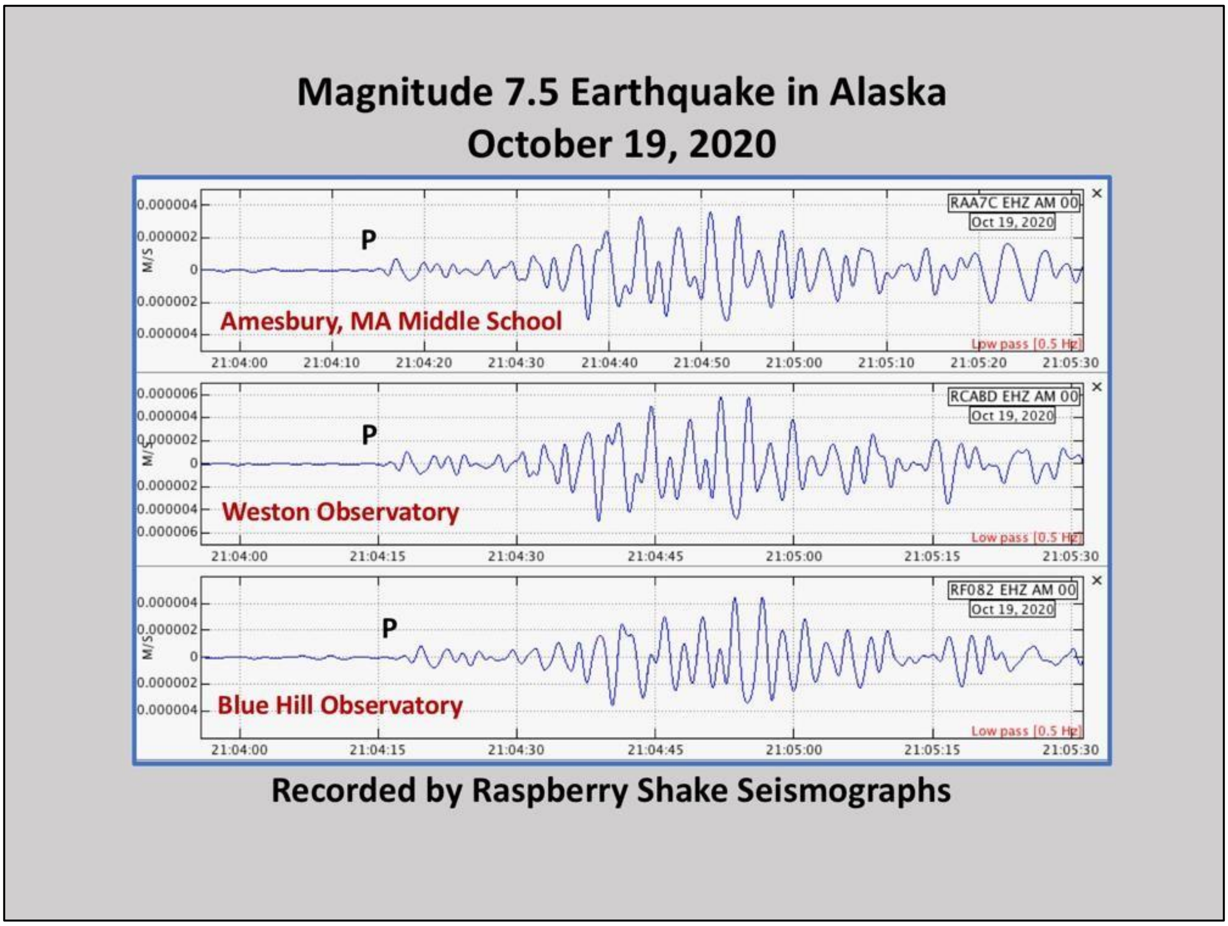


**Figure 2:** Seismograms recorded in New England (at Weston Observatory, and at a middle school and a science education center) from a magnitude 7.5 earthquake that occurred in Alaska.

### A Complicated, but Interesting, Example: Recording a "PKIKP" Wave with Low-Cost Citizen Seismographs

An example of high-quality research-grade data recorded with a low-cost seismograph is shown in Figure 3, in which seismograms are plotted for four Boston-area RS records of a magnitude 6.9 earthquake in Indonesia. These recordings are of a seismic wave called "PKIKP", which penetrates deep within the Earth's outer and inner core and arrives, well-recorded, at RS sites. This observation illustrates aspects of how (in 1936) the inner core was discovered by seismologist Inge Lehman. Also shown in Figure 3 is the path of the PKIKP wave, from the earthquake through the deep interior of the Earth, and eventually arriving at the citizen seismograph stations.

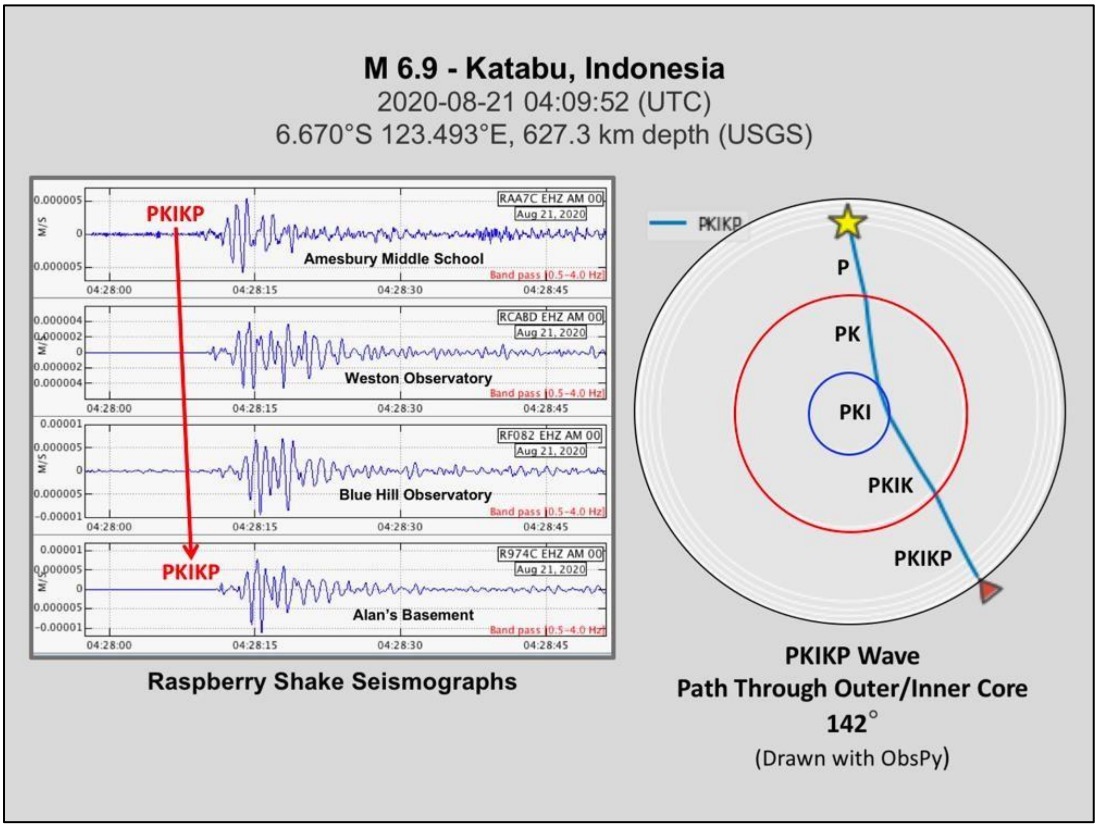


**Figure 3:** Four seismograms recorded by RS seismographs in the Boston-area from a magnitude 6.9 earthquake in Indonesia. These recordings are of a seismic wave called "PKIKP", which penetrates deep within the Earth's outer and inner core and arrives, well recorded, at the RS sites.

This observation is fascinating, illustrates a lot about seismology and Earth structure, and can be used to show citizen seismologists how details of seismic waveforms are important observations used in research studies. But it would be very hard for non-seismologists to recognize this waveform (and its significance), and making this display required me to think through and experiment with a lot of geophysics and signal processing. It is unlikely that this observation would have been identified and understood in a typical citizen seismology situation without a well-trained seismologist partner. And yet, it is an excellent example of the pedagogical value of people having their own low-cost seismograph.

Also, the waveform of the PKIKP wave on these seismograms is complex, and not like some textbook diagrams of simple P-wave pulses. These types of complexities are both a challenge for identifying and interpreting the seismic signal, as well as a great opportunity for learning a lot of science, if the citizen scientists have a trained seismologist guide.

**More Examples of Complicated, but Interesting, Seismograms: Regionally Recorded Earthquakes**

Many different kinds of earthquakes, in many different kinds of situations, are well-recorded by RS seismographs. But each situation involves a lot to explain that usually cannot be interpreted without extensive training in seismology. The observed seismograms are the result of effects due to different earthquake sizes, depths, and mechanisms of faulting, as well as different types of instruments, frequency bands, signal amplitudes, and background noise. All of these effects combine in complex ways that result in the observed seismograms, which are usually very different from textbook cases. And untangling how these kinds of effects result in the observed seismogram lies at the essence of seismology research.

At the same time, there are characteristics of these real seismograms that do show aspects of what is seen in textbook cases. And a well-trained seismologist can explain how all of that fits together. Figure 4 shows earthquakes that were recorded on RS seismographs at regional distances from earthquakes in New England. Seismograms recorded at these regional distances are typically very complicated, because they have high-frequency (and short wavelength) content which is affected by complex details of the crust in the region and local site effects. Compare these regional seismograms with that of the magnitude 6.4 earthquake in Puerto Rico, also shown in Figure 4. Although the Puerto Rico seismogram does exhibit some complexity beyond that of a simple "textbook" seismogram, seismic waves at these longer distances have lower frequency (and longer wavelength) content which makes them less affected by complex details of Earth structure. Thus, the Puerto Rico seismogram looks closer to what is often shown in a textbook.

But regional seismology is perhaps the best application of citizen seismographs. People want to know about earthquakes and earthquake hazards "in their own backyard." They might feel the shaking and directly experience the phenomenon of earthquakes. And yet, the complex nature of regional seismograms means that this is a situation in which you would want to have a trained seismologist around to help you interpret what it is that you recorded. And interpreting all of these complexities of regional seismograms is what enables research seismologists to solve problems regarding the nature of earthquakes and earthquake hazards "in your backyard."

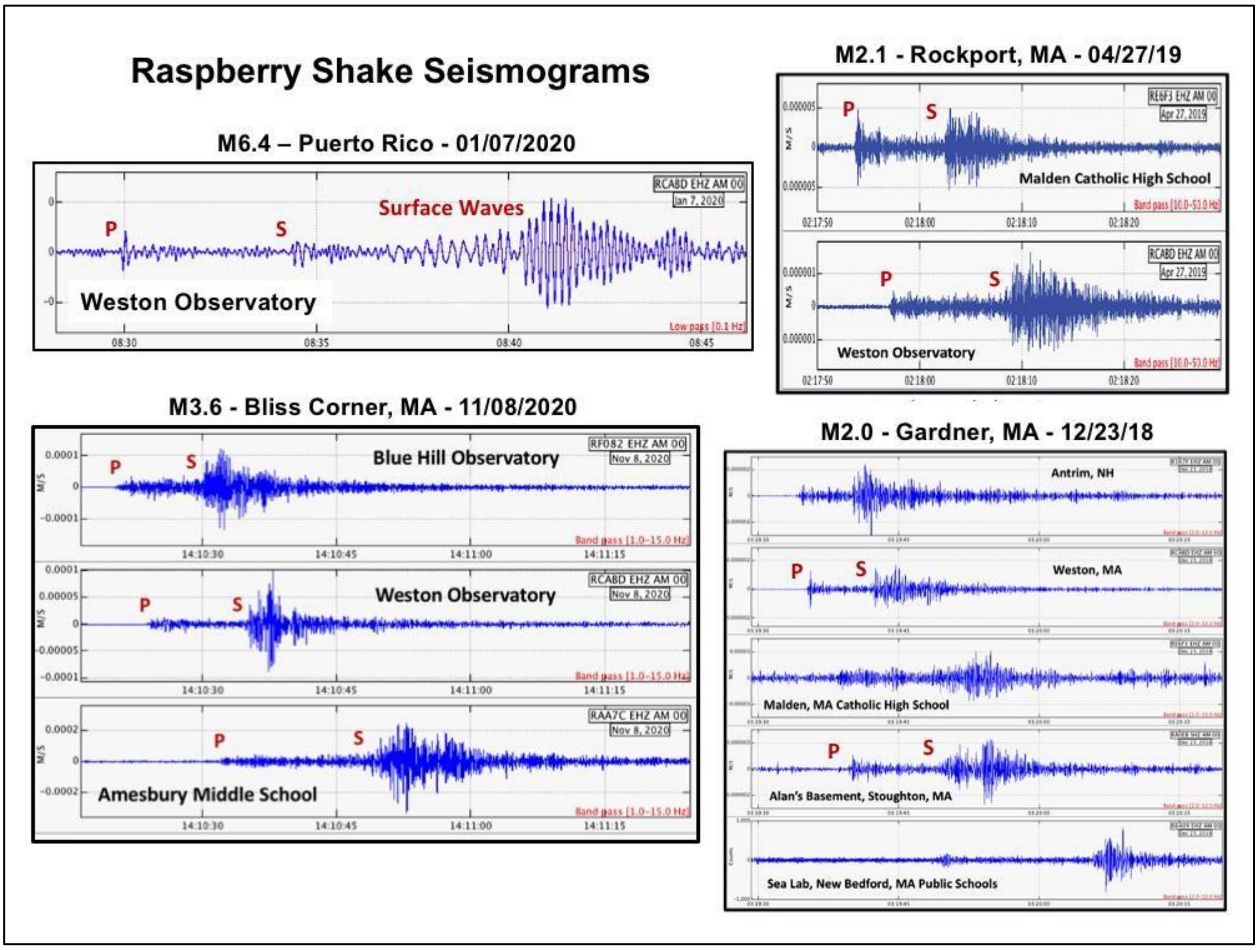


**Figure 4:** Earthquakes that were regionally recorded on RS seismographs in New England, and the magnitude 6.4 earthquake in Puerto Rico (also recorded by an RS in New England).

**Integrating Basic Research, Science Education, and Citizen Science:**

There is a growing number of examples of projects around the world where the overlapping missions of earthquake monitoring, research, science education, and citizen seismology are well integrated using RS seismographs. A few notable examples are projects in Haiti (e.g., Calais et al., 2019), Nepal (e.g., Subedi, et al., 2020), Oklahoma (e.g., Walter, et al., 2020), and Greenland (e.g., Jeddi, et al., 2020). These, and other, examples involve projects in which RSs are used to complement and densify existing seismic networks, lower detection thresholds for monitoring and studying earthquakes, engage and inform residents about earthquake hazards and preparation, and improve education in science, technology, engineering, and math for students of all ages.

A recent example of how citizen seismographs can be valuable in research is the Lecocq et al. (2020) study of global seismic quieting due to COVID-19 lockdowns. Citizen seismographs can be quite noisy because they are often purposely installed near people and other human cultural noise sources, such as road traffic. We want our citizen seismographs to be near where people are. That can be a problem for seismic monitoring of earthquakes, but it is not always bad for other aspects of the science of seismology.

Thomas Lecocq of the Royal Observatory of Belgium, and 75 seismologist colleagues from around the world, analyzed hundreds of global stations, and about a third of those were RS citizen seismology sites. They made use of the citizen seismographs in noisy locations to complement other research seismographs in a study of changes in human activity around the world due to COVID-19 lockdowns. When the COVID-19 lockdowns were imposed there was a drop-in human activity such as walking, driving, and use of public transportation. This meant there was a decrease in ways that humans create seismic vibrations of the Earth beneath our feet. Lecocq et al. (2020) were thus able to, with the help of citizen seismographs, quantify the decrease in global human activity due to the pandemic lockdowns. This demonstrated the possibility of using citizen seismographs to help monitor the effectiveness of COVID-19 lockdown measures.

## Opportunities (and Challenges) Ahead for Citizen Seismology

Low-cost seismographs are not just providing new opportunities for improving education. They also offer opportunities for students and other citizen scientists to participate as research partners in the scientific community. These types of partnerships provide new ways for scientists to engage with a more public audience, making science more approachable to a wider audience. But this will only work for a wider audience of students and other citizen scientists if professional seismologists are willing to commit time and effort to be active partners in this endeavor.

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