EDUQUAKES

Educating for Earthquake Science and Risk in a Tectonically Slowly Deforming Region

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ABSTRACT

Over the past decade, scientists have been called to participate more actively in public education and outreach (E&O). This is particularly true in fields of significant societal impact, such as earthquake science. Local earthquake risk culture plays a role in the way that the public engages in educational efforts. In this article, we describe an adapted E&O program for earthquake science and risk. The program is tailored for a region of slow tectonic deformation, where large earthquakes are extreme events that occur with long return periods. The adapted program has two main goals: (1) to increase the awareness and preparedness of the population to earthquake and related risks (tsunami, liquefaction, fires, etc.), and (2) to increase the quality of earthquake science education, so as to attract talented students to geosciences. Our integrated program relies on activities tuned for different population groups who have different interests and abilities, namely young children, teenagers, young adults, and professionals.

Online Material: Figures and descriptions of hands-on experiments.

INTRODUCTION

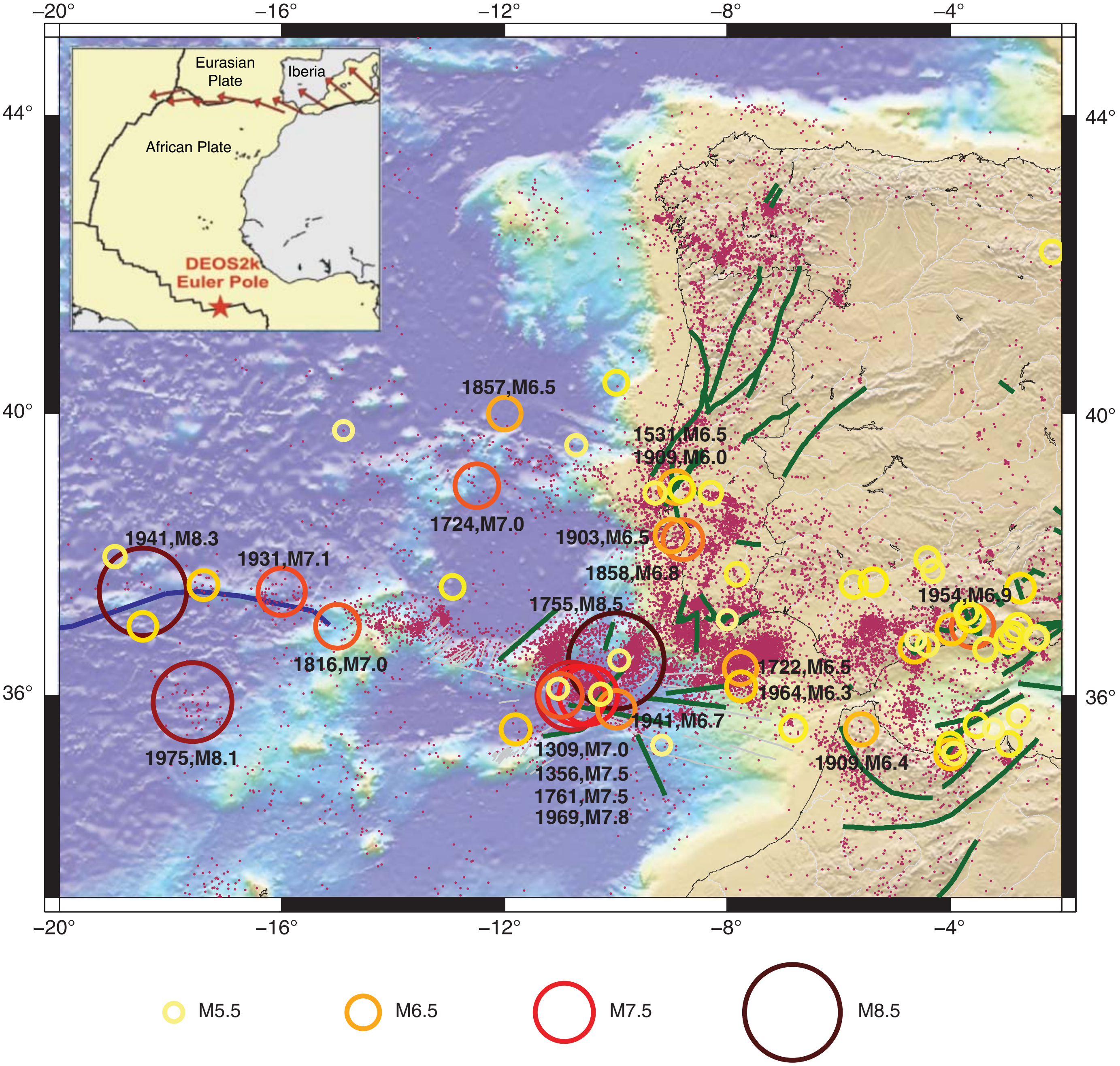
Mainland Portugal, on the southwesternmost tip of the European continent, has been repeatedly affected by severely damaging earthquakes throughout its history (e.g., Oliveira, 1986; Martins and Mendes-Víctor, 1990; Moreira, 1991; Vilanova and Fonseca, 2007; Baptista and Miranda, 2009). However, tectonic deformation occurs at low rates, and therefore the intervals between strongly felt earthquakes are long (Vilanova and Fonseca, 2007; Baptista and Miranda, 2009; Cunha *et al.*, 2012). The need to educate for earthquake risk is recognized at a high level by educators, scientists, and civil protection authorities (Wallenstein and Rebelo, 2010; Autoridada Nacional de Protecçã Civil 2011), but educational efforts are hampered by a mix of cultural and sociological factors, namely the lack of a prevention culture and a generally low earthquake risk perception (Lima, 1993). In recent decades, scientists worldwide have been called to participate more actively in public education and outreach (e.g., Leshner, 2005, 2007). In this article, we describe an adapted education and outreach (E&O) program for earthquake science and risk, which aims at being more effective by addressing the cultural specificities of our tectonic setting.

TECTONIC SETTING AND HISTORICAL EARTHQUAKES

Mainland Portugal is located directly north of the plate boundary that separates Nubia (Africa) from Iberia (Eurasia) (Fig. 1). In this region, the two tectonic plates converge obliquely at low rates of 4–5 mm/yr (Calais *et al.*, 2003; Fernandes *et al.*, 2003; McClusky *et al.*, 2003; Serpelloni *et al.*, 2007; Nocquet, 2012). Nevertheless, written documents testify to a long history of felt and damaging earthquakes (Oliveira, 1986, and references therein). The earthquake history of Portugal includes the landmark great Lisbon earthquake of 1 November 1755 (Fonseca, 2005; Mendes-Victor *et al.*, 2009, and references therein). This earthquake remains the largest to date in the European historical record (Grünthal and Wahlström, 2012; Stucchi *et al.*, 2013), with an estimated M_w of 8.7 ± 0.39 (Johnston, 1996). At the time, Lisbon was the capital of a vast overseas empire and one of the busiest and richest cities in Europe. The ground shaking, tsunami, and fires caused by the 1755 earthquake destroyed the city of Lisbon and marked a turning point in the history of the country.

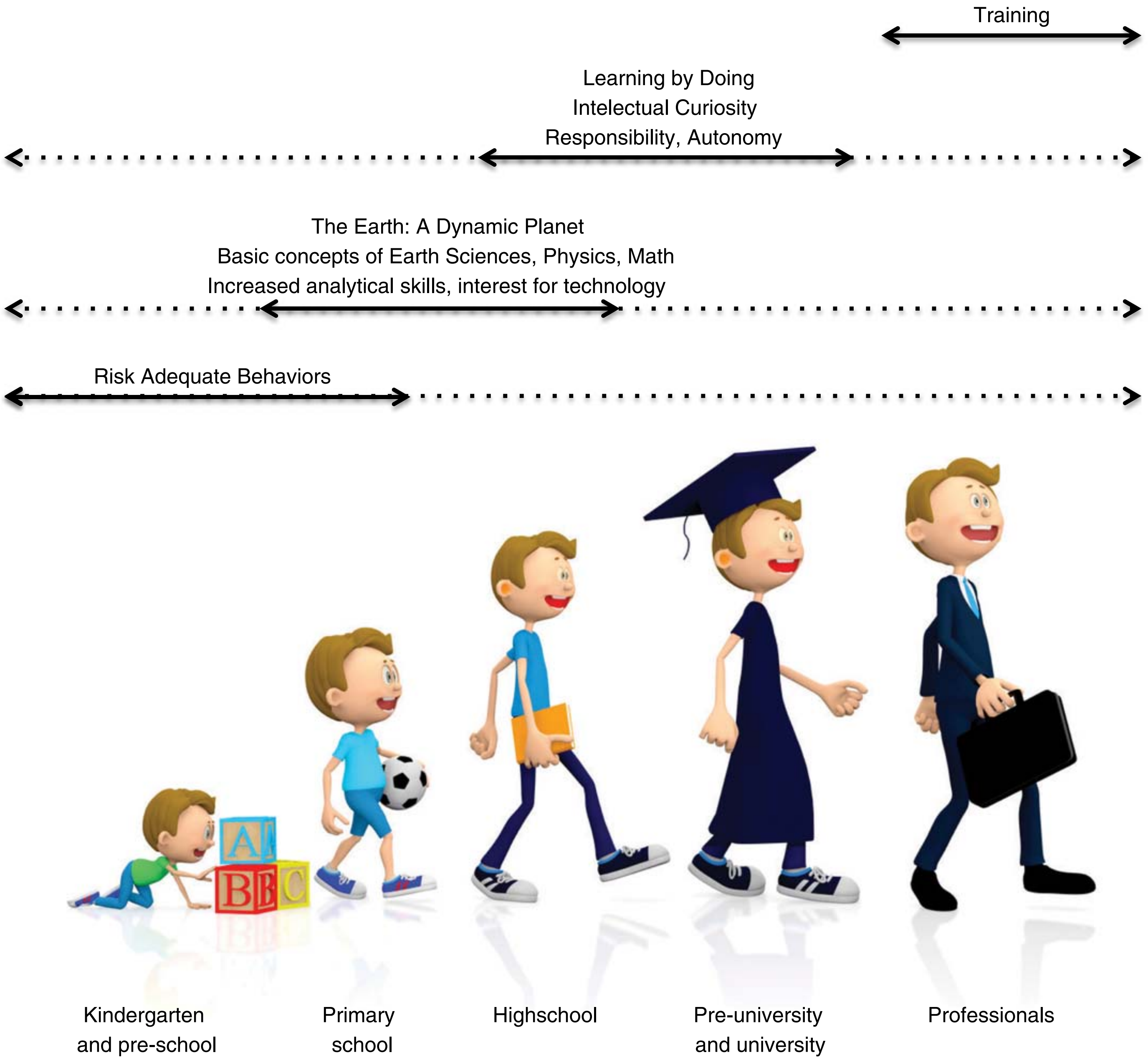
This earthquake was the subject of various considerations by philosophers and naturalists across European cultural circles. It was also the first earthquake whose effects were thoroughly documented by detailed inquiries sent out to parishes (Pereira

doi: 10.1785/0220150239



▲ **Figure 1.** Mainland Portugal and southwestern Europe. Portugal is located north of the plate boundary between Nubia (Africa) and Iberia (Eurasia). Locally, the boundary accommodates oblique convergence oriented northwest–southeast, which occurs at slow rates of ~4 mm/yr (Fernandes *et al.*, 2003; Serpelloni *et al.*, 2007). The figure shows topography in the background (SRTM30+, Becker *et al.*, 2009), potentially active faults (thick lines) identified in the European Database of Seismogenic Faults (EDSF) (Vilanova *et al.*, 2014; Basili *et al.*, 2013), the Gloria fault (thick line) according to the NNR-MORVEL56 plate boundary compilation (Argus *et al.*, 2011, Gordon, and DeMets), historical earthquakes with magnitude >5.5 (circles) identified in the SHARE European Earthquake Catalogue (SHEEC) database (Grünthal and Wahlström, 2012; Stucchi *et al.*, 2013), and instrumental seismicity since 1961 (dots) (Carrilho *et al.*, 2004). The color version of this figure is available only in the electronic edition.

de Sousa, 1919). This survey and the subsequent efforts to rebuild Lisbon as an earthquake-safe city are commonly described as the birth of modern seismology and earthquake engineering (Mineiro, 2005). Other significant historical earthquakes in Portugal include the intraplate 1531 **M** 6.5–7.1 Lower Tagus Valley earthquake, the 1858 **M** 6.8–7.2 Setúbal earthquake, and the 1909 **M** 6 Benavente earthquake (Martins and Mendes Víctor, 2001; Stich *et al.*, 2005; Vilanova and Fonseca, 2007; Stucchi *et al.*, 2013; Baptista *et al.*, 2014; Locati *et al.*, 2014). The last large earthquake in Portugal occurred in 1969. It was an M_s 7.9



▲ **Figure 2.** Activities for different groups are focused differently. Both risk-adequate behaviors and earthquake science should be promoted at all ages. However, we find it more useful to emphasize risk-adequate behavior in activities for small children and families and to emphasize science and technology with older students. During adolescence, the use of technologies makes seismology an especially attractive topic. Pre-university and university students should take responsibility for their activities and can act as educators of youngsters. The training of professionals (e.g., teachers and civil protection agents) allows us to reach a much wider public than using only our own resources. The color version of this figure is available only in the electronic edition.

earthquake located offshore, southwest of Cape St. Vincent (Fukao, 1973). The earthquake was felt with a maximum 1992 European Macroseismic Scale (EMS-92) intensity of 8.5 in southern Portugal, where houses collapsed (Paula and Oliveira, 1996). The earthquake was strongly felt throughout the whole mainland.

Although earthquakes in this region have been strong and persistent, the association of historical earthquakes with active faults in Portugal remains elusive (e.g., Fonseca *et al.*, 2005; Besana-Ostman *et al.*, 2012; Cabral *et al.*, 2013). Classical methods to identify and characterize active faults typically fail in regions of slow tectonic deformation. Erosion, sedimentation, and anthropogenic activity all collude to erase geomorphological signatures, differential geodetic rates are very low and usually unresolvable by existing instrumentation, and seismicity maps often show dispersed earthquake epicenters. In the last decades, a number of geophysical and geological studies aimed at identifying and characterizing active seismic faults in mainland Portugal and adjacent offshore (Terrinha *et al.*, 2009; Zitellini *et al.*, 2009; Besana-Ostman *et al.*, 2012; Cabral, 2012). A compilation of potentially active faults was published by Vilanova *et al.* (2014). A detailed revision of the recent Portuguese instrumental seismicity was published by Custódio *et al.* (2015), allowing a clear identification of clusters and lineations of earthquakes. Puzzlingly, a clear relationship between clusters and lineations of earthquakes and geologically mapped faults does not exist, opening several interesting questions about the local seismotectonics (Custódio *et al.*, 2016). Thin-sheet modeling suggests that maximum long-term fault slip rates are between 1 and 2 mm/yr, resulting in very long (>1000 years) return periods for $M_w > 8$ earthquakes (Cunha *et al.*, 2012; Matias *et al.*, 2013).

CULTURAL BACKGROUND AND RISK CULTURE

Portugal became a stable democracy in 1974, after five decades of an authoritarian political regime. Twelve years later, in 1986, Portugal joined the European Union. Between 1970 and 2014, basic illiteracy rates dropped from 25.7% to $<5\%$ and gross domestic product per capita increased by over 250%, from €6,000 to €16,000 (at constant prices of 2011) (see Data and Resources). The quick evolution that Portugal experienced in the recent past has allowed safety prevention to start receiving attention. Portugal currently benefits from an expanded public education system, and education is compulsory for children of ages between 6 and 18 years old. Much still remains to be done, and public schools presently face serious hardships posed by an ongoing economic crisis and ensuing public policies. Nevertheless, schools have played and continue to play a key role in the education of the population, in terms of both formal knowledge and citizenship (Fernandes and Mendes, 2000; Figueiredo and Silva, 2000). Good examples are the active health and environmental education programs (Schmidt *et al.*, 2011; see Data and Resources). A national strategy for risk education, however, is still lacking. A positive first step was given recently with the publication of the first guidelines on risk education within the scope of citizenship education (Saúde *et al.*, 2015).

OBSERVED BEHAVIORS

The following observations prompted us to tailor our E&O activities, taking into account human behavioral considerations.

1. *Experience- and age-dependent risk perception:* During E&O activities, we observed that individuals raised in mainland Portugal with a heightened earthquake risk perception seem to belong to one of two groups: they are either young children (up to primary school ages) or older adults who experienced the strong M_s 7.9 earthquake in 1969. Individuals of ages inbetween, teenagers and adults who never experienced a strong earthquake (in fact, many never felt an earthquake at all) seem to perceive earthquakes as something that happens in other places, to other people. Dedicated studies show that risk perception is lower in mainland Portugal than in the the Azores islands, where earthquakes are felt more frequently (Lima, 1993). Social psychological work on seismic risk perception shows that experience plays a key role in how prominently people think of earthquakes (for a review, see Solberg *et al.*, 2010).
2. *Risk denial and scientific knowledge as a tool to educate for risk:* We observed that some of the participants in our E&O activities are so terrified about earthquakes that they prefer to ignore earthquake risk altogether. Social science studies indicate that, when people are exposed to risks that they cannot mitigate, they can shut off their awareness as a psychological protective measure (e.g., McKenna, 1993). In these cases, talking about earthquakes in a scientific manner seems to help participants think about earthquakes in a more emotionally detached manner.
3. *Children as a privileged means to educate adults:* Although teenagers and adults who never experienced an earthquake generally have a low earthquake risk perception, they easily become engaged and aware when explaining earthquake science and risk to young children.

AN ADAPTED E&O PROGRAM

Taking into account the observed behaviors, we adopted E&O strategies to cope with the specificities of our setting, where earthquake risk is not immediately perceived as significant. The program has two main goals: (1) to increase the awareness and preparedness of the population to earthquake and related risks (tsunami, liquefaction, etc.); and (2) to increase the quality of earthquake science education, promoting the attraction of talented students to geosciences. Although educating for both earthquake risk and earthquake science go hand in hand, we find it more effective to stress one or the other, depending on the specific group we are teaching (Fig. 2). Our program is designed to match the interests and needs of different population groups, taking into account social sciences knowledge on risk perception of extreme events.

Next, we describe the philosophy of the activities for different target groups: (1) young children and families, (2) teenagers, (3) pre-university and university students, and (4) professionals. Some of these activities are carried out in schools by teachers leading seismology-related projects, whom we support with our E&O programs. Our E&O activities and experiments are mostly well known to earthquake scientists with an interest in education, thus they are not the focus of this article. Ⓔ We focus mainly on how we take advantage of these well-known activities with different audiences. A more-detailed description of the activities is available in the electronic supplement to this article.

Young Children and Families

Activities with young children (up to primary school ages) are some of the most rewarding in our E&O program. Young children are curious, unashamed, and easy to involve in simplified scientific discussions, in contrast with the more shy and reluctant teenagers. They are also more likely to be free of prejudice and more readily comprehend concepts that might not be as easily absorbed by structured adult minds (Anderson, 2009). For example, young children often surprise us by solving the Pangea puzzle (placing the continents back together in their Pangea shape) more easily than adults. Children simply try to match the shapes of the continents, whereas adults place barriers in their minds to settings that do not match their current knowledge about the distribution of continents. This is consistent with cognitive psychology regarding the assimilation of new information given previous knowledge systems (Anderson, 2009). Small children are open to a strong imprint in terms of absorbing scientific concepts, understanding the importance of science, and interiorizing risk-adequate behaviors. In particular, the window for promoting risk-adequate behaviors gets much narrower at the beginning of adolescence, as we will see in the next section. E&O for young children is thus an essential part of any comprehensive plan for earthquake education (United Nations Office for Disaster Risk Reduction, 2007).

In our experience, young-age children can easily comprehend the notion that the Earth is a dynamic planet. They will also easily understand that planet Earth is our home and that citizens must behave responsibly toward their home planet, respond to its changes, take advantage of its resources wisely, and act properly in case of disaster. Children's and adults' perception of risk is markedly different. The nature of risk perception in adults is related to their perception of control and past experiences (Cohn *et al.*, 1995). Children, in turn, will easily apprehend the notion of earthquake risk and will accept the need to prepare for earthquakes, even if they never felt the ground shaking before.

One of our activities consists of training the public on earthquake self-protection actions. We use a shake table, with a school desk on top, and ask students to drop, cover, and hold on, while the "ground" is shaking. We observe that, of all audiences, small children are the ones who seem to take this exercise most seriously. Figure 3 shows the results of this activity, carried out with a class of primary school students. Students' drawings show that they retained interesting common features: (1) the ground was shaking (motion marks); (2) the ground shaking was fake (electric plug, wheels on the shake table, also expressed verbally in written reports); (3) the danger of falling objects (objects on the table, also expressed verbally in written reports); and (4) the correct "drop, cover, and hold on" position (fetal position, with one arm over the neck).

In our experience, educating children is a privileged means to educate adults, too. When children assume correct behaviors, adults often change their incorrect behaviors to mimic the correct behaviors of children. Correct behaviors then become habits. This strategy was successfully used in Portugal in the last decades to promote environmentally correct behaviors, such as waste separation and recycling. In Portugal, where the memory of a scary earthquake is now becoming faint, it is virtually impossible to convince adults to prepare disaster emergency kits. On the other hand, children accept rather easily the need to build their own emergency kits and will often go home to successfully convince their parents. We capitalize on this behavior by assigning children to prepare their emergency kits at home, with their parents, as homework.

Finally, young children are receptive to the involvement of their caretakers in the school environment, which benefits children but, maybe more importantly, also benefits adults. In an ongoing Parents-in-Science initiative, a close cooperation between parents, science teachers, and scientists resulted in the development of regular sessions for young children in which caretakers and older students participate in storytelling, hands-on experiments, and short theater plays. With very simple stories and science activities, parents and teachers are able to trigger curiosity, eagerness, and critical thinking in very young children (from 3–4 years of age onward, after verbal communication is established). Simultaneously, adults reported that their perception of earthquake risk was heightened by the exercise of transmitting basic earthquake knowledge to the children.

Teenagers

During adolescence, independence and intellectual capabilities develop quickly, and, equally quickly, risk perception fades. This transition is essentially related to a sharp increase in the perception of control, which leads to a decrease in risk perception (Cohn *et al.*, 1995). Accordingly, our activities for teenagers focus less on risk and more on science. Although the promotion of risk-adequate behaviors should be continuously trained at all ages, we find it more effective to emphasize the topic at younger ages. In general, adolescents are uninterested by, and may even be averse to, the topic of appropriate behaviors. Exposing teenagers to shocking images and personal accounts of earthquake destruction may serve to increase teenagers awareness of earthquake risk. However, psychological studies indicate that a too-strongly simulated exposure to a risk that the public has no ability to mitigate can actually lead to an awareness shut off (Lehman and Taylor, 1987; Liberman and Chaiken, 1992).

Because of its multidisciplinary nature, seismology is better addressed in school-wide projects. Earthquake-related concepts can be straightforwardly worked into physics, geology, mathematics, and geography, as well as other less obvious classes such as history, languages, computer science, electronics, information technologies, psychology, sociology, economics, and even multimedia and visual arts. In one school, teachers of geology, information technologies, and visual arts collaborated to help students translate a Incorporated Research Institutions for Seismology video animation about seismology into Portuguese. Teachers reported that this multimedia activity resulted in the engagement of students who were previously not motivated toward science.

Seismology-at-school programs have been in place for several years around the world (e.g., Courboulex *et al.*, 2012). The basic concept of these programs is to deploy seismometers in

▲ **Figure 3.** Drop, cover, and hold on exercise performed by a primary school class. A portable shake table was borrowed by a high school, which invited nearby primary schools to come learn about earthquakes. (a) Students learning about earthquakes. (b) A child practices the correct earthquake position while the "ground" is shaking (c–f) Drawings made by the students show interesting common features: ground motion, fake ground shaking, falling objects, and correct protection position. The color version of this figure is available only in the electronic edition.

▲ **Figure 4.** Young adults act as educators in education and outreach activities for youngsters, thus consolidating their knowledge of Earth sciences: (a) mountain building analog modeling of the collision between India and Eurasia and (b) volcanic eruption modeling. The color version of this figure is available only in the electronic edition.

schools. Teachers and students collaborate to operate their seismic station and to decipher seismograms. These programs advantageously exploit the growing sense of independence of teenagers, giving them a feeling of adultness. In Portugal, seismic stations were first deployed in schools in 1996, and the effort has since been continued. Schools that do not own seismometers also take advantage of new technologies to raise interest for seismology. Any school can easily access seismograms recorded at other schools or by global seismic stations, teachers can show students how to install applications that turn their mobile devices into seismometers, and students can learn how the accelerometer inside their mobile devices contributes to its capabilities. Although at these ages we still use practical hands-on activities in the classroom, we find that teenagers engage particularly well in projects that use new technologies and that have a global dimension.

Pre-University and University Students

In general, we find that the most effective activities are those in which participants (1) make an active effort and (2) are given control of the activity. This is particularly true for young adults, namely pre-university and university students, who by that age have the ability and maturity to work independently. A common type of activity is to bring young adults into our laboratories and to let them be seismologists for a few days. In addition, we often engage young adults as educators in our E&O activities. In this role, young adults can develop their own educational materials and participate in E&O sessions for the younger teenagers and children (Fig. 4). Teaching is a compeling driver of knowledge consolidation (e.g., Laursen *et al.*, 2007). Pre-university and university students often report that they better understand seismological concepts after participating in E&O activities as educators than after solving class exercises. In fact, we have started to give our own undergraduate students the option to participate in E&O activities as an alternative to handing in part of their class exercises.

Life-Long Training of Professionals

Life-long training of professionals is a key pillar of our E&O program. In Portugal, like in most western countries, most earthquake teaching is done by teachers of the biology and geology group, most of whom are biologists with a limited physics background. These teachers feel a real need to learn more about seismology, and they become highly motivated participants in training sessions. Motivated and knowledgeable teachers have the capacity to reach out to a very wide audience. The training that we provide aims at the development of both theoretical and practical skills. We focus on improving the teachers' scientific background, with lectures that include active discussion and by exploring hands-on classroom activities. At the end of the training period, teachers are asked to develop new materials to teach seismology in the classroom, a task that they often accomplish with surprising enthusiasm, creativity, and innovation. The materials developed are then presented to and shared with the whole community.

In one case, a teacher developed an experiment to show how ground shaking depends on seismic-wave properties. The experiment was based on acoustic waves, representing the propagation of P waves. The setup consisted of a sound system, preferably a subwoofer, which was laid down with the speaker facing upward. A sheet of canvas was then placed horizontally at a given distance above the subwoofer. Lego parts (human figures and constructions) were placed on the canvas. Then the music was turned on, and the volume was increased progressively. As we increased the volume, the Legos on the canvas started to shake and eventually fell to the ground. The experiment was repeated with the canvas placed at different distances from the speaker, to show the attenuation of acoustic waves with distance from the source. The experiment was also repeated with different music styles (classical, pop, rock, and heavy metal) to allow an appreciation of the different frequency content of the different acoustic waves and their effect on the shaking of the canvas.

To support the teaching of seismology at schools, we made copies of our educational materials. One set of materials is reserved for lending for independent use by schools, civil protection, museums, and so on. Lending of the material is preceded by training of the educators. This strategy eases the load on our staff, gives responsibility and independence to schools and other educational partners, and allows time for users to explore the materials thoroughly. It also provides schools with innovative experimental materials at a time when many schools are facing severe resource constraints.

The training sessions for professionals described above are mostly aimed at teachers. However, we have received participants with different backgrounds, namely from the civil protection and private-sector business continuity sectors. The multilateral exchange of knowledge between us, teachers, civil protection agents, and private-sector representatives has been a very positive and fruitful experience for all involved.

FINAL REMARKS

Most university E&O programs target pre-university students in an effort to attract students to colleges and universities. However, our observations over more than two decades of active public outreach led us to develop a wider E&O program. This wider program aims at more effectively achieving the twin goals of educating for earthquake science and risk, by taking advantage of the specific interests and behaviors of different population groups.

We expect that E&O activities will need to be adapted regionally, depending on local culture and tectonic setting, both of which impact local earthquake risk perception. In this article, we explained the basic philosophy of an E&O program adapted to Portugal, a region of slow tectonic deformation, where large earthquakes occur with long return periods. We hope that our experience will be useful to other educators and that the directions pointed to here can be further explored in programs that better take into account risk perception and other human behavior considerations.

DATA AND RESOURCES

All data used in this article came from published sources listed in the references. Some figures were made using Generic Mapping Tools v.5.1.2 (Wessel and Smith, 1998). Changes in gross domestic product were accessed from http://www.pordata.pt. The active health and environmental education programs, available at http://www.dge.mec.pt/educacao-para-saude, and http://ecoescolas.abae.pt/projetos_14_15/, provide examples of how schools can play a key role in the education of the population. All the above websites were last accessed on March 2016.

ACKNOWLEDGMENTS

We are grateful for the comments and suggestions provided by two anonymous reviewers and by Eduquakes Editor Alan Kafka, which significantly contributed to improving the article. Our education and outreach (E&O) program benefited from the support of Ciência Viva, Portugal. We thank the fruitful collaboration and engagement of the Municipal Civil Protections of Lisbon, Setúbal, and Cascais. Experimental materials were kindly provided or resulted from collaborations with Comandante José Silva (Municipal Civil Protection of Caldas da Rainha), Paulo Fonseca (Universidade de Lisboa), Pedro Costa (Universidade de Lisboa), and Tanya Atwater (University of California, Santa Barbara). We are indebted to a number of collaborators and participants on our education and outreach (E&O) activities, including Ana Domingues, Carlos Corela Daniela Alves, Inês Rio, Iolanda Morais, Isabel Rodrigues, Joana Carvalho, Joana Santos, José Luis, Josep Batlló, Paula Teves Costa, and Verónica Antunes. Finally, our program would not have been possible without the interest and commitment of countless schools and teachers. This article is a contribution of projects QuakeLoc-PT (PTDC/GEO-FIQ/3522/2012) and SPIDER (PTDC/GEO-FIQ/2590/2014), funded by the Portuguese Science Foundation (FCT) and the COMPETE Programme, and of Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation project (NERA project) (EU-FP7 GA-262330). This research is cofunded by FCT and the COMPETE Programme under the contracts UID/GEO/50019/2013, Instituto Dom Luiz (IDL) and UID/Multi/00611/2013 (Centro de Investigação da Terra e do Espaço da Universidade de Coimbra [CITEUC]).

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