Using paired teaching for earthquake education in schools

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Abstract.

In this study, we have created ten geoscience video lessons that follow the paired teaching pedagogical approach. This method is used to supplement the standard school curriculum with video lessons instructed by geoscientists from around the world coupled with activities carried out under the guidance of classroom teachers. The video lessons introduce students to the scientific concepts behind earthquakes (e.g., Earth's interior, plate tectonics, faulting, and seismic energy), earthquake hazards and mitigation measures (e.g., liquefaction, structural and non-structural earthquake hazards). These concepts are taught through hands-on learning where students use everyday materials to build models to visualize basic Earth processes that produce earthquakes, and explore the effects of different hazards. To evaluate the effectiveness of these virtual lessons, we tested our videos with school classrooms in Dushanbe (Tajikistan) and London (United Kingdom). Before and after video implementations, students completed questionnaires that probed their knowledge on topics covered by each video including the Earth's interior, tectonic plate boundaries, and non-structural hazards.

Our assessment results indicate that while the paired teaching video lessons appear to enhance student knowledge and understanding of some concepts (e.g., Earth's interior, earthquake location forecasting, and non-structural hazards), they bring little change to their views on causes of earthquakes and their relation to plate boundaries. In general, the difference between UK and Tajik students' level of knowledge prior to and after video testing is more significant than the difference between pre- and post-knowledge for each group. This could be due to several factors affecting curriculum testing (e.g., level of teachers' participation and classroom culture) and students' learning of content (e.g., pre-existing hazards knowledge and experience). Taken together, to maximize the impact of school-based risk reduction education, curriculum developers must move beyond innovative content and pedagogical approaches, take classroom culture into consideration, and instil skills needed for participatory learning and discovery.

1 Introduction

The impacts of earthquake disasters are not only physical, psychological and economic, but also educational. Approximately 1.2 billion students are enrolled in primary and secondary schools, with about 875 million living in high seismic zones (UNICEF, 2014). Recent devastating earthquakes such as those that struck Pakistan in 2005, China in 2008, Haiti in 2010 and Nepal in 2015 have demonstrated how vulnerable school communities are to earthquake disasters (Fig. 1). In the most affected regions, these earthquakes resulted in the collapse of over 80% of schools (Pazzi et al., 2016). In China alone, the Wenchuan earthquake destroyed more than 7,000 school buildings and significantly damaged more than 10,000. The number of school children affected was estimated to be in the millions. Similarly, in Pakistan, UNICEF reported at least 17,000 school children were killed, most of them in the collapse of more than 7,500 school buildings, as well as some 2000 teachers lost their lives, were seriously injured or displaced (Winser, 2005; Halvorson and Hamilton, 2010).

Scarce resources, inadequate building codes, and unskilled building professionals are often cited as the underlying drivers for unsafe school buildings (Sharma et al., 2016; Bilham and Gaur, 2013; Erdik and Durukal, 2008). Other contributing factors include

40 a lack of science-based earthquake education, awareness of hazards and mitigation measures, and sociocultural factors influencing knowledge, beliefs and practices (Lownsbery and Flick, 2020; Cavlazoglu and Stuessy, 2013; Halvorson et al., 2007). In some societies, the lack of access to science-based earthquake information can hinder preparedness by cultivating misconceptions such as those relating to fatalism and God's will (Yeri et al., 2019; Paradise, 2005) or by blaming and shaming of the vulnerable population (Simpson, 2011; Halvorson and Hamilton, 2007). Previous work has identified school-based disaster risk reduction

45 (DRR) education as one of the main contributors to the long-term resilience and empowerment of communities (Subedi et al., 2020; Oktari et al., 2018; UNICEF, 2014; Twigg, 2009). An effective DRR curriculum can prepare children and youth as "agents of change" by actively engaging them in learning about geo-hazard science and school safety measures, and preparing them to share their learning with the wider community (see Mitchell et al., 2009, and references within). However, many schools around the world lack the resources and incentives that are required for a successful school-based DRR education, for example curricular

50 resources, and trained teachers. This study aims to improve teachers' access to DRR content focusing on earthquake education, and to facilitate content teaching by connecting teachers with Earth scientists.

Different approaches to school-based DRR curriculum are summarized in a comprehensive report by UNICEF/UNESCO which includes case studies from thirty countries (Selby and Kagawa, 2012). In general, curriculum development and integration are textbook-driven and/or carried out as co- or extra-curricular activities in the form of pilot projects or special events in schools (e.g.,

55 earthquake drills or playing serious games). While some DRR content is easily woven into specific school subjects such as geography or natural sciences, a textbook-driven approach hinders the achievement of skills, attitudinal and action learning outcomes required for effective DRR learning. Co-curricular and extra-curricular activities, on the other hand, can provide a means for innovative teaching and interactive and participatory learning.

60 Here, we apply an innovative teaching technique, known as paired teaching to create a series of video lessons taught by a scientist and the in-class teacher to enhance science-based earthquake education that also covers topics related to earthquake hazards and safety measures. We share results of our curriculum classroom testing in schools in Tajikistan and the United Kingdom where natural hazard topics are often textbook-driven and discussed briefly, with no/little active learning exercises. The video lessons, therefore, are an opportunity to ignite active learning in school classrooms and allow for bringing scientists into school classrooms

65 (as video teachers) without additional resources.

2 Methods

We created and published ten free (Attribution-NonCommercial Creative Commons license) online video lessons. The videos are archived with Technische Informations Bibliothek (TIB) AV-Portal (https://av.tib.eu/media/47600) and can be accessed via the YouTube channel of the European Geosciences Union (https://www.youtube.com/user/EuroGeosciencesUnion). The video series

70 was created collaboratively by nine early-career Earth and environmental scientists and educators from academic institutions across the United Kingdom and Germany. Many of the video presenters are experienced educators who have developed and taught STEM related subjects and activities in both formal and informal settings including K-12 schools. To create the series, we adapted protocols for creating interactive videos by Larson and Murray (2017) and applied them to lessons plans developed by Mohadjer et al. (2010). These protocols incorporate the paired teaching pedagogy (see section 2.1), and blend well with the interactive

75 exercises that accompany the lesson plans. For a thorough discussion on the protocols, we refer readers to Larson and Murray (2017).

The video lessons are not intended to replace an existing curriculum but rather to support the teaching of concepts related to earthquakes through interactive, hands-on activities and discussions that are guided by a guest scientist and the in-class teacher. In

80 addition, the videos are developed for the global school community and do not target or adhere to the educational standards of a specific region or country. However, teachers are encouraged to contextualize the curriculum content according to their local environment, and are given relevant guidelines in the teacher segment at the end of each video (see supplementary material for more details). Below, we introduce the paired teaching approach and describe our video evaluation strategy.

85 **2.1 Paired teaching pedagogy**

We used a pedagogical model known as paired teaching (or teaching-duet) developed by the MIT BLOSSOMS (Blended Learning Open Source Science or Math Studies) initiative. This approach enables scientists and educators from around the world to create and instruct virtual lessons and activities that are carried out under the guidance of in-class teachers in school classrooms. A typical virtual lesson contains four to six short video segments taught by the video-teacher. Each segment is followed by a live active-

90 learning segment in the classroom, guided by the in-class teacher. For example, the class starts with segment 1 of a learning video. Toward the end of this segment, the video-teacher gives a challenge to the class. The video fades into black and is replaced with a still image of activity instructions or questions. The in-class teacher pauses the video, and guides the students in an active learning exercise in the classroom. After the exercise is concluded, the in-class teacher resumes the video, allowing the video-teacher to take over the teaching. The passing of teaching between the in-class and video-teachers is a type of blended learning referred to as

95 the paired teaching. Fig. 2 shows the workflow of our paired teaching approach. See supplementary material for an example of a video module from our earthquake video series.

In this study, the above technique was adapted and applied to earthquake education lesson plans of Mohadjer et al. (2010). These lesson plans have been tested, evaluated and improved by Teachers Without Borders and other educational institutions in the

100 training and guidance of teachers to facilitate DRR learning in schools in China, Tajikistan, Afghanistan, India and Haiti. To turn these lesson plans into learning videos, we followed protocols created and used by MIT BLOSSOMS for producing >100 STEM videos. The protocols included three key steps before videotaping began: (1) the writing of the concept for the video lesson, (2) mapping out the structure and content of the video lesson, and (3) preparing a pseudo-script to show how the video lesson will be presented when taped. The lesson plans and learning videos cover similar topics, but they differ in teaching pedagogy (paired

105 teaching vs 5E instructional model of Bybee et al., 2006) and the delivery method (video lessons vs lesson plans).

2.2 Curriculum evaluation

To evaluate the effectiveness of our video series, we selected and tested three video lessons with school students and teachers in Tajikistan and the United Kingdom. We compared pre- and post-assessment data collected from students on the first and last days of video implementation, respectively. This was done by using a questionnaire that assessed students' learning of main concepts

110 covered in each video that was selected for classroom implementation. This comparison is possible since students answered the same questions in pre- and post-assessment questionnaires. Ethical approval for this study was sought and received from the participating schools and institutional partners that coordinated this effort in 2018-2019. The ethical procedures were designed to

adhere to current standards of assent and consent regarding in-school research and to provide participants with anonymity. As a low-risk, school-based study focused on learning outcomes from regular teaching activities, the consent of the school-based stakeholders, i.e. the principals and teachers, were considered sufficient to proceed with the pre- and post-tests. All participation was voluntary, and students were given the opportunity to assent or refuse participation at both the pre- and post-test points in time. The pre- and post-tests were anonymous with students creating their own codenames, which were known only to them, that were used to match the pre- and post-tests for analysis purposes. No sensitive or identifying information was collected, and the anonymous data are stored in a secure location within the European Union that is password protected, in accordance with GDPR regulations. The data will be destroyed upon completion of this research project. Below, we describe the questionnaire, our video selection, and testing sites.

2.2.1 Pre- and post-assessment questionnaires

The questionnaire (see supplementary material) contained seven questions, with each question designed to evaluate students' learning of a topic that was explored in selected videos. To elicit a wide range of responses from the students, we used open-ended questions (e.g., what are the causes of earthquakes?), drawing strategies (e.g., draw the Earth's interior) and analysis of photographs (e.g., can you identify non-structural hazards in each photo?). We also included questions requiring a "yes" or "no" answers (e.g., Can earthquakes be predicted?). For these questions, we included "I don't know" and "other (please specify)" in answers to select from. The only demographic information collected was student gender. To anonymously link the pre- with post-assessment data collected from each individual student, we asked students to create a confidential identifier unique to themselves, and write it on both pre- and post-assessment questionnaires. Using this method, we were able to collect data from a total of 77 students from Tajikistan and the UK.

2.2.2 Data Analysis

Students' written responses to survey questionnaires were first categorized into appropriate groups based on the individual response to each question. We then assigned a score value to each response group, indicating the level of understanding associated with the response. For examples, students who mentioned volcanoes and mountains in their answers as the primary cause of earthquakes received a score of 1; those mentioning plate tectonics received a score of 2; those with no or irrelevant answers received a score of 0. Similarly, students' graphical responses (question 6 in the survey) were analysed using the evaluation rubric of Steer et al. (2005). For example, students' drawings of the Earth's interior were scored 0 (no conceptual framework) to 5 (advanced understanding). Students' scored responses to pre- and post-assessment questions were then analysed for comparison using a two-sample t-test when data followed the normal probability distribution and the non-parametric Kolmogorov-Smirnov (KS) test when the probability distributions were non-normal. For survey questions that required binary answers (yes/no questions such as questions 3-4 in the survey), we used the McNemar test to compare results. The significance level (alpha value) was set to 0.05, and results were considered statistically significant if $p < 0.05$.

2.2.3 Video selection

We selected three videos for classroom testing in the UK and Tajikistan. These videos included the first two earthquake science video lessons in the series (i.e., Earth's interior and Plate boundaries) and the last earthquake hazard and safety video (i.e., Non-structural hazards) (see Fig. 3). These videos were chosen since they required no previous knowledge of earthquakes, and cover the fundamental concepts related to earthquakes (i.e. Earth's interior, plate tectonics) and the most common cause of earthquake-related injuries (i.e., non-structural hazards). Furthermore, these videos use a wide range of pedagogical approaches to teaching

150 and learning. For example, the Earth's interior video follows a model-based, conceptual change approach to teaching to improve students' understanding of Earth's structure while the plate boundaries video is data-driven and follows the jigsaw method of cooperative learning (i.e., students depend on each other to succeed) as shown in Sawyer et al. (2005). The non-structural hazards video uses a place-based approach, promoting learning that is rooted in students own "place" (i.e. their classroom) to raise awareness about non-structural hazards and mitigation measures in school classrooms where videos were tested. This range of
155 teaching methods tested allows us to gain the most information about students' diverse and complex individual learning needs in response to paired teaching, from the information collected in the questionnaires.

2.2.4 School settings

The three aforementioned videos were tested with 38 sixth-grade students (12 years of age, 50% female) and 39 ninth-grade students (12-14 years of age, 42% female) from two school classes in Dushanbe (Tajikistan) and London (United Kingdom),
160 respectively. The school in Dushanbe (capital city of Tajikistan) is a public school located in the city center and was selected for this study by the Tajik Institute of Earthquake Engineering and Seismology because of its previous collaboration with Mohadjer et al. (2010). The school was recently built in compliance with the existing seismic building codes of Tajikistan. Interactive whiteboards are included in many of its classrooms, and there is a new computer lab with individual workstations. The video testing was conducted over 5 days during school hours (i.e. 8:00-12:00) by the lead author with assistance from local teachers. The
165 local language (Tajik) was used in teaching and in all written and media materials including the videos which were dubbed in Tajik. Resources needed for testing (e.g., maps, Slinky toys and Playdough) were provided by the lead author. The school in London (United Kingdom) is a secondary (11-18 years of age) academy located in the heart of the city. The London school was selected through our existing teachers' network in the UK. The videos were tested by two geography teachers with 1-3 years of teaching experience over a testing period of approximately 50 days. The difference in the testing periods between the two schools
170 was to accommodate different schedules teachers had to follow. While the UK teachers could spread out the video lessons in a 50-day period, the lead author of this manuscript had to follow a restricted schedule of five days for video testing in Tajikistan.

3 Results

Using the methods described in section 2, we created ten online video lessons. The videos were tested with school classrooms in Tajikistan and the United Kingdom during the 2018-2019 period. Below, we briefly introduce the videos and share the results of
175 our classroom implementation.

3.1 Paired-teaching video series

Table 1 summarizes the teaching approach, topics covered, and classroom activities for each video as well as video duration and its digital object identifier (doi). The video durations range from 12 to 24 minutes (excluding the teacher segment). In addition to our paired-teaching pedagogy, each video lesson incorporates a wide range of teaching strategies to create an active learning
180 environment. While some strategies are based on group work methods such as cooperative learning (as used in the *Discovering Plate Boundaries* video lesson), others include classroom experiments that involve students in collecting data, making predictions and reflecting upon their observations (as shown in the *Earthquake Machine* video lesson). Most video lessons incorporate analogies and models to enhance conceptual understanding of some topics such as Earth's interior structure and material properties while allowing students to construct and critique their models. All classroom activities are low-tech and require materials that can
185 be easily obtained and assembled anywhere in the world.

3.2 Video classroom testing

To test the effectiveness of our paired teaching technique, we selected and tested three video lessons with school students in Tajikistan and the United Kingdom. Since both groups watched the same videos and completed the same questionnaires prior to and after the testing of video lessons, full comparison of results between groups is possible. In the following sub-sections, we summarize students' responses to six questions they were asked in the pre- and post-assessment surveys. The statistical test results are shown in the supplementary materials (Table 2).

3.2.1 Students' understanding Earth's interior

Students' understanding of the Earth's interior before and after classroom testing of the *Earth's Interior and Plate Tectonics* video is shown in Fig. 4. While the majority of the Tajik students' responses, both before and after watching the video, show no to little understanding of the Earth's interior (scores of 0-2), responses given by the UK students are more evenly distributed between no/little understanding and higher levels of understanding (scores of >2). Both groups, however, show an increase in their understanding of the Earth's interior after watching the video. These observations are supported by statistical analysis of the results. More specifically, 74% of students (28 students) from Tajikistan and 48% from the UK (19 students) demonstrated having a no/basic conceptual framework about the Earth's interior (scored 0-1) prior to video testing. After video testing, a large percentage of Tajik and UK students (58% and 52%, respectively) demonstrated an increased level of understanding of the Earth's interior (scored 3 or higher). The difference between Tajik students' responses before and after video testing was statistically significant above 95% level using the Kolmogorov-Smirnov (KS) test (D-stat: 0.31, D-crit: 0.30). Similarly, the difference between UK and Tajik students' responses before and after video testing was significant above 95% (D-stat: 0.33 and D-crit: 0.30).

3.2.2 Students' understanding of causes of earthquakes

We grouped students' responses into six categories (Fig 5). In their responses to "What are the causes of earthquakes?", 90% (35 students) of UK students mentioned plate tectonics while 46% (17 students) of Tajik students made references to mountains and volcanoes (with only 1 out of 38 students mentioning plate tectonics) before video testing. After video testing, Tajik students showed little improvement in their understanding of the causes of earthquakes. The difference between UK and Tajik students' responses prior to video testing as well as their responses afterwards was significant above the 95% level using the KS test (D-stat: 0.84, 0.79 and D-crit: 0.30 and 0.30, respectively).

3.2.3 Students' understanding of non-structural hazards

Figure 6 shows students' ability to identify non-structural hazards in example photographs. Non-structural earthquake hazards are caused by the furnishings and non-structural elements of a building (e.g., suspended ceilings and windows). In general, students from both groups identified non-structural hazards that are located above the ground (e.g., hanging television set and plant pots stored above cabinets) and missed those near the floor (e.g., desks and chairs). Both groups demonstrated some knowledge of non-structural hazards found in typical school classrooms prior to video testing, and showed some improvement after video testing. However, only the difference between pre- and post-assessment responses by the UK students was statistically significant above the 95% level as indicated by the KS test (D-stat: 0.43, D-crit: 0.30).

3.2.4 Earthquake prediction

Figure 7a shows students' responses to "Is it possible to know the exact timing of earthquakes before they occur?" While the majority of Tajik students indicate "no" in their responses before and after video watching (55% and 68%, respectively), UK

students' responses are more evenly distributed between three categories of "no", "sometimes" and "I don't know" prior to video watching (36%, 33% and 28%, respectively) as well as after video testing (46% indicate "no", 38% indicate "sometimes"). After video watching, a notable percentage of Tajik students (21%, 8 students) believes that it is possible to know the exact timing of an earthquake.

In their pre-assessment responses to whether it is possible to know where an earthquake can occur (Fig 7b), a significant percentage of both groups (47%: Tajik, 41%: UK) believe that is sometimes possible. After video watching, Tajik students' responses are divided almost evenly in four different categories: 26% (10 students) indicate that it is possible to know where earthquakes can occur (category "yes") while 18% (7 students) believe otherwise (category "no"), 21% (8 students) indicate it is sometimes possible, and 26% (10 students) give irrelevant answers. In contrast, the majority of UK students' post-assessment answers is "yes" to earthquake location prediction (62%, 24 students) with "sometimes" indicated in 28% (11 students) of responses. The differences between UK pre- and post-assessment responses is statistically significant above the 95% level as indicated by the McNemar test (chi-stat: 6.66, chi-crit: 3.84).

Additionally, we asked students an open-ended question: where in the world earthquakes occur most often? Based on their answers, we created five response categories (Fig 7c). A large percentage of students' responses from both groups include country names before and after watching the videos. UK students also included plate boundaries in their responses both before and after watching videos (21% and 40% respectively). In contrast, Tajik students made references to mountains/volcanoes (39% and 44%, respectively). These observations match students' responses to causes of earthquakes (Fig. 5). The differences between UK and Tajik post-assessment responses is statistically significant above the 95% level as indicated by the KS test (D-stat: 0.38, D-crit: 0.30).

4 Discussion

4.1 Factors influencing students' learning

The differences between students' pre- and post-assessment responses to survey questions were only significant above the 95% level when they were asked to indicate if it was possible to know where earthquakes happen (section 3.2.4), sketch a cross- section of the Earth (section 3.2.1), and identify non-structural hazards in example photographs (section 3.2.3) (Table 2 in the supplementary material). These results indicate that our paired teaching videos appear to change student views and understanding of some concepts including (i) Earth's interior for the Tajikistan group, (ii) earthquake location forecasting for both the Tajikistan and UK groups, and (iii) non-structural hazards for the UK group. However, our curriculum did not significantly change students' understanding of other concepts including causes of earthquakes and their relation to plate boundaries. Below, we discuss possible factors improving or hindering students' learning of these targeted topics.

Interior of the Earth - While a notable percentage of Tajik students' responses (50%, 19 students) indicate an increase of at least one score point in their understanding of the Earth's interior, only four (out of 38) students demonstrated an advance understanding of the Earth's interior structure where scale is important (score 4-5). This is despite the fact that students were shown a diagram of a cross-section of the Earth (with all layers drawn to scale and labelled) by the video teacher, and participated in a classroom activity during which they compared the interior structure of a hard-boiled egg with that of the Earth. These concepts, however, were unfamiliar to Tajik students prior to video testing and were not repeatedly reinforced during and after video implementation.

It is important to note that more than 50% of Tajik students did not label the Earth's layers in both pre- and post-assessment surveys since this was not specified by the question. However, the post-assessment data shows a 24% increase in the number of students who draw the interior of the Earth as concentric circles. Therefore, it is possible that students' understanding of the Earth's interior after video watching is underestimated. For the UK group, 46% (18 out of 39 students) showed no or basic conceptual framework of the Earth's interior after video testing, with only 31% (12 students) showing some improvement. We therefore conclude that diagrams and simple analogies can bring some improvement to learning these concepts, but to make significant conceptual advances, concepts must be revisited and reinforced repeatedly.

Causes of Earthquakes - The Earth's interior and Plate boundary videos did not increase students' understanding of earthquakes and associated processes. After video testing, only one Tajik student (out of 38) listed plate tectonics as the main cause of earthquakes. The relationship between plate tectonics and earthquakes was briefly mentioned by the video teacher in the Earth's interior video. However, during the testing of the Plate boundary video, students used different datasets (including an earthquake map) to observe data behaviour near/at plate boundaries. It is possible that students' incomplete understanding of the Earth's interior structure (as described above) hindered their learning process associated with earthquakes as shown by Barrow and Haskins (1996). Another hindering factor could be the lack of previous exposure and concept reinforcement during/after video testing. Relating earthquakes to volcanoes and mountains is part of students' pre-existing knowledge as demonstrated in 39% to 50% of students' pre-responses to Question 1 (i.e., What are the causes of earthquakes?) and Question 4 (i.e., Where in the world do earthquakes occur most often?), respectively. Students' pre-existing knowledge of why and where earthquakes occur was revisited and reinforced in the Plate boundary video and the accompanying classroom activities where students explored relations between distribution of volcanoes, topography, and earthquakes. Relating these processes to plate boundaries, however, was a new concept that was not reinforced. Unlike previous work by Mohadjer et al (2010), we documented no mention of myths, legends, or religious explanations in Tajik students' responses to causes of earthquakes. This could be due to (1) different data collection methods (anonymous survey questionnaires [this study] vs individual/group interviews [Mohadjer et al., 2010]), (2) differences in students age/grade level (the 2010 participants were 2-3 years older than the 2018 participants), and/or (3) may reflect changing earthquake perceptions over the last decade. In contrast, nearly all UK students (35 students) connect earthquake occurrence with plate tectonics prior to video watching. Because of their previous knowledge, it is difficult to assess the effectiveness of the plate boundary curricular activities conducted with this group.

Earthquake prediction and forecasting - The two closed survey questions that assessed students' views of earthquake prediction (Question 2 and 3) in terms of earthquake location and timing were not directly addressed by our curricular material. However, these questions were selected to (1) assess students' current perception of and views on earthquake prediction and forecasting in general and (2) to find out whether learning about the Earth's interior and earthquake-related processes alone can change students' views of earthquake prediction and forecasting. This information is important since earthquake prediction/forecast, or lack thereof, may influence preparedness attitudes and behaviors in some communities. Prior to video watching, approximately 60% (23 Tajik students) said "no" to earthquake prediction (in terms of date and time) and "yes" or "sometimes" to earthquake forecasting (in terms of location). In contrast, these values for the UK group are lower (36%, 14 students) and higher (77%, 30 students), respectively. The only significant difference (95% level) between students' pre- and post-answers was observed for the UK group for earthquake location forecasting. This may indicate that our curricular material (particularly plate boundary classroom activity), which emphasizes that earthquake locations are not random, was effective in changing students' understanding of earthquake location forecasting. A notable portion of Tajik students (26%, 10 students), however, misinterpreted the survey question as evident in their irrelevant responses to earthquake location forecasting (e.g., listing streets and schools as locations of earthquakes).

Non-structural hazards – For both student groups, our non-structural hazard video increased the students' ability to identify non-structural hazards in example classroom photos. However, the increase in hazard identification is significant (95% level) only for the UK group. This could be due to lack of exposure to earthquake shaking during which non-structural elements of a building can pose hazards to building occupants. Having experienced earthquakes and familiar with some hazards, Tajik students' give similar responses before and after video watching.

4.2 Teacher feedback

UK teacher feedback- Both teachers found the curricular material to be presented clearly, appropriately geared to the level of their students, and valuable in helping students understand and learn the lesson content. However, there were differences in how they rated the materials in terms of relevance. In general, classroom activities carried out during video breaks were described as relevant by both teachers. However, both teachers found activities related to cost-benefit analysis of non-structural hazards in Video 3 to be irrelevant with low levels of student engagement when compared with other assignments in their class. One teacher explained, "[students] did not find the tasks that useful/applicable to life as we are not in an earthquake prone area." Similarly, another teacher said, "[…] compared to the way we normally teach tectonic hazards, this (1 hr 40 minutes) felt like a lot of curriculum time on a relatively narrow aspect of the topic." There were some differences between teachers' opinions and experiences with video testing. For example, while one teacher found the egg analogy to be a "very relevant" activity and described students' level of engagement with this activity as "a great deal more" than other classroom assignments, the other teacher recommended omitting this activity, "[…] I think they could have completed this task more effectively without being given and cutting up the egg (which took up time and were a distraction)." Teachers played the entire videos in the classroom with the exception of the plate boundary video for which one teacher played only two out of five video segments, and skipped related classroom activities. The same teacher described students' level of engagement to be below average for the two activities that were carried out.

Tajik teacher feedback - Video testing in Tajikistan had to be conducted by the lead author (a geosciences researcher and teacher) due to the local teachers' lack of interest and/or confidence in having the required teaching skills and knowledge. This was despite making teaching materials accessible and available in the local language in advance of video testing, and holding an informal meeting with local teachers during which they were introduced to paired teaching and lesson content. To further support and encourage the local teachers to participate in video testing, a trained teaching assistant familiar with the paired-teaching videos was made available. The school principal was supportive of teachers' participation but did not require it. Due to limited time and resources, we had to carry out the video testing with little contribution from local teachers. The teacher feedback discussed here, therefore, reflects our experience with video testing.

With the exception of the plate boundary video, the level of content covered in both the Earth's interior and non-structural hazards videos were appropriate for Tajik students. During the plate boundary video testing, most students were not only challenged by the lesson content (e.g., understanding maps, data relationships and classification), but also struggled with understanding and following the pedagogical approach (e.g., collaborative learning) required for classroom activities. This lowered the class pace, and therefore, the video was played partially, with some classroom activities omitted. Students' level of engagement was the lowest for the plate boundary video, and the highest for the non-structural hazard video which focused on a topic most student could relate to (identifying hazards in their own classroom). The level of student excitement with lessons, however, was the highest when watching the Earth's interior video which was taught by a UK-based video-teacher. The excitement was less for the subsequent videos which were taught by the lead author who had to act as both the video and the in-class teachers.

The video testing was affected by both the classroom testing period and the choice of space and place for curriculum implementation. For example, the Earth's interior video was tested during normal school hours but outside the classroom environment in Tajikistan. For this lesson, the stage in the school theatre was selected by school authorities because the equipment required (e.g., projector, screen, and sound system) was only available for use there. For the remaining two videos, the teaching space was changed to a regular classroom and a computer lab. While the latter restricted students' movements and group formation for activities, the former provided a familiar and flexible space where students and in-class teacher could easily rearrange chairs and tables according to their needs. In addition, it is possible that the differences in the testing periods between the UK and Tajikistan groups (50 days versus 5 days, respectively) influenced the study results. For example, due to time constraints, some in-class activities had to be shortened or skipped in Tajik classrooms. That combined with technological issues posed additional challenges to video testing by shortening video testing period. Teacher feedback highlights some important differences and similarities during classroom video implementation in two geographically and culturally different parts of the world. As the above observations show, students' experience with earthquakes and related hazards influence their level of engagement with lesson content. While technological shortcomings and ineffective classroom space and management significantly challenged video testing in Tajikistan, these factors were non-existent in the UK school. The poor classroom management in the Tajik school was exacerbated by the lack of local teachers' involvement which led them to bring in a new teacher (lead author) who was unfamiliar with the specifics of the classroom culture. Despite these differences, both the UK and Tajik teachers acted flexibly with video testing by modifying the video lessons according to the needs of their students and their local environment (e.g., skipping video segments irrelevant to students' lives or shifting to printed lesson plans and other resources when technology failed). Taken together, to maximize the impact of our paired teaching approach to earthquake education, we suggest to exercise flexibility when using our videos and contextualize video content and learning activities to increase their relevance. To encourage and assist teachers with lesson preparation, we plan to improve our "teacher segment" by creating a guide for each video in a printable format with descriptions of activities covered in each segment as requested by UK teachers.

4.3 Lessons Learned

This study brought together a group of early-career Earth scientists to develop and test a series of earthquake education video lessons to support school teachers with earthquake education worldwide. The paired teaching technique provided an effective means for these scientists to connect and co-teach curricular materials with school teachers that might have not been able to invite, host, and co-teach lessons with them. In the case of Tajikistan, these lessons were implemented in a country that lacks the economic resources to develop and promote a school-based geohazards education (Mohadjer et al., 2010) despite a clear need for it. Therefore, our paired teaching video lessons can be an effective way for Earth scientists worldwide to engage with school teachers regardless of their locations (assuming language and technological barriers are addressed as it was the case in this study). Below, we discuss some of the lessons learned in this study, to increase the impact of future Earth sciences education and outreach efforts taken by Earth scientists worldwide.

Classroom culture- An effective DRR-related school-based education is one that is contextualized to meet local needs, and carried out in the cultural context that surrounds the implementation of the curriculum. Students' and teacher's needs and goals, local constraints and schools' pedagogical values are some of the factors that shape a classroom culture. While some topics such as Earth's interior and plate tectonics are often covered to varying degrees in most schools around the world, knowing how to identify and fix non-structural hazards related to earthquakes might not be as relevant to schools located in non-seismically active regions.

Similarly, content taught using pedagogical approaches that are unfamiliar to some teachers and students can hinder effective learning. For example, most of the learning activities in this study were based on cooperative learning (e.g., jigsaw concept) and involved group discussions where everyone's input was encouraged. Unfamiliar with this approach, these activities appeared to be unstructured to most Tajik students, leaving some uncomfortable with sharing their opinions.

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The low level of engagement by local teachers in Tajikistan in serving as in-class teachers in the paired-teaching approach may be due to their unfamiliarity and discomfort with collaborative learning methods and the use of video technology. Since the paired teaching video lessons were designed to be a complete resource (i.e., containing video segments, teacher's guides, downloadable handouts and lists of other resources relevant to the topic), no teacher training was provided for using these videos. However,

390 teachers were encouraged to view the videos and familiarize themselves with the content before using them in their classrooms. This study, however, reveals that these videos may not be seen as a complete resource by some teachers. While the UK teachers tested the videos with minimal input from video creators, teachers in Tajikistan asked to observe classroom testing of the videos. This request was made despite the fact that the teachers were offered training to deliver the videos, and/or the option to co-teach the video lessons with experienced instructors. Similar to teachers in Tajikistan, teachers in China, Japan and Malaysia, where rote

395 learning dominates classroom culture, experienced difficulties with paired teaching (Larson and Murray, 2017). Therefore, the textbook-based classroom culture may partly explain why Tajik teachers did not want to actively engage in video testing. In addition, teachers' low level of technology acceptance and readiness for teaching and learning has been shown to hinder their engagement with technology-based pedagogical approaches (Shukor et al., 2018). Our study, therefore, shows that the paired teaching pedagogy is not a "one size fits all" teaching approach, and depends on the classroom culture and teacher's comfort

400 operating within it. Taken together, when developing curricular material, teachers' and students' involvement are key to ensuring an appropriate selection of content and pedagogical approaches. This can be achieved through informal classroom observation and discussions of goals and pedagogical expectations with classroom teachers and students as well as providing ongoing, high-quality pedagogical training that support teachers with adopting a more student-centered and collaborative teaching style for their classrooms.

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Curriculum evaluation- The importance of public engagement activities is increasingly recognized by scientists, funding institutions and policymakers (NSF 2015, Rauws, 2015; European Union, 2002). However, many of those who practice science education and outreach do not always evaluate their work rigorously, and even fewer publish and share their results in peer-reviewed journals. By testing our videos in school classrooms located in different countries (UK and Tajikistan), we were able to

410 assess the effectiveness of our educational materials and identify potential factors that influence learning. However, the assessment of our evaluation strategy revealed several issues. While using questionnaires with students may be a time/cost-efficient method of collecting information anonymously, if not designed and explained carefully, the students may interpret the questions differently. This was the case with some students in Tajikistan where they perceived the questionnaire as an exam and strived for correct answers as opposed to freely sharing their existing knowledge. Despite gaining new knowledge, some Tajik students gave identical

415 responses to pre- and post-assessment questions in order to be consistent as opposed to be correct. We, therefore, recommend using questionnaires as one of several methods for collecting and evaluating data. Strategies such as conducting face-to-face interviews with students or arranging for and recording group interviews can minimize misunderstanding and provide important insights into student-student and student-teacher interactions that enhance or hinder learning. Taken together, an effective evaluation strategy should consider students' familiarity with data collection methods to ensure students understand what they are being asked to do

420 and why.

5 Conclusion

In this study, we created ten geoscience video lessons focusing on earthquake science and hazards. The paired teaching approach was used to engage geoscientists as video teachers who introduce and discuss concepts in brief video segments. In between segments, these concepts were explored through hands-on activities under the guidance of an in-class teacher. We tested three

425 videos (Earth's interior, Plate boundaries, and Non-structural hazards) with a total of 77 students (12-14 years of age) from schools in Dushanbe (Tajikistan) and London (United Kingdom). Our analysis of students' pre- and post-assessment responses to survey questions indicate: (1) students' pre-existing conception about the causes of earthquakes is difficult to modify if new concepts are not repeatedly reinforced, and (2) students' incomplete understanding of the Earth's interior hinders their learning process associated with earthquakes. Comparison of results from the UK and Tajikistan groups reveal significant differences between

430 students' views on the Earth's interior and why and where earthquakes generally occur. Possible factors influencing students' learning are those related to students' own experience with earthquakes, pre-existing knowledge, and unfamiliarity with some content (e.g., data maps) and pedagogical approaches (e.g., collaborative learning). These factors should be taken into account in order to maximize students' learning during paired teaching.

435 Despite documenting an increase in students' understanding of some concepts covered in the tested videos, the effectiveness of our entire video series cannot be fully assessed without furthering testing. This is because the series follows a stepwise approach to increasing students' understanding of earthquake science and hazards, with later lessons in the series building on topics covered in earlier lessons. This approach allows for reinforcement of some difficult concepts. However, excessive workload, restrictive curriculum, and increased pressure to achieve good result limit teachers' decisions to use the entire series which includes ten videos

440 (total of 10-20 hours of classroom time). Therefore, we recommend selecting and using video segments that are relevant to (and can enhance) the teaching of specific topics covered by an already existing curriculum. In addition, our videos can serve as a resource for teachers who cannot easily arrange for an in-person or a virtual live session between their students and an Earth scientist.

445 Geoscience and natural hazard researchers' contribution to developing resilient communities is often through engagement in disaster risk reduction (Gill et al., 2021). We hope that lessons learned in this study can benefit the scientific and wider DRR community by highlighting some of the key factors that influence the teaching and learning of geo-hazard content. There is already a wide range of tools and resources developed by the geo-hazard community to ensure meaningful access to scientific information relevant to DRR. Examples include Hazard Ready (a hazard preparedness web application developed for specific cities in the

450 United States), the Central Asia Geohazard database (a searchable repository of active fault and earthquake information by Mohadjer et al., 2016) and various earthquake data products created by the Global Earthquake Model team (e.g., the Global Seismic Hazard Map shown in Fig. 1). These resources, if contextualized appropriately, can be effectively incorporated into DRR educational materials (e.g., our paired teaching videos, animations, and exercises) used with the K-12 and higher education communities.

455 **Data availability**

All video files are archived and available for download at Technische Informations Bibliothek (TIB) Av-Portal (https://av.tib.eu/media/47600). In addition, videos are available for view at the YouTube channel of the European Geosciences Union: https://www.youtube.com/user/EuroGeosciencesUnion.

Author contribution

460   SM and SGM were responsible for video production, direction, editing and planning the study. Videos evaluated in this study were presented by MK and SM. Classroom testing of videos in Tajikistan was coordinated by AI and led by SM. MK and SG arranged and coordinated the video testing in the UK school. Data analysis was done by SM and SGM. All authors contributed to manuscript preparation.

Completing interests

465   The authors declare that they have no conflict of interest.

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475   T.A.E.).

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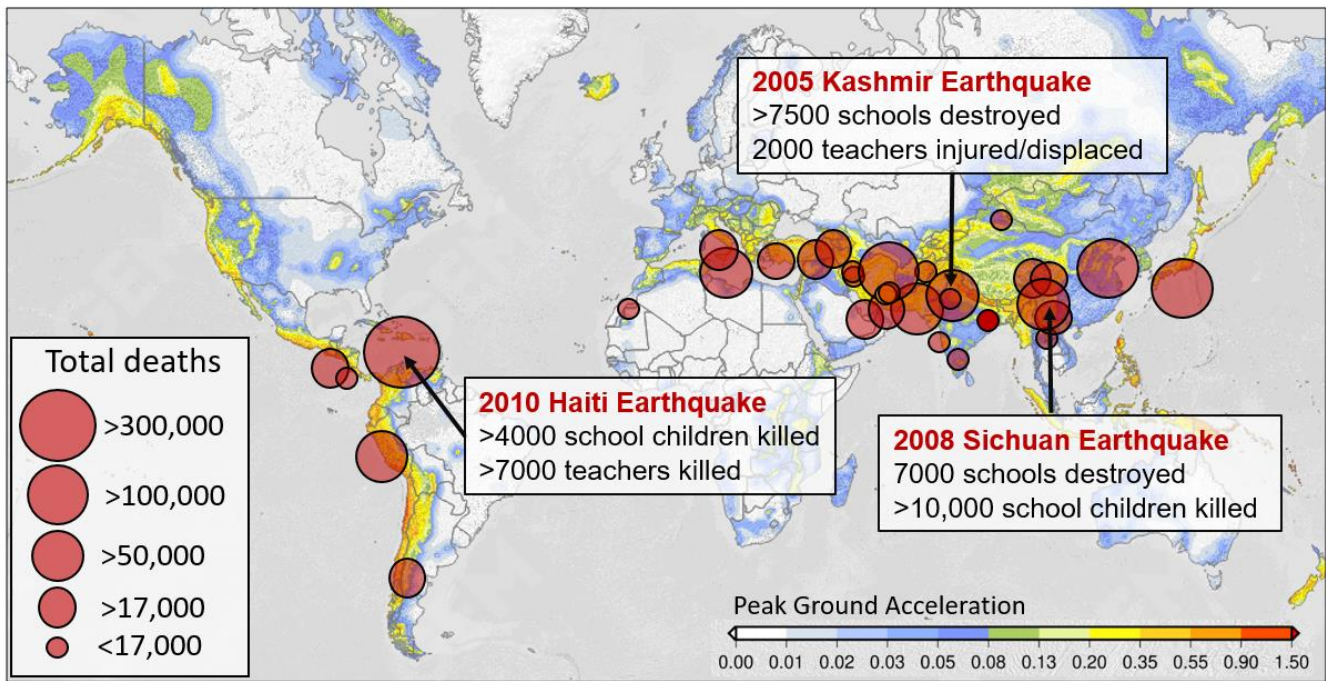
Figure 1. Significant earthquakes from NOAA database superimposed on the Global Seismic Hazard map of Pegani et al. (2018). Impact details of recent earthquakes discussed in text are shown in white boxes.

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In-class Teacher

Video Teacher

In-class Teacher
(~25 minutes)

Video Teacher
(~25 minutes)

Introduction
Ask a question or
Invite students to do an activity

2 minutes

Classroom Activity 1

Summarize results
Present content
Ask a question
Invite students to do an activity

3-4 minutes

Iterative process

Classroom Activity 2

Summarize results
Draw conclusions
Invite students to learn more

3-4 minutes

Teacher's guide
(for in-class teacher only)

5 minutes

Figure 2. Paired teaching pedagogy
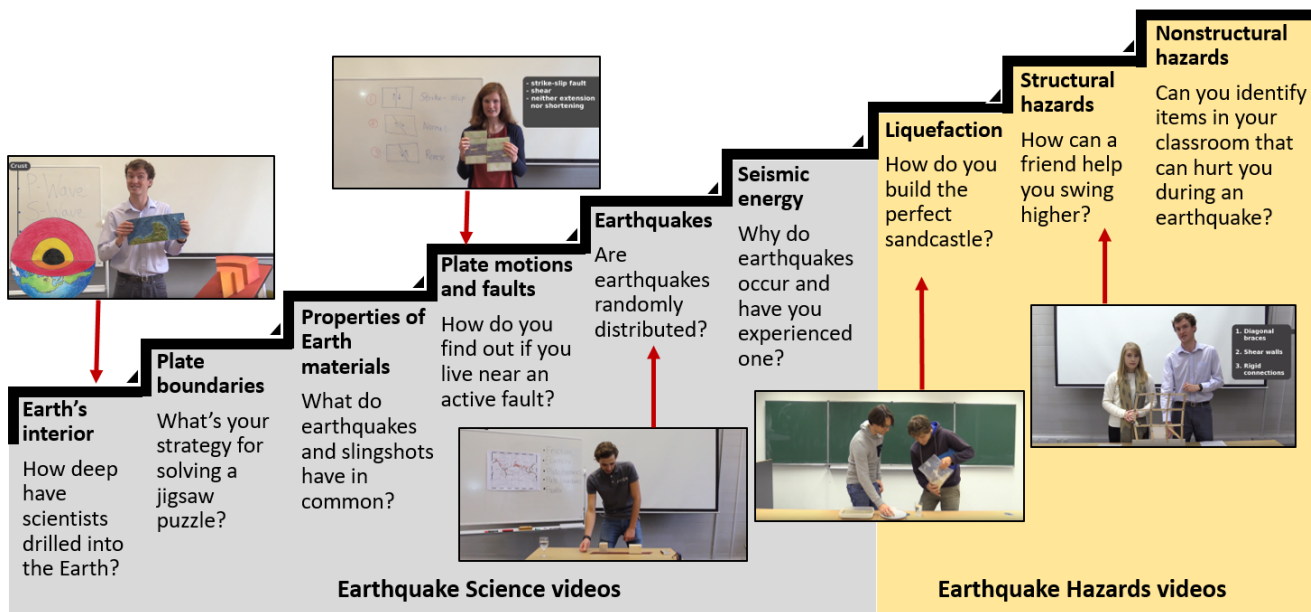
Figure 3. Stepwise earthquake education curriculum (modified from Mohadjer et al., 2010)

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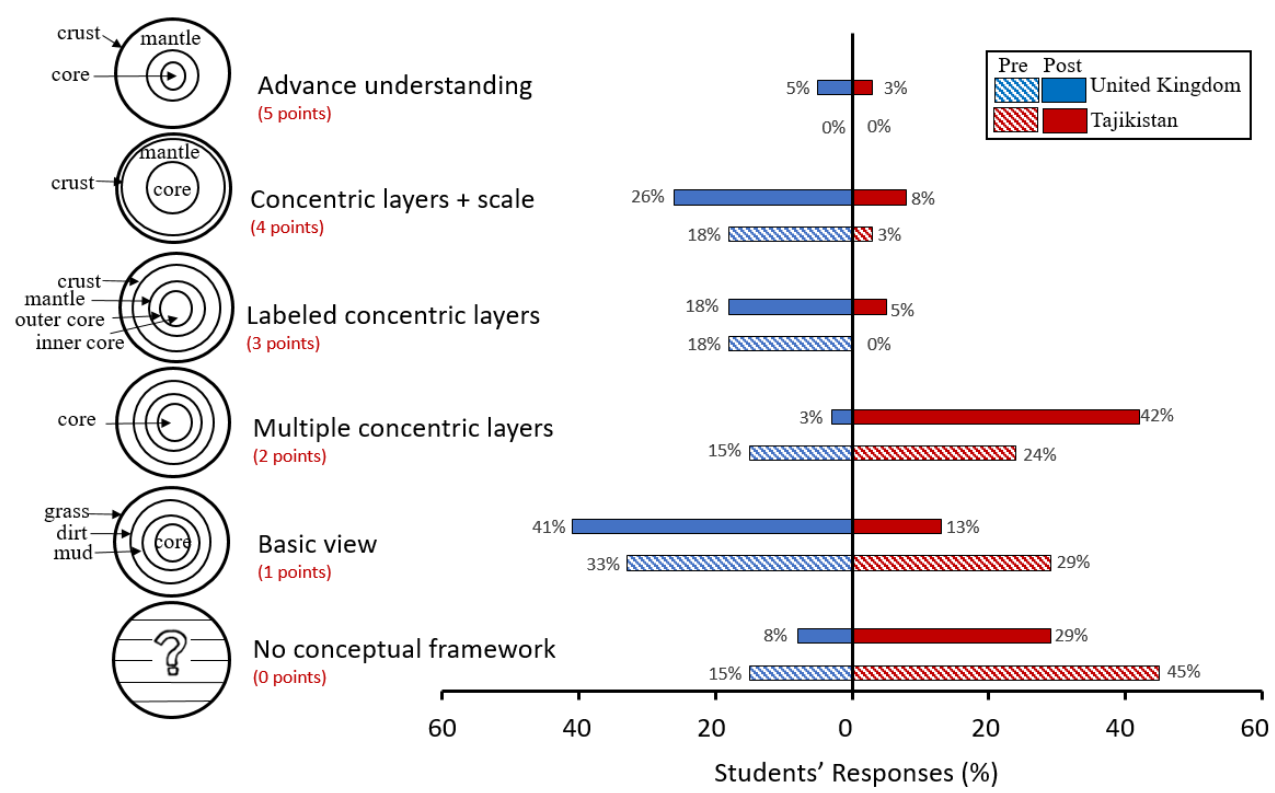
Figure 4: Students' understanding of Earth's interior (right) when asked to sketch a cross section of the Earth, evaluation rubric after
675 **Steer et al., 2005 (left)**
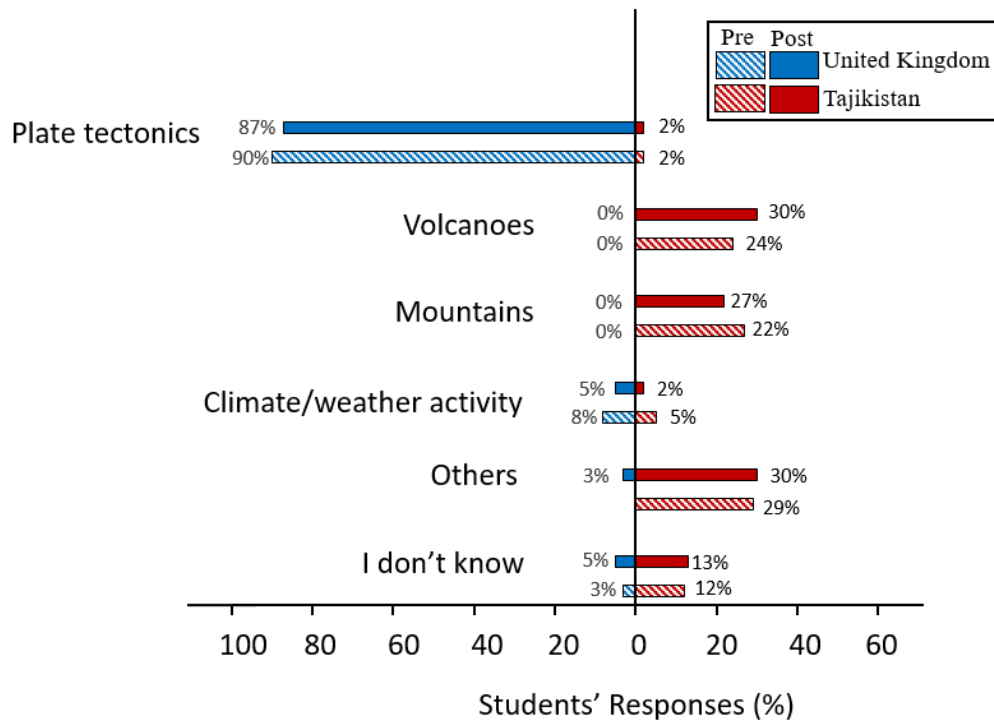
Figure 5: Causes of earthquake according to students.

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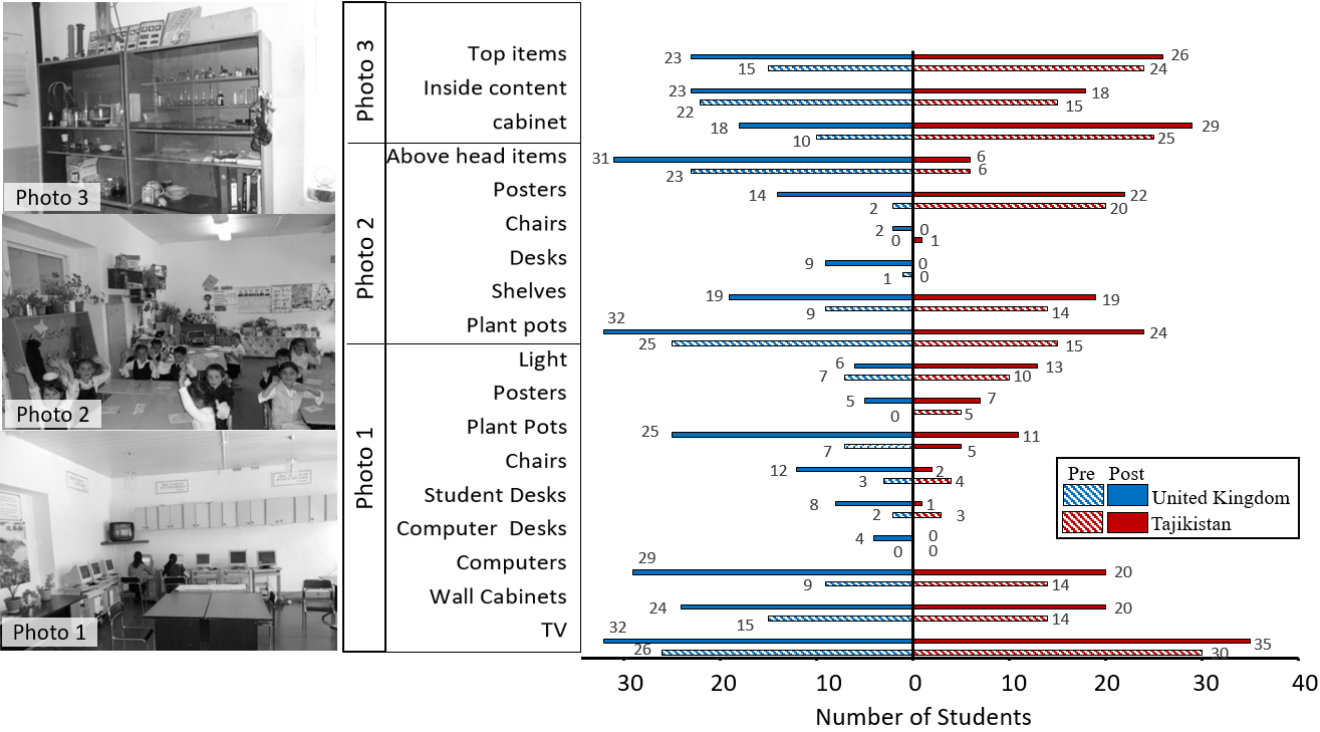
Figure 6: Students' understanding of non-structural hazards. (from left to right) Photographs used in questionnaires for non-structural hazard identification, items identified correctly as non-structural hazards, and pre-/post-assessment results. Photo credit: AKDN/DRMI, 2011 (www.akdn.org).

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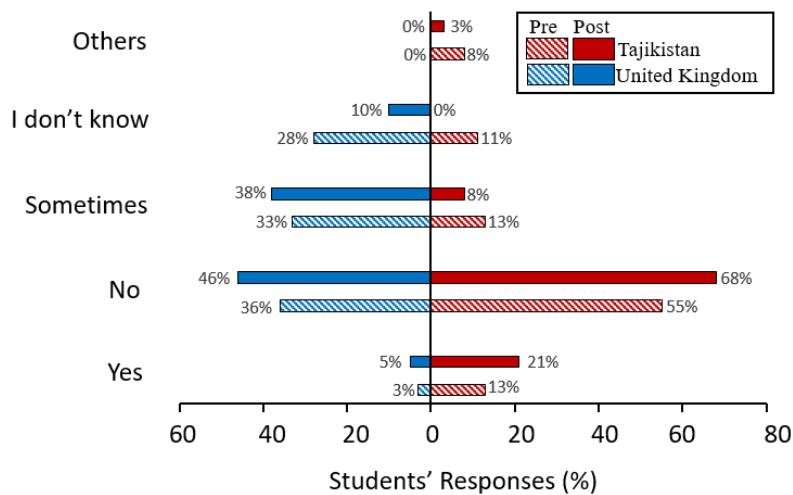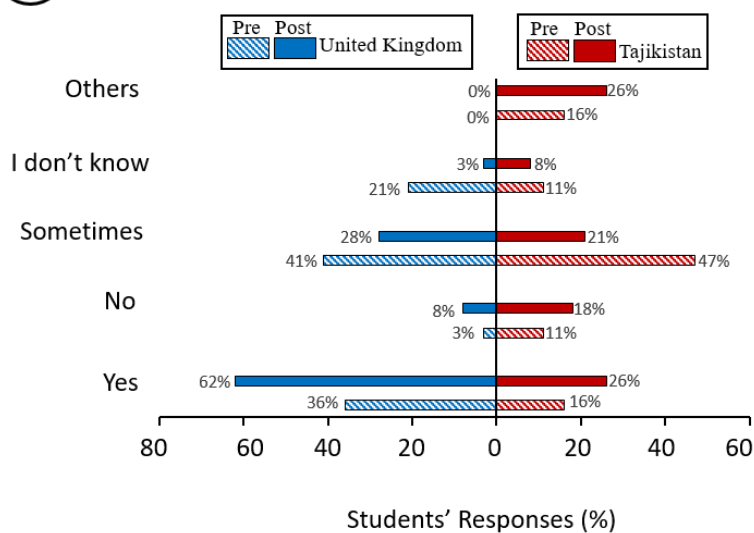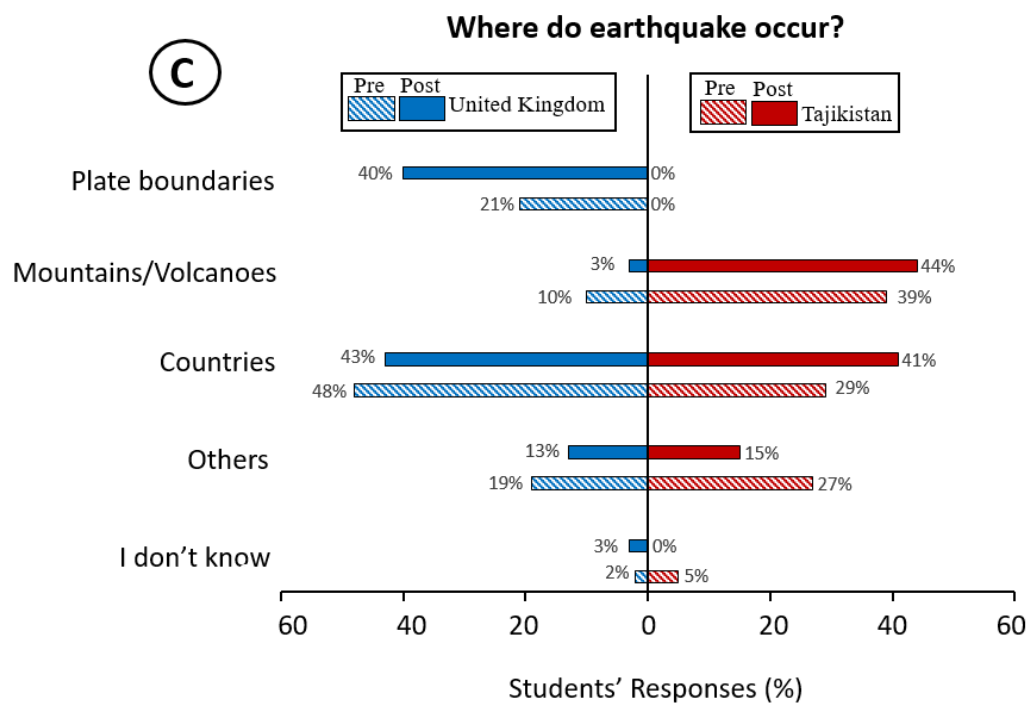
Figure 7: Students' understanding of earthquake prediction including earthquake timing (a), location (b) and where in the world earthquake occur most often (c).

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Title	Teaching approach	Topics covered	Main classroom activities	DOI & video length
Journey to the center of the Earth: Earth's interior and plate tectonics	Conceptual model, interactive lecture demonstrations, use of analogies and other visualize aids	Earth's internal layers, methods for investigating Earth's interior including seismic waves	Using an hard-boiled egg as a scale model for the layers of the Earth; using Slinky toys to model seismic waves; discussing model limitations	https://doi.org/10.5446/47600 16 min
Living on the edge: Discovering plate boundaries	Cooperative learning (jigsaws), role playing, and data-driven exercises	Linking plate boundary processes to scientific observations, and the scientific method	Using data maps (e.g., earthquakes, volcanoes, seafloor age, topography) to investigate plate tectonic boundary processes	https://doi.org/10.5446/47601 24 min
Soft rocks and hard liquids: Properties of Earth materials	Interactive lecture demonstrations (using everyday objects)	Why and how materials deform; what controls deformation and energy transfer	Applying force to everyday objects, observing and identifying factors influencing their behavior	https://doi.org/10.5446/47700 13 min
Do you know your faults? Plate motions and faults	Use of models, teaching with visualizations (photos) and art	Causes and types of plate tectonic stress and resulting strain, mechanics of fault rupture	Using a dough to model Earth's crust under stress, building different fault models using pieces of cardboard	https://doi.org/10.5446/47701 14 min
What causes that Rock'n'Roll? The Earthquake machine	Classroom experiments (building and operating models)	Earthquake mechanisms, stick-slip motion, and earthquake prediction	Operating a mechanical model of a fault to observe fault motion during an earthquake, exploring the effects of several variables, and discussing model limitations	https://doi.org/10.5446/47702 12 min
Rocking, rolling and bouncing: How do earthquakes move the Earth?	Interactive hands-on demonstrations, use of models and animations	Waves as energy transfer, seismic waves and how they travel through different materials	Using a setup to show how seismic waves can travel through different materials, modeling seismic waves using Slinky toys and human bodies (human waves)	https://doi.org/10.5446/47703 21 min
Flow with the sand: Introduction to soil liquefaction	Classroom experiments, use of models and visualizations	Soil saturation and consolidation, causes of soil liquefaction and mitigation measures	Building a liquefaction model and using a shake table to test its response to shaking	https://doi.org/10.5446/47704 13 min
Safe or unsafe: Nonstructural hazards during earthquakes	Place-based learning and role playing	Nonstructural hazards identification and mitigation, rapid visual screening method, repair cost analysis	Identifying nonstructural hazards in school classrooms and discussing and proposing mitigation strategies	https://doi.org/10.5446/47705 20 min
On shaky ground: Structural hazards during earthquakes (Part I)	Classroom experiments	Introduction to shake table; how different materials respond to different loads	Constructing building models and testing them on a shake table, discussing model limitations	https://doi.org/10.5446/47706 13 min
On shaky ground: Structural hazards during earthquakes (Part II)	Classroom experiements, group discussions	Earthquake engineering of buildings, frequency, natural frequency and resonance	Constructing and testing building models on a shake table, modifying them to reduce resonance, and discussing model limitations	https://doi.org/10.5446/47707 16 min

Table 1. Summary of the teaching approaches, topics covered, and classroom activities for each video including video duration and its digital object identifier (doi).