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Geoeducation as a novelty strategy for inclusive teaching of natural hazards in primary and secondary educational institutions

Geoeducación como una estrategia innovadora para la enseñanza inclusiva de riesgos naturales en instituciones educativas de primaria y secundaria

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Abstract

Geoeducation emerges as a pivotal strategy for inclusive instruction on natural hazards in primary and secondary educational institutions. This approach aims to expand comprehension of geological sciences across diverse audiences, seamlessly integrating them into environmental conservation education programs. The collaboration among educational institutions, universities, and local communities is imperative for the success of this initiative. It's crucial for educational authorities to acknowledge the significance of geological sciences and support their gradual integration into curricula, ensuring that students are equipped with a comprehensive understanding of geological phenomena and their implications. The primary objective of this initiative is twofold: firstly, to provide direct support to educators for effective knowledge transfer, empowering them with resources and strategies to engage students in meaningful learning experiences related to geoscience; secondly, to advise decision-makers on the vital role of geoscience in daily life, advocating for the inclusion of geoscience education in educational policies and initiatives. Additionally, this initiative endeavors to furnish a diverse array of activities and materials, ranging from interactive workshops to multimedia resources, to cater to the varied learning styles and preferences of students. These resources are designed to facilitate hands-on exploration and inquiry-based learning, fostering a deeper understanding of relevant geoscientific topics such as geological hazards, earthquakes, volcanic eruptions, geomorphological hazards, and floods. By offering comprehensive support and resources, this initiative aims to empower educators and inspire students to become informed and proactive citizens capable of understanding and addressing the complex challenges posed by natural hazards.

Keywords**:** Santander; geoeducation; school curriculum; geosciences; natural hazards.

Resumen

La geoeducación emerge como una estrategia fundamental para la enseñanza inclusiva de los riesgos naturales en instituciones educativas primarias y secundarias. Este enfoque tiene como objetivo ampliar la comprensión de las ciencias geológicas entre audiencias diversas, integrándolas de manera fluida en programas educativos de conservación del medio ambiente. La colaboración entre instituciones educativas, universidades y comunidades locales es imperativa para el éxito de esta iniciativa. Es crucial que las autoridades educativas reconozcan la importancia de las ciencias geológicas y apoyen su integración gradual en los planes de estudio, asegurando que los estudiantes estén equipados con una comprensión integral de los fenómenos geológicos y sus implicaciones. El objetivo principal de esta iniciativa es doble: en primer lugar, proporcionar apoyo directo a los educadores para la transferencia efectiva de conocimientos, dotándolos de recursos y estrategias para involucrar a los estudiantes en experiencias de aprendizaje significativas relacionadas con las ciencias geológicas; en segundo lugar, asesorar a los tomadores de decisiones sobre el papel vital de las ciencias geológicas en la vida cotidiana, abogando por la inclusión de la educación geocientífica en las políticas e iniciativas educativas. Además, esta iniciativa se esfuerza por proporcionar una amplia gama de actividades y materiales, que van desde talleres interactivos hasta recursos multimedia, para satisfacer los diversos estilos y preferencias de aprendizaje de los estudiantes. Estos recursos están diseñados para facilitar la exploración práctica y el aprendizaje basado en la investigación, fomentando una comprensión más profunda de temas geocientíficos relevantes como riesgos geológicos, terremotos, erupciones volcánicas, peligros geomorfológicos e inundaciones.

Palabras clave**:** Santander; geoeducación; plan de estudios escolar; ciencias de la Tierra; riesgos naturales.

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1. Introduction

Earth sciences (geosciences) allow us to understand the natural phenomena that have contributed not only to the evolution of our planet but also to life, and their study is focused not only on the rational use of natural resources but also on studying the causes that originate natural phenomena that affect humans and their impact on nature. It is considered that currently Geology is one of the main factors that most influence human development, and more specifically determines, and it is believed that it will continue to do so in the future, determining the evolution of our society [1]. In the closing session of the VII International Geological Congress held in St. Petersburg (Russia) in 1897, at the initiative of the French paleontologist A.G. Godri, it was decided that the governments of all countries that had participated in the event should be suggested to introduce the teaching of geology in basic education schools. Almost ninety years later, Dr. U.G. Cordani, then president of the International Union of Geological Sciences, in the opening ceremony of the 28th International Geological Congress held in Washington (United States), noted: "It is our responsibility to reintroduce earth science curricula into educational programs, preferably in secondary schools, where students are taught about the environment and the serious problems it faces". National Geographic has adopted the term "Geoeducation" to describe education about our world, providing students with a global understanding of how to work at the local, regional, and global scales. In a world where science advances by leaps and bounds, we all need to use scientific information to participate in decision-making and make them the most accurate [2]. In the current modernization and diverse societies, Geoeducation plays an important role in integrating local communities for the improvement of their quality of life, providing them with social equity [3]. The Geoeducation Center in the city of Kielce (Poland) acts as an initiator and coordinator of many cyclical or occasional events that promote the geological resources of the Świętokrzyskie Province. Gosselin [4] integrates geosciences into undergraduate education related to the environment, society, and sustainability. Recently, scientists and educators have shown interest in the development of Geoeducation [5-6]. Therefore, the global panorama of Geoeducation in general has changed according to the priorities of each nation, advances in science and technology, and progress in scientific education, among other aspects [7]. The educational system should be given priority attention in the training of people with critical and creative skills in today's world, because it is necessary to make education more attractive, especially by giving students the opportunity to engage in meaningful and current activities and/or respond to the challenges and difficulties faced by the current world. In order to ensure the transfer of scientific knowledge, it is important to disseminate information about the teaching of geosciences in local communities, which should be more effective in formal settings [7]. Most geoscience professionals consider knowledge, experience, and guidance to be vital for addressing many of the most acute environmental challenges facing society, however, few of these professionals are directly involved in sustainable development [8]. To effectively reach out, it is necessary to "contextualize science" by generating explicit relationships between the content being taught and everyday situations [2], starting from a real problem that affects the community, which will be analyzed and conclusions will be drawn. Biernacki et al. [9] developed the "Geo-Education Methodology" project within the European Erasmus program, whose main objective was to exchange good practices and experiences in outdoor geo-education. According to Mohamed et al. [5], there is a big gap between educational and scientific systems. Similarly, geo-education describes learning experiences both inside and outside of school where students learn about how the world works, which is essential for maintaining our economic competitiveness, protecting our national security, preserving our natural resources, and preserving the quality of life in local communities. Place-based education is designed to use the space or physical location that the recipient experiences and is connected to, is interdisciplinary and intercultural, and is informed and contextualized by the natural, cultural, and socioeconomic attributes of the place [10]. This type of instruction tends to motivate through social, humanistic, and scientific engagement with the surrounding environment, which leads to the promotion of community and local ecosystem sustainability [11]. According to the above, it is necessary to specify that geosciences are fundamental and should be implemented in the education systems in Colombia. However, due to the socio-economic problems of the country, local communities have no idea about their importance. Therefore, it is necessary to take care of the geological heritage, as well as to strengthen the links with the rest of the heritage values, both natural and cultural, promoting citizen empowerment and responsible public use. A better understanding of geosciences and their field of action contributes to the awareness of Geoconservation of great importance to ensure the protection of our planet. On the other hand, geosciences in the Colombian territory have focused on the fields of exploration and exploitation of oil and gas, development of geological maps at the local and regional scales, exploration, exploitation, and beneficiation of mineral and metallic deposits, exploration and exploitation of water resources, research in their different areas of action with the generation and transfer of basic and applied knowledge and social projection. For this reason, it is categorical to question why Geoeducation is important today. The answer is often influenced by local environmental and socioeconomic conditions. Experiencing and understanding different natural phenomena in the environment tends to develop a personal and emotional connection with the world. The above is important in the face of the challenges of creating awareness of the changes that occur in society and its natural environment as part of global change. The concept of Geoeducation is not known in Colombia because geosciences have not been given importance. In the same line, it is also necessary to specify that geological heritage

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and geodiversity are other inextricable components when carrying out a Geoeducation process.

According to Carcavilla-Urquí et al. [12], Geological Heritage is the set of geological natural resources of scientific, cultural, and/or educational value, such as geological formations and structures, landforms, minerals, rocks, meteorites, fossils, soils, and other geological manifestations that allow us to understand, study, and interpret the origin and evolution of the Earth, the processes that have shaped it, past and present climates and landscapes, and the origin and evolution of life. Geological heritage, through adequate management, can become an important piece of the social and economic well-being of a territory; its use as a center of interest for teaching, tourism, or scientific research can contribute, on occasion, very effectively to the economic dynamization of its areas of influence [13]. Similarly, Geodiversity refers to the variety of geological elements, including rocks, minerals, fossils, soils, landforms, geological formations and units, and landscapes present in a territory that are the product and record of the evolution of the Earth [12]. These two concepts are of fundamental importance because without them, geoconservation policies may be limited to short-term government management [14]. Geological heritage and geodiversity are sometimes subject to threats that can generate irreversible damage or loss if they are not properly identified and managed. The most important threats are: agro-industrial exploitation; installation of infrastructures and urbanization; location of landfills and dumps; dredging, excavation, and extractive activities; sports practices; rock, mineral, and fossil collection; and installation of tourist infrastructures. Therefore, in order for knowledge of Earth sciences to advance, it will be necessary to conserve geological heritage and geodiversity, and for future generations to be able to make use of them. According to Carcavilla-Urquí et al. [12], Geological Heritage is the set of natural geological resources with scientific, cultural, and/or educational value, including geological formations and structures, landforms, minerals, rocks, meteorites, fossils, soils, and other geological features that allow us to understand, study, and interpret the origin and evolution of the Earth, the processes that have shaped it, past and present climates and landscapes, and the origin and evolution of life. Through adequate management, geological heritage can become an important element of the social and economic well-being of a territory; its use as a focus for teaching, tourism or scientific research can contribute, on occasion, very effectively to the economic revitalization of its areas of influence [13]. Similarly, Geodiversity refers to the variety of geological elements, including rocks, minerals, fossils, soils, landforms, geological formations and units, and landscapes present in a territory that are the product and record of the evolution of the Earth [12]. These two concepts are of fundamental importance, as without them, geoconservation policies can be limited to government management without a long-term perspective [14].

Thus, there is a wide range of groups that benefit from geoconservation: researchers in Earth sciences; professionals in the industries that exploit geological resources and managers of the natural environment; landowners, soil managers, public services, and authorities responsible for planning; universities and educational institutions; associations and groups interested in geology; the general public; communities within places of interest for geological tourism. Therefore, geoconservation is defined as the set of techniques and measures aimed at maintaining the conservation (including rehabilitation) of geological heritage and geodiversity, based on the analysis of their intrinsic values, vulnerability, and the risk of degradation. However, these initiatives should be part of broader conservation strategies: conservation of the environment, natural resources, habitats, and living species, etc., and as such, integrated and considered on equal terms when conservation plans or programs are addressed [13]. Geoconservation not only aims to prevent the destruction of the geological element but also to prevent, correct, or minimize possible damage to which they may be exposed; to maintain the natural rhythm of active geological and geomorphological processes; and finally, to protect the cultural, aesthetic, and landscape values related to geological elements. However, geoconservation actions must be supported by public legislation in the field of nature conservation and land use planning [15].

Dingwall [16] states that long-term conservation of geologically significant elements is more effective when done in legally protected areas. However, there are few laws directly referring to the conservation of geological heritage. Geological features are often implicitly referred to as natural features and landscapes. Geoconservation and geoconservationism should be a developing philosophy and practice that pervades both social sectors and professional media of Earth sciences, as well as media committed to nature conservation [13]. Therefore, promoting the establishment of geoparks is conserving the Earth's heritage, educating the public, and promoting socio-economically sustainable development of local communities [17]. The philosophy underpinning the concept of geoparks and sustainable development geopolitics [18] can be traced back to the origins of the 1st International Conference on Geological Heritage in Digne (France) in 1991 [19]. This pioneering event not only marked a milestone in the understanding and appreciation of geological heritage but also laid the foundation for the subsequent evolution of geoparks as powerful tools for conservation, education, and sustainable development worldwide. The connection between the vision behind geoparks and the ideals of sustainable development geopolitics originates from this historic gathering, where the importance of protecting and responsibly utilizing our geological environment was clearly articulated. In Colombia, the country is recognized worldwide for its natural and cultural richness, much of which is unknown despite having made progress in its National System of Protected Areas [20]. Therefore, it is essential to adopt the necessary measures to establish an effective system of collective protection of national heritage. The Colombian Political Constitution of 1991 establishes the

shared responsibility between the State and the individual, as well as the obligation to protect Colombia's cultural and natural wealth. The Law 99 of 1993, in Article 1, establishes, among other aspects, that the country's biodiversity, as part of national heritage and of human interest, must be protected as a priority and used sustainably. Environmental protection and recovery of the country are a joint task of the State, community, non-governmental organizations, and the private sector. The National System of Protected Areas (SINAP) represents all the protected areas of public, private, and community governance that includes national, regional, and local management areas and different actors, strategies, and management tools to contribute to the country's conservation objectives [21]. Garavito [22] presents references to the natural and cultural heritage of Colombia and establishes two periods, before and after the Colombian Political Constitution of 1991, complementing with the inclusion of the peculiarities of national and local contexts in its definition and management. The Colombian Political Constitution of 1991 provides a constitutional and cultural heritage and recognizes the need for natural protection and environmental protection [23]. It also establishes the State's duty to protect the diversity and integrity of the environment [24]. Geoeducation is, in short, a strategy that contributes to the conservation of the territory and is considered the most effective way to ensure long-term preservation of the environment, providing a combination of understanding, attitudes, and skills.

2. Historical Overview (Geosciences in School Education)

The present initiative on geoeducation is the transfer of knowledge about the importance of geosciences in building citizenship in the school curriculum arose in early 2015 as a result of the absence of a specific discipline in the primary and secondary basic education and high school education curriculum in Colombia, with topics that are not developed in the classroom or are developed in a fragmented way in the curriculum, which not only makes it difficult to understand the importance of geosciences in our society but also the comprehension of the complex and dynamic Earth system. According to the Ministry of National Education, the standards aim for the generations being formed to not only accumulate knowledge but also to learn what is relevant to their lives and be able to apply it to solve new problems in everyday situations. In an increasingly complex, competitive, and changing environment, educating in science means contributing to the formation of citizens capable of reasoning, debating, contributing, coexisting, and developing their creative potential to the fullest. The Ministry of National Education has included geoscience concepts in the basic competence's standards in science; however, these concepts have been poorly articulated and disseminated due to various social, political, and economic factors. The work team aims to integrate academic knowledge and the daily reality of children from grades 1 to 11 through the design of pedagogical strategies for the development of various activities, such as games, drawings, clay modeling, scientific experiments, questionnaires, maps, models, geological collections, photographs, field trips, and visits to museums. The work proposal includes the development of activities with different groups of students, separated according to their ages (Grades 1-3, Grades 4-5, Grades 6-9, and Grades 10-11).

The project presents participants with the history and evolution of planet Earth, covering the basic concepts of Geosciences for the understanding of the world in its natural aspects, promoting reflection on the consequences of human actions on the environment, starting from a systematic and integrated vision of the natural processes and phenomena of the planet [25]. The scope of this initiative is to design strategies for the transfer of geoscientific knowledge and the formation of a generation capable of understanding how our planet works, the processes involved in that functioning, how it reached its current state along with the different ecosystems formed, and how human activity can be responsible for changes in terrestrial conditions at the local, regional, and global scales. To achieve this mission, the following specific objectives are proposed: Translate geosciences into language and learning opportunities that can be understood by students in primary and secondary education and in higher education; Narrow the gap between scientific knowledge and school knowledge in geosciences; Design and implement pedagogical resources for achieving learning according to the cognitive development stage of the students; Assist primary and secondary teachers in the challenge of making students aware of the importance of geosciences and their relevance to society; Motivate the implementation of geosciences in educational curricula. In this way, it is expected to promote greater awareness and understanding of the world and its phenomena in the community, as it is essential for the general community to understand the processes and relationships between society and nature, which must be grounded in primary and secondary schools and higher education. Therefore, this work is aimed at educating for participation, generating attitude changes, creating and strengthening social organizations, accompanying environmental projects and disaster prevention processes, promoting interdisciplinary work, developing research processes, and contributing to the dissemination of environmental rights and duties [26].

3. Materials and methods

Inclusive teaching of natural hazards in schools is crucial to prepare students for events that may occur in their environment. The educational methodology applied in this study follows a constructivist, experiential, and multidisciplinary approach, emphasizing active student engagement, observation, and experimentation. The approach combines didactic instruction, hands-on activities, and reflective exercises to facilitate understanding of natural phenomena, while ensuring accessibility for students of different abilities and learning styles.

3.1. Diagnosis

At the beginning of each workshop, an inquiry of prior knowledge, verbal description, and visual description will be carried out. This phase establishes a baseline understanding of students' knowledge and misconceptions about natural hazards and guides the subsequent design of activities.
Inquiry of prior knowledge: Students and teachers are consulted regarding their knowledge of natural hazards based on geosciences. The KPSI instrument (Knowledge and Prior Study Inventory) by Tamir and Lunetta [27] may be used to determine prior understanding and misconceptions. This instrument is applied before and after each phase to evaluate knowledge gains.
Verbal description: Characteristics and limits of each topic are explained by a geoscience professional using accessible terminology, real-life examples, and demonstrations.
Visual description: Diagrams, maps, videos, and models are used to illustrate geoscientific concepts that are otherwise difficult to observe due to scale, vegetation, or anthropogenic modifications.

3.2. Design of activities that involve all students

Activities are designed to ensure inclusivity and engagement across diverse abilities, learning stages, and ages, following the Piaget's stages of cognitive development.
Concrete operational stage: Students manipulate physical objects to understand concepts.
Pre-operational stage: Students begin to conceptualize simple ideas detached from objects.
Formal operational stage: Students engage with abstract concepts without the need for concrete manipulation.
Activities are clearly separated from expected learning outcomes, using videos, presentations, games, debates, and collaborative exercises to facilitate active participation while promoting critical thinking about natural hazards.

3.3. Use of accessible materials and experimentation

Accessible materials, visual aids, and hands-on experiments are used to promote understanding of complex natural processes. Examples include drawings, clay modeling, experiments, quizzes, maps, and photographs. Observation and experimentation are emphasized to allow students to directly interact with simplified representations of natural phenomena, such as earthquakes, volcanic eruptions, floods, tsunamis, and landslides. Technology, including videos and virtual tools, supports the learning process and enhances conceptual understanding. These activities are designed as methods rather than outcomes; they provide the framework for observing, manipulating, and analyzing phenomena, while actual comprehension and knowledge gains are measured separately through evaluation and feedback.

3.4. Adaptation of the teaching-learning process to individual needs

The teaching-learning process is flexibly adapted to individual students' needs, including those with physical or sensory disabilities. Group collaboration encourages peer learning and knowledge sharing, fostering inclusion and equitable participation.

3.5. Sensitization about natural threats

Students are engaged in cultural and contextual understanding of natural hazards, learning how local communities respond to risks. Emergency drills, simulations, and community participation are incorporated, ensuring accessibility and inclusivity. Students are encouraged to develop resilience, coping skills, and an understanding of both local and broader environmental implications.

3.6. Evaluation and feedback

A system of evaluation and feedback will be implemented to assess students' progress in learning about natural hazards and to evaluate the effectiveness of the proposed teaching methodology. This process will combine both formal and informal assessment strategies in order to capture different dimensions of the learning experience. Formal evaluation methods may include quizzes, short tests, or written exercises designed to measure students' understanding of key concepts related to geosciences and natural hazards. In addition, informal evaluation methods such as teacher observation, group discussions, and student reflections during the activities will help monitor participation, engagement, and collaborative learning processes. Together, these evaluation strategies provide a broader perspective on student learning, allowing educators to assess not only conceptual understanding but also the development of skills such as observation, critical thinking, and teamwork in the context of natural hazard education.

3.7. Methodological limitations of the approach

Although the workshops provide an experiential and multidisciplinary approach to teaching natural hazards, it is important to recognize several limitations associated with this methodology. Acknowledging these constraints helps clarify the scope of the activities and avoids overgeneralizing the results obtained from classroom simulations. First, the physical models and simplified experiments used in the workshops cannot fully reproduce the complexity of real natural phenomena. Simulations of volcanic eruptions, tsunamis, floods, or earthquakes rely on scaled-down models and simplified processes that only approximate natural dynamics. For example, reactions such as vinegar and baking soda used to simulate eruptions represent didactic approximations rather than the real geological processes involved. Additional limitations are related to cognitive and logistical factors. Students may focus on the visible effects of experiments rather than on the underlying processes or

broader socio-environmental implications. Moreover, the availability of materials, space, and supervision may influence the implementation and reproducibility of the activities in different educational contexts. Despite these limitations, the workshops remain a valuable pedagogical tool for introducing students to geosciences and raising awareness about natural hazards. To strengthen learning outcomes, these activities should ideally be complemented with theoretical instruction, analysis of real case studies, and, when possible, field-based experiences.

4. Educational workshops on natural hazards

This section describes a series of educational workshops designed to facilitate the transfer of geoscience knowledge to children and adolescents in educational institutions. The activities include games and simple experiments aimed at promoting understanding of natural phenomena such as earthquakes, volcanic eruptions, floods, tsunamis, and landslides, fostering an interactive teaching–learning process.

4.1. Workshop on ¿How does an earthquake occur?

Objective. To develop students' conceptual understanding of earthquake generation and its effects on the built environment, enabling them to interpret seismic phenomena and reflect on risk and preparedness.

Academic framework. The workshop is grounded in seismology and geophysics, integrating analytical, spatial, communicative, and collaborative learning processes. Students interpret tectonic plate interactions, fault mechanics, and seismic wave propagation through diagrams, discussion, and experimental modeling, while reflecting on the social and environmental implications of earthquakes. Resources: A tray (≈20×15×5 cm), sand, water, two small heavy objects (e.g., iron nuts), and a wooden or aluminum board (~10×10×0.3 cm).

Activity and analytical approach. Earthquakes are sudden ground motions produced by tectonic or volcanic disturbances that release accumulated stress along geological faults. In some regions of the Americas, minor seismic events are referred to as temblores, while stronger events are classified as earthquakes. Figures 1a–1b illustrate the real and schematic consequences of seismic events in urban environments. The experiment constructs a simplified physical model of seismic effects on water-saturated, unconsolidated soils. First, a thin sand layer is placed in the tray and partially covered with the board, which is then buried under additional sand. The sand is saturated with water, and two heavy objects are positioned on the surface to represent buildings founded on sandy ground (Fig. 1c). Seismic motion is simulated by horizontally moving the tray, as indicated in Fig. 1d. The resulting displacement and instability of the substrate may cause movement or collapse of the "structures" (Fig. 1e), illustrating how ground shaking can damage buildings constructed on poorly consolidated materials.

Academic significance. The experiment operates as a scaled conceptual model to analyze the interaction between seismic motion and local geological conditions. By observing the deformation of saturated sediments and the response of surface loads, students relate tectonic stress release and seismic wave propagation to potential structural damage in urban settlements. This analytical approach links theoretical seismology with real-world vulnerability, fostering scientific reasoning about seismic hazards and the dynamic nature of the Earth system.

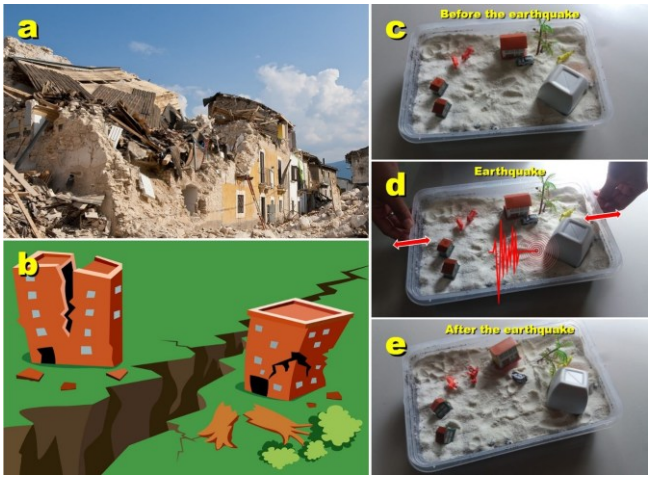


Figure 1. (a)-(b) Photograph and diagram of the consequences of an earthquake in urban settlements. (c) Model of the experiment before the simulation of the seismic movement. (d) Direction of movement (red arrows) to carry out the simulation of an earthquake. (e) Model of the experiment after the seismic movement, with the material damage that it could cause. Source: Authors.

4.2. Workshop on seismic waves

Objective. To introduce students to the fundamental principles of seismic waves and their scientific relevance for understanding earthquakes and assessing seismic hazards.

Academic framework. This workshop is based on seismology and geophysics, combining conceptual explanation, visual interpretation, and experimental modeling. Through diagrams, discussion, and physical simulation, students explore the propagation of seismic waves and their role in interpreting Earth's internal structure and seismic events. Resources: One or more slinky springs. Colored dots or stickers can be placed on some coils to make the motion of the spring easier to observe.

Activity and analytical approach. Earthquakes are sudden ground movements produced by the release of energy from the Earth's interior due to processes such as rock fracturing along faults, volcanic activity, or, less commonly, artificial explosions. Unlike other natural hazards, earthquakes cannot be predicted with precision. To introduce these concepts, audiovisual materials (short videos, images, and diagrams) can be used to illustrate seismic processes and global

examples. Students are encouraged to reflect on the observable effects of an earthquake by discussing hypothetical scenarios; for example, what they might observe through a window if a strong earthquake occurred in their surroundings. This reflection connects theoretical explanations with everyday experience and risk awareness. To link theory with practice, the activity illustrated in Fig. 2 is carried out. Figure 2a presents a schematic representation of an earthquake generated by a geological fault, highlighting the hypocenter (the point where energy is released) and the epicenter (the surface point directly above it). The experiment then models the main types of seismic waves using a slinky spring. P-waves, which propagate parallel to the direction of motion, are represented by compressing and releasing the spring. S-waves, characterized by motion perpendicular to the direction of propagation, are simulated by moving one end of the spring vertically. Surface waves are illustrated through horizontal and elliptical oscillations of the spring, representing L-waves and R-waves, respectively (Fig. 2b–2e).

Academic significance. The experiment functions as a simplified physical model that helps students visualize how seismic waves propagate through different media. By observing distinct motion patterns in the spring, students identify the mechanical differences between body waves (P and S) and surface waves. This approach facilitates the interpretation of seismic records and highlights how seismologists use wave behavior to locate earthquakes and infer the structure of the Earth's interior. Consequently, the workshop links theoretical concepts with practical visualization, strengthening students' understanding of seismic processes and their relevance for hazard assessment and community preparedness.

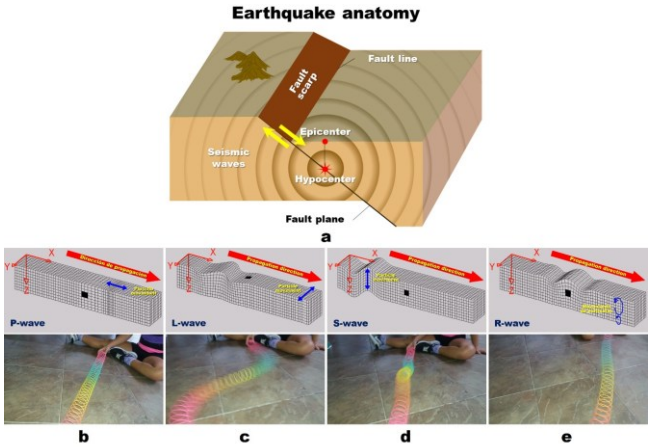


Figure 2. (a) Anatomy of an earthquake. (b)-(e) Main components of seismic waves: P-wave, which moves in the direction of propagation, L-wave which moves at 90° to the direction of propagation, S-wave which moves at 90° to the direction of propagation, and R-wave which moves in an oval path. Source: Authors.

4.3. Workshop on ¿how to build an earthquake resistant structure?

Objective. To provide students with a clear conceptual understanding of the hypocenter and epicenter of earthquakes and to analyze how seismic intensity and distance from the epicenter influence structural damage.

Academic framework. This activity integrates principles from seismology, geophysics, civil engineering, and materials science, combining conceptual explanation with experimental modeling. Through diagrams, discussion, and hands-on simulation, students explore the spatial relationship between hypocenter, epicenter, and seismic wave propagation, while examining their implications for structural vulnerability. Resources: Table, hammer, 10 × 10 cm board, cardboard sheet, markers, compass, dice or cubes, two books, rubber balls (≈2.54 cm diameter), rubber bands, toothpicks, plasticine, and scissors.

Activity and analytical approach. Following the introduction to basic seismological concepts, students construct a simplified experimental model to visualize the relationship between seismic energy release and surface damage. First, a series of concentric circles (8–10) is drawn using a compass to represent increasing distances from the epicenter (Fig. 3a). This sheet is aligned with another diagram showing the internal structure of an earthquake, ensuring that the epicenter corresponds to the smallest circle. The diagram is placed on a board positioned on a table (Fig. 3b). Small "buildings" are then constructed using dice or cubes and arranged around the epicenter at different radial distances. A light tap on the table with a hammer simulates seismic shaking originating from the epicentral location. The reaction of the structures is observed and recorded. The experiment is repeated with greater force and with different spatial arrangements of the buildings, including positions farther from the epicenter (Figs. 3c–3d). Students compare the structural response under varying shaking intensities and distances.

Academic significance. This experiment serves as a conceptual model illustrating how seismic energy released at the hypocenter propagates toward the surface, producing stronger effects near the epicenter. By observing variations in structural stability across different distances and shaking intensities, students analyze the relationship between seismic magnitude, energy attenuation, and structural vulnerability. The activity also introduces fundamental ideas from earthquake engineering, highlighting how construction design and materials influence resilience to seismic forces. Therefore, the workshop links theoretical seismology with basic engineering principles, encouraging students to interpret earthquake effects critically and to reflect on the importance of earthquake-resistant construction for community safety.

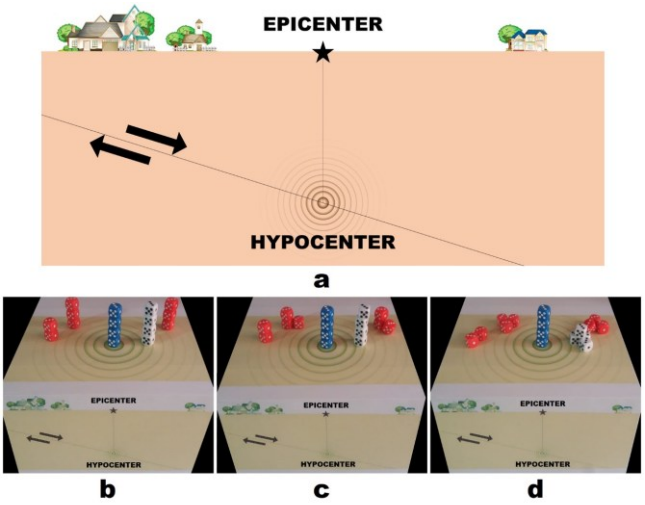


Figure 3. (a) General outline of an earthquake generated by a geological fault, with its respective hypocenter and epicenter. (b) Initial model of the experiment, with representations of buildings around the epicenter. (c)-(d) Different variations and arrangements of the buildings around the epicenter. Source: Authors.

Objective. To enable students to observe and represent the behavior of L surface waves during seismic events and to analyze their effects on surface structures.

Academic framework. The workshop integrates concepts from seismology, geophysics, civil engineering, and materials science, combining conceptual explanation with experimental modeling. Through physical simulation and observation, students examine how surface waves propagate and how their horizontal motion can affect built structures. Resources: Four rubber balls, two large rubber bands, cubes or dice, and two thin rigid surfaces.

Activity and analytical approach. The activity begins with a brief explanation of L surface waves and their propagation along the Earth's surface. After gathering the required materials (Fig. 4a), the two rigid surfaces are joined with rubber bands (Fig. 4b). Four rubber balls are then placed between the surfaces at the corners to act as flexible supports (Fig. 4c). Small cubes or dice are positioned on the upper surface to represent buildings or houses (Fig. 4d). To simulate seismic motion, the upper surface is moved horizontally from side to side (Fig. 4e). This movement represents the lateral displacement characteristic of L surface waves. The response of the structures placed on the surface is then observed (Fig. 4f), illustrating how horizontal ground motion can destabilize or damage buildings during an earthquake. Following the experiment, students discuss earthquake preparedness by reflecting on appropriate actions before, during, and after seismic events, linking the physical behavior of surface waves with real-world risk management and safety measures.

Academic significance. The experiment functions as a simplified model of surface-wave propagation, allowing students to visualize how lateral seismic motion interacts with structures at the ground surface. By observing structural responses to simulated horizontal displacement, students relate wave mechanics to potential damage in urban environments. This approach reinforces understanding of the role of surface waves in earthquake impacts and highlights the importance of structural design and preparedness strategies for reducing seismic risk.

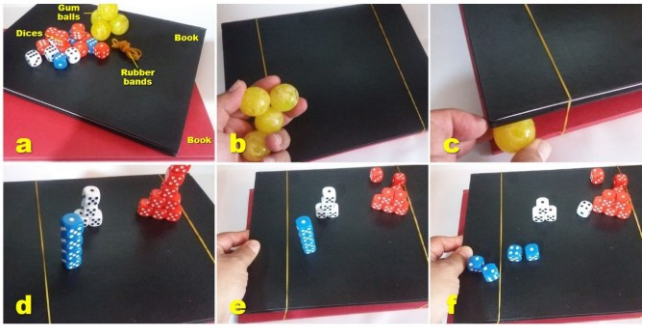


Figure 4. (a) The necessary materials for this experiment. (b) Advisable way to join the two surfaces with rubber bands. (c) Positions in which the rubber balls should be placed between the two surfaces. (d) Arrangement of cubes or dice on the upper surface. (e)-(f) Final result of the force applied in the previous step. Source: Authors.

4.4. Workshop on volcanic eruptions

Objective. To provide students with a conceptual understanding of volcanic eruptions, including their causes, processes, and environmental impacts, while promoting awareness of volcanic hazards and associated risks for nearby communities.

Academic framework. The workshop draws on volcanology, volcanic geology, physical geography, environmental sciences, and risk communication, integrating conceptual learning with experimental simulation. Through visual resources, discussion, and hands-on modeling, students examine volcanic structures, eruptive processes, and their implications for environmental and societal safety. Resources: Brush, brown/green/red/yellow/white vinyl paint, plastic tray, cardboard base, glue, adhesive tape, newspaper or toilet paper, plastic or aluminum bottle, sodium bicarbonate (or Alka-Seltzer), liquid soap, vinegar, water, red dye, and protective glasses.

Activity and analytical approach. The activity begins with an introduction to basic volcanological concepts using audiovisual materials, diagrams, and discussions addressing questions such as the parts of a volcano, the nature of lava, and the types of materials emitted during eruptions. Well-known volcanoes around the world may also be presented to contextualize the phenomenon. Students then construct a simplified volcano model (Fig. 5a–5d). A bottle is fixed on a cardboard base and covered with newspaper or paper pieces attached with glue to form a conical volcanic structure. After drying, the model is painted to represent the volcanic edifice. To simulate the eruption, baking soda, liquid soap, and vinegar are introduced into the bottle (Figs. 5e–5f). The chemical reaction between acetic acid and sodium bicarbonate produces carbon dioxide, generating foam that rises and flows down the sides of the volcano (Figs. 5g–5h).

Red dye may be added to visually represent lava flow. This process allows students to observe a visible analogue of eruptive activity, where pressurized gas drives the expulsion of material from the volcanic conduit. Following the simulation, students analyze the observed behavior and discuss questions related to volcanic hazards; for example, how nearby settlements could be affected by lava flows or more explosive eruptions.

Academic significance. Although simplified, the experiment functions as an analog model of volcanic eruption dynamics, illustrating how gas generation and pressure buildup can lead to the expulsion of material from a volcanic system. By relating the model to real volcanic processes, students develop a clearer understanding of eruption mechanisms and their potential environmental and societal consequences. The workshop also encourages reflection on volcanic risk, highlighting the importance of scientific monitoring, preparedness, and informed land-use planning in volcanic regions.

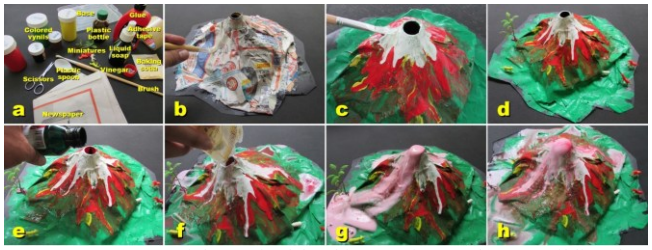


Figure 5. (a) Materials required for this experiment. (b)-(c) Building the volcanic cone. (d) Structure of the finished volcano. (e)-(f) Moments when vinegar and baking soda are introduced into the volcano's crater, respectively. (g)-(h) Eruption process of the volcano. Source: Authors.

4.5. Workshop on floods

Objective. To develop students' understanding of flood processes, their causes and impacts, and the strategies that can reduce vulnerability and improve preparedness in flood-prone areas.

Academic framework. This workshop integrates concepts from hydrology, meteorology, geology, and civil engineering, combining conceptual explanation with experimental modeling. Through visual representations and practical simulation, students analyze how river dynamics, terrain characteristics, and intense rainfall can generate flooding and affect nearby settlements. Resources: A physical model representing an urban center located near a river, constructed with materials such as cardboard, sand, clay, and water.

Activity and analytical approach. The activity begins with an introduction to the concept of floods, defined as the temporary occupation by water of areas that are normally dry due to processes such as river overflow, intense rainfall, snowmelt, storm surges, or other hydrometeorological events. Audiovisual materials and real-world examples are used to illustrate how floods occur and how they can affect urban and rural environments. Students then analyze schematic flood models representing urban environments (Figs. 6a–6d) and rural environments (Figs. 6e–6h). In the rural model, a channel with an approximate slope of 15° (Fig. 6e) is constructed and partially filled with sand and clay to simulate river sediments and floodplains (Fig. 6f). Water is gradually poured into the channel to represent increasing river discharge (Fig. 6g). As the flow intensifies, the channel begins to overflow, eroding sediment deposits and flooding the surrounding areas (Fig. 6h). Small structures placed on the model represent houses or infrastructure that may be affected by rising water levels. Through observation of the model, students analyze how increased discharge leads to river overflow, sediment erosion, and floodplain inundation, illustrating the physical processes that occur during real flood events.

Academic significance. The model functions as an analog representation of river flooding, enabling students to visualize interactions between water flow, sediment transport, and human settlements. By comparing the effects of flooding in different spatial configurations, students evaluate how land use, terrain, and proximity to rivers influence vulnerability. This analytical approach encourages critical reflection on flood risk management, including preventive measures such as appropriate land-use planning, watershed management, and infrastructure design. Ultimately, the workshop links hydrological processes with social and environmental impacts, fostering awareness of flood hazards and the importance of preparedness and mitigation strategies.



Figure 6. (a)-(d) Flood modeling process in urban areas. (e)-(h) Flood modeling process in rural areas: (e) Suggested model for making the mockup. (f) Schematic model of the urban center next to the river. (g) Beginning of the flooding of the model. The current flow is illustrated by blue dotted lines. (h) Erosion and flooding caused by the water flow increase. The eroded areas are signaled by yellow dotted lines. Source: Authors.

4.6. Workshop on tsunamis

Objective. To develop students' understanding of tsunami generation, propagation, and coastal impacts, while promoting awareness of preparedness and risk mitigation strategies in coastal environments.

Academic framework. This workshop integrates concepts from seismology, oceanography, meteorology, geology, civil engineering, environmental sciences, and disaster risk management. Through conceptual explanation and experimental simulation, students analyze the mechanisms that generate tsunamis and the processes that control their

propagation and coastal impact. Resources: A glass or plastic container, gravel, sand, cardboard or plastic houses, water, and a stirrer or spatula.

Activity and analytical approach. The activity begins with an introduction to tsunamis using audiovisual resources and discussions addressing their principal causes, including submarine earthquakes, volcanic eruptions, underwater landslides, glacier collapses, and meteorite impacts. Students examine how large vertical displacements of water generate waves that travel long distances across the ocean and intensify as they approach coastal areas. To visualize these processes, a simplified coastal model is constructed by placing sand and gravel inside a container to represent a shoreline and seabed (Fig. 7a). Water is then added to simulate the ocean, and the initial configuration of the model is observed (Fig. 7b). A spatula or stirrer is used to displace the water toward the coast, generating waves that propagate across the model basin. As the disturbance increases, the wave height and thickness change, producing a progressive invasion of the coastal zone (Figs. 7c–7d). The experiment may be repeated with stronger agitation to exaggerate the effect and analyze variations in wave magnitude and coastal inundation (Fig. 8a–8d). Students are then encouraged to reflect on the observed behavior of the waves, discussing how changes in the intensity of the disturbance influence wave size and the extent of coastal flooding.

Academic significance. This experiment serves as an analog model of tsunami generation and coastal inundation, illustrating how sudden water displacement can produce waves that increase in height when approaching the shoreline. By observing the interaction between waves and coastal settlements represented in the model, students analyze the vulnerability of coastal environments to tsunami hazards. The activity also promotes discussion of early warning signs, evacuation procedures, and risk management strategies, linking physical oceanographic processes with disaster preparedness and community resilience.

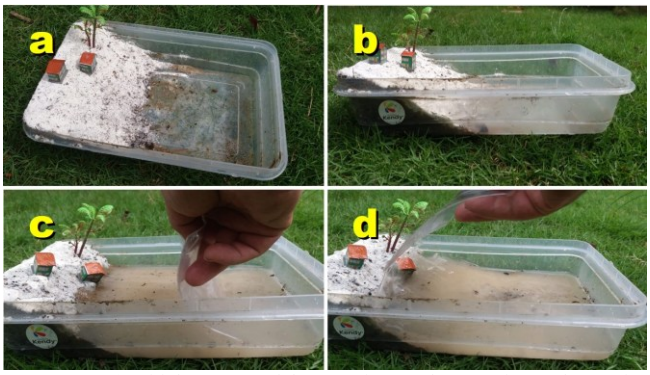


Figure 7. (a) Initial moment of the experiment. (b) Experimental setup in profile view. (c) First wave generated due to the agitation of the spatula that begins to invade the beach. (d) Moment when the wave surpasses the beach. Source: Authors.

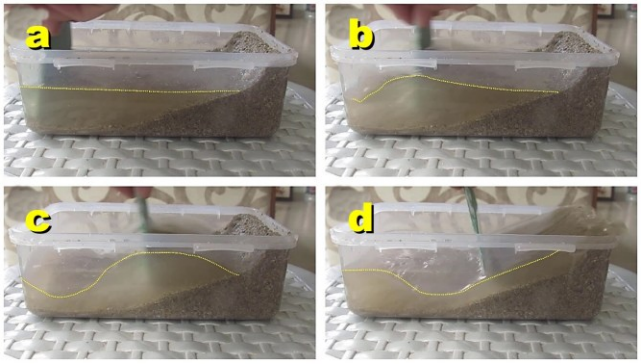


Figure 8. (a) Initial moment of the experiment. (b) Moment when the first wave is generated due to the agitation of the spatula. (c) Instant when the wave is about to reach the beach. (d) Moment when the wave surpasses the beach. Source: Authors.

4.7. Workshop on sea level rise

Objective. To develop students' understanding of sea level rise, its underlying causes, and its potential impacts on coastal environments and human settlements, while promoting reflection on adaptation and mitigation strategies.

Academic framework. This workshop integrates concepts from oceanography, climatology, geology, civil engineering, environmental sciences, and socio-economic studies, linking climate change processes with coastal dynamics and risk management. Through conceptual discussion and experimental modeling, students explore how global warming contributes to rising sea levels and increasing coastal vulnerability. Resources: A glass or plastic container, gravel, sand, cardboard or plastic houses, water, and ice cubes (approximately three).

Activity and analytical approach. The activity begins with a discussion on the relationship between global warming and sea level rise, including processes such as glacier and polar ice melt and the thermal expansion of seawater. Audiovisual materials and real-world examples are used to illustrate how these processes contribute to changes in ocean levels and coastal environments. To visualize these processes, a simplified coastal model is constructed by placing sand and gravel inside a container to simulate a beach or shoreline (Fig. 9a). Water is then added to represent the ocean. Ice cubes are dropped from a height of approximately 15 cm into the water, representing the sudden introduction of meltwater from glaciers or ice masses. When the ice impacts the water, it generates a wave that propagates toward the simulated coastline (Fig. 9b). The progression of the wave across the coastal slope is then observed (Fig. 9c) until the maximum inland advance is reached (Fig. 9d). Students analyze the behavior of the generated waves and discuss how additional water input can influence coastal dynamics and flooding potential.

Academic significance. The experiment functions as a conceptual model illustrating the interaction between added water volume and coastal wave dynamics. Although simplified, it allows students to visualize how increased water input and associated wave activity may affect coastal

zones. By connecting the model with real-world processes such as glacier melting and climate-driven sea level rise, students examine the potential impacts on coastal ecosystems, infrastructure, and communities. The workshop therefore encourages critical reflection on climate change, coastal management, and adaptation strategies aimed at reducing future environmental and socio-economic risks.

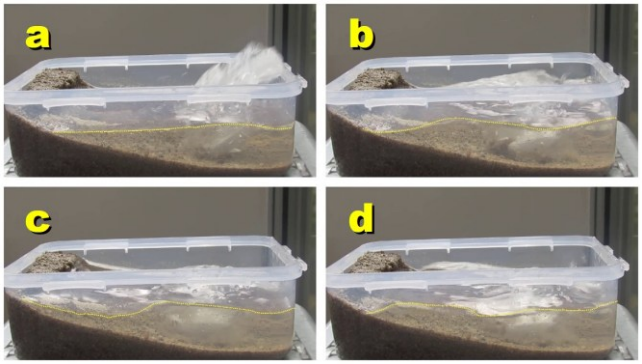


Figure 9. (a) Initial moment of the experiment, when the ice comes into contact with the water. (b) The first wave generated by the falling ice. (c) Shows the progression of the wave from the previous image. (d) The maximum advance of the wave on the beach. Source: Authors.

4.8. Workshop on landslides

Objective. To develop students' understanding of landslides, their triggering factors, environmental impacts, and strategies for prevention and risk mitigation in vulnerable areas.

Academic framework. This workshop integrates concepts from geomorphology, soil science, geology, geotechnical engineering, hydrology, meteorology, environmental sciences, and social sciences. Through conceptual discussion and experimental simulation, students analyze slope stability, erosion processes, and the influence of vegetation on terrain stability. Resources: Two plastic boxes, soil materials (earth, sand, gravel), newspaper, cardboard or plastic houses, plastic trees, grass, a watering can, and water.

Activity and analytical approach. The activity begins with an introduction to landslides as a type of mass movement occurring when a slope becomes unstable and soil or rock masses move downslope along a failure surface. Audiovisual resources and supporting materials are used to explain key concepts such as slope gradient, slope stability, and the role of vegetation in erosion control. Two experimental slope models are then constructed using plastic boxes filled with soil, sand, and gravel, forming slopes of approximately 30° (Figs. 10a–10b). In the first model, only limited vegetation is placed on the slope, while the second model is covered with abundant artificial trees and grass to simulate dense vegetation cover. Small houses are positioned on the upper parts of both slopes to represent settlements (Figs. 10c–10d). Students are first asked to predict which slope is more susceptible to erosion and instability. To simulate intense rainfall, water is poured over both models using a watering can. As the water infiltrates and flows across the slopes, students observe the different responses of the two systems (Figs. 10g–10h). The model with sparse vegetation typically shows stronger erosion and soil displacement, while the vegetated slope remains comparatively more stable.

Academic significance. The experiment functions as an analog model of slope instability and erosion, illustrating how rainfall and vegetation cover influence landslide susceptibility. By comparing the behavior of the two slopes, students analyze the role of root systems and vegetation in stabilizing soil and reducing mass movement. This activity connects geomorphological processes with environmental management and land-use practices, encouraging reflection on the consequences of deforestation and unsustainable development. Ultimately, the workshop promotes critical understanding of landslide hazards and highlights the importance of ecosystem conservation and responsible territorial planning in reducing disaster risk.



Figure 10. (a)-(b) Sloping terrains with two different contexts regarding vegetation cover on the ground. (c)-(d) Experimental setup during the summer season. (e)-(f) Experimental setup during the winter season. (g)-(h) Final result after intense rainfall. Source: Authors.

4.8. Workshop on school risk management plan for natural hazards

Objective. To provide students with the knowledge, skills, and strategies necessary to develop and implement effective school risk management plans for various natural hazards, enhancing preparedness and safety within educational institutions.

Academic framework. This workshop draws on disaster science, emergency management, geography, engineering, education, psychology, sociology, and public policy. Students analyze risk assessments, hazard maps, and response strategies, integrating theoretical knowledge with practical applications such as evacuation planning, emergency kits, and safety drills. The workshop emphasizes interdisciplinary learning, combining environmental, social, and engineering perspectives on natural hazards. Resources: Infographics on school risk management plans, instruction sheets, paper, colors, pencils, and other materials for creating hazard models.

Activity and analytical approach. The activity begins with a discussion of school responsibilities in risk management, structured around three phases: (1) risk prevention and management, (2) crisis and emergency response, and (3) post-emergency actions (Fig. 11). Students first review different types of natural hazards (earthquakes, floods, landslides, tsunamis, volcanic eruptions, and hurricanes) through audiovisual resources and discussions. Students are divided into small groups, each assigned a specific hazard. They research the hazard, take notes, and construct a physical or diagrammatic model demonstrating its potential effects on a school. Groups present their models to the class, followed by discussion on mitigation strategies, evacuation procedures, and communication protocols. Practical exercises include organizing emergency kits, identifying safe zones, planning evacuation routes, and simulating emergency responses. Students reflect on what actions should be taken before, during, and after a disaster, applying knowledge to realistic scenarios.

Academic significance. The workshop provides a hands-on understanding of school risk management, integrating theoretical frameworks with practical preparedness strategies. Students learn to assess vulnerabilities, plan responses, and implement mitigation measures. By engaging with models and simulations, they develop critical thinking, teamwork, and problem-solving skills. The activity emphasizes the importance of community participation, interdisciplinary knowledge, and proactive safety planning, fostering a culture of resilience within the school environment.

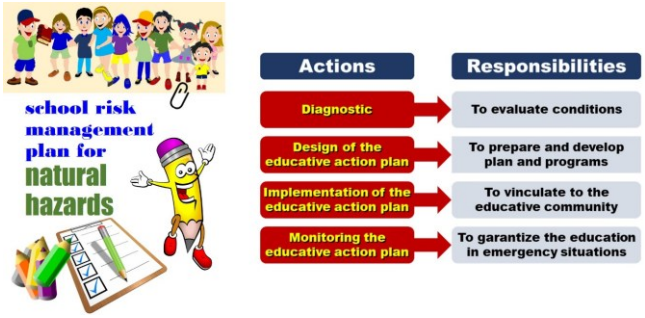


Figure 11. Left, School risk management plan for natural hazards. Right, Risk prevention and management: actions and responsibilities. Source: Authors.

5. Considerations and limitations of the experimental approach

Although the workshops provide a comprehensive, practical, and multidisciplinary learning experience, it is important to recognize that the approach has inherent limitations. While hands-on experiments and model-based simulations allow students to engage directly with natural phenomena, observe their dynamics, and develop a foundational understanding, these activities cannot fully capture the complexity, scale, and unpredictability of real-world events. Additionally, the effectiveness of the workshops depends on available resources, teacher guidance, and the students' prior knowledge, which may vary across educational contexts. Therefore, while the workshops serve as a valuable starting point for exploring natural hazards and fostering risk awareness, it is essential to consider these limitations when interpreting the results and drawing conclusions from the activities.

5.1. Methodological and experimental limitations

The physical models and simplified experiments (such as plastic volcanoes, L-wave simulations with surfaces and cubes, or flood models) do not fully reproduce the complexity of natural phenomena. For example, the propagation of a real tsunami or the dynamics of an earthquake involve physical variables that cannot be fully captured in a laboratory setting. The scales and magnitudes used in the experiments are necessarily reduced, limiting the ability to extrapolate results to real-world situations. Some chemical or mechanical reactions used to simulate phenomena (such as vinegar and baking soda for volcanic eruptions) are educational approximations and do not reflect the true physics and chemistry of geological processes.

5.2. Cognitive and comprehension limitations

The hands-on approach may emphasize observation and manipulation over deep understanding of underlying processes, potentially leaving gaps in conceptualizing complex phenomena such as seismic wave behavior or flood dynamics in urban ecosystems. Students may focus on the immediate effects of experiments while overlooking more complex contextual variables, such as socioeconomic factors, urban infrastructure, or the ecological impact of natural disasters.

5.3. Logistical and resource limitations

The availability of materials and adequate spaces can restrict participation and the quality of experiments. For instance, modeling floods, tsunamis, or landslides requires space, materials, and supervision that may not always be available in every educational environment. The reproducibility of experiments depends on the precision of material preparation and teacher guidance, which can generate variability in the observed results.

5.4. Contextual and safety limitations.

Simulations cannot replicate the real impacts of a disaster and therefore do not substitute for field experiences or professional training in risk management. Some workshops involve minor risks (such as handling liquids, vinegar, baking soda, or moving masses) that require strict supervision to prevent accidents. Reflections and discussions on the human and social effects of disasters depend on the students' cultural

and geographic context; transferring knowledge to other communities may be limited.

The experimental and multidisciplinary approach of the workshops provides a valuable educational framework for awareness, observation, and initial understanding of natural phenomena. However, the limitations mentioned suggest that these activities should be complemented with more detailed theoretical studies, real case analyses, field visits, and the integration of social, environmental, and economic factors to provide a more comprehensive and realistic training in natural hazard management and disaster resilience.

6. Conclusions

The present initiative led by the Basic and Applied Geology Research Group (GIGBA) of the Industrial University of Santander underscores the vital role of geoeducation in disseminating geoscience knowledge to wider audiences. This endeavor offers an expansive perspective on education for nature conservation and advocates for the integration of geosciences within the educational strategies of primary and secondary schools, universities, and local communities. The significance of geosciences in addressing societal needs is crucial, prompting the involvement of experts from the Ministry of National Education and curriculum developers to gradually incorporate geoscience concepts into the academic curriculum.

The project's scope extends beyond academia, aspiring to equip primary and secondary school teachers with the tools to effectively convey geological knowledge and to advise decision-makers and citizens on the relevance of geosciences in everyday life. By facilitating activities and materials designed for educational projects, such as addressing geological risks, earthquakes, volcanic eruptions, and other geomorphological hazards, the initiative seeks to bridge the gap between complex Earth systems and the comprehension of students.

The integration of geosciences into education is pivotal, not only for fostering a rational understanding of natural resources but also for comprehending the origins of natural phenomena that impact humanity and the environment. Geology's influential role in human development and societal evolution positions it as a pivotal factor that necessitates comprehensive inclusion within educational curricula. The initiative's dedication to geoeducation emerged from a recognized absence of focused geoscience education in Colombian curricula, resulting in fragmented and insufficient coverage of geological topics. This deficiency hinders the grasp of geosciences' importance, as well as the understanding of Earth's intricate dynamics.

Aligned with contemporary educational principles that prioritize relevant and applicable learning, the initiative aims to nurture critical thinking, problem-solving skills, and creative potential in students. To accomplish this, a diverse array of pedagogical strategies encompassing interactive workshops, games, experiments, and real-world examples will be employed. Inclusivity stands as a central tenet, catering to diverse learning styles and cognitive developmental stages.

The initiative's holistic approach includes sensitizing students to diverse cultural responses to natural threats, engaging parents and communities, and promoting resilience through awareness and coping skills. The fusion of accessible materials, technological aids, and hands-on experimentation enriches the learning experience, while the commitment to continuous updates and teacher training ensures the program's ongoing relevance and effectiveness.

To assess progress and facilitate growth, a comprehensive evaluation system encompassing formal assessments and ongoing feedback mechanisms will be implemented. In summary, the work undertaken by the GIGBA team exemplifies the transformative potential of geoeducation, reshaping how geoscience knowledge is conveyed, understood, and embraced.

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