

A low-cost earthquake simulator for early-years science education: A hands-on approach to teaching seismic concepts in kindergarten and primary school

Dimitrios Korakas¹ , Nikolaos Kyriazis² , Georgios Stylos^{2*} , Konstantinos T. Kotsis² 

¹ Science Education Advisor, Directorate of Secondary Education of Ioannina, GREECE

² Department of Primary Education, University of Ioannina, Ioannina, GREECE

*Corresponding Author: gstylos@uoi.gr

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ABSTRACT

Children growing up in seismically active regions such as Greece are routinely exposed to earthquakes from an early age, yet age-appropriate, classroom-ready resources for introducing seismological concepts in kindergarten and early primary years remain scarce. This paper describes the design, construction and classroom use of a simple, low-cost experimental earthquake simulator intended for children aged approximately four to eight years. The device is a qualitative classroom analogy rather than as a physically exact reproduction of seismic-wave propagation or ground-motion dynamics. The device is assembled from a paper box, a cardboard platform suspended on rubber bands, wooden building blocks and an optional 1.5 V DC motor with an eccentric cam, at a total material cost of approximately 5.50 to 20 euros, and it is embedded within a structured inquiry sequence consisting of introduction, prediction, trial, observation and discussion phases. Classroom implementation in kindergarten and early primary settings in the Region of Epirus, Greece, suggests that children in the target age range engage strongly with the device and can begin to reason, in age-appropriate language, about the relationship between distance from the epicentre, qualitative intensity of shaking and the stability of model structures. These observations are exploratory and should not be interpreted as formal evidence of measured learning gains. The device provides conceptual scaffolding for the school-based earthquake-preparedness programmes already operating in Greek schools and offers a transferable model for early-childhood disaster risk reduction education in other seismically active regions. Systematic evaluation of children's learning outcomes through a multi-site, instrument-based study is identified as the priority for follow-up work.

Keywords: earthquake education, early childhood science education, hands-on learning, inquiry-based learning, low-cost laboratory equipment

INTRODUCTION

Over the past two decades, the volume of scientific information that young learners are expected to engage with has grown rapidly. Natural science has come to occupy an increasingly central role in early-childhood and primary curricula across Europe and worldwide (Aksa, 2022). Familiarising preschool and primary-school children with natural phenomena from an early age is widely held to support the gradual development of a scientific habit of mind, which in turn provides a foundation for the more formal experimental work that follows in secondary and tertiary education. Within this broader curricular movement, geosciences, and Seismology in particular, occupy a special place for children growing up in seismically active regions, since the phenomena under study are part of their everyday experience and, on occasion, a source of acute personal and community risk.

The case for introducing earthquakes early in a child's education has been strengthened in recent years by international policy frameworks. The Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations Office for Disaster Risk Reduction [UNDRR], 2015) explicitly identifies education as a priority area for reducing exposure and vulnerability to natural hazards, and subsequent reviews have underscored that schools are among the most consequential entry points for disaster risk reduction (DRR) in the wider community (Mutch, 2026). Recent research further indicates that children are not merely passive recipients of disaster information but active agents whose preparedness, cognitive, behavioural and emotional, can be cultivated from the earliest years of formal schooling (Raccanello et al., 2023). Yet despite this consensus, age-appropriate, classroom-ready resources for introducing seismic concepts to the 4–8 age band remain comparatively scarce, and much of the published literature continues to focus on secondary or upper-primary pupils rather than on the early years (Aksa, 2022).

Greece offers a particularly compelling setting for early earthquake education. The country lies close to the convergent boundary between the Eurasian and African lithospheric plates, and as a consequence experiences more seismic events each year than the rest of Europe combined, ranking among the six most earthquake-prone countries in the world (Moshou, 2024). Although the great majority of these events take place offshore and pass without consequence, the destructive earthquakes that have struck the country in recent decades, and the comparable events that have occurred across the wider Mediterranean, have repeatedly demonstrated that a poor public understanding of seismic risk substantially erodes the effectiveness of antiseismic measures (Saraò et al., 2014). In this context, the development of curricula and classroom resources that allow children to acquire elementary knowledge about earthquakes, seismic safety and the reduction of seismic risk is a matter of practical, not merely academic, importance.

A growing body of work in science education suggests that the most effective approach to this task at the early-years level is one grounded in active, inquiry-based experimentation rather than in didactic transmission. Inquiry-based learning, in which children formulate questions, manipulate variables and draw evidence-based conclusions, has been shown to produce more durable conceptual understanding of natural-hazard phenomena than traditional lecture-based instruction (Aksa, 2022). Hands-on engagement with a physical model also supports the development of process skills and helps children to perceive the connections between science, technology and society from an early age (Korakas, 2020). The use of simple homemade apparatus has also been shown to be effective in physics education because it allows learners to approach basic concepts through direct observation, manipulation and qualitative experimentation (Stylos & Kotsis, 2021). For these reasons, an extensive international literature has emerged around the use of small-scale shake tables, low-cost seismic networks and similar educational analogues in the seismology classroom (Berenguer et al., 2020; Böse et al., 2026; Mendoza et al., 2008; Savasci, 2011; Subedi et al., 2020), and similar approaches have been adopted in DRR programmes more broadly (Raccanello et al., 2020). However, most of the devices reported in this literature are either designed for older students, or rely on equipment and budgets that place them out of reach of the typical kindergarten or primary-school teacher, particularly in publicly funded schools.

Existing educational approaches to seismology range from school-based seismic networks and technologically supported programmes to small-scale earthquake simulators intended primarily for older primary, secondary or university students (Berenguer et al., 2020; Mendoza et al., 2008; Savasci, 2011). The present simulator differs from these approaches in four principal respects. First, it is designed specifically for children aged approximately four to eight years. Second, it can be assembled from familiar classroom materials at an estimated cost of approximately €5.50–9.50 for the manually operated version and €12–20 for the motorised version. Third, it is embedded within a short, developmentally appropriate pedagogical sequence involving introduction, prediction, controlled trial, observation and discussion. Fourth, its conceptual scope is deliberately qualitative and limited to ideas accessible to young children, including relative distance from the epicentre, observable shaking effects, structural stability and reinforcement. The contribution of the device therefore lies not in reproducing earthquake dynamics with engineering accuracy but in integrating a low-cost physical model with a guided early-years inquiry sequence.

The present paper addresses this gap by describing the design, construction and classroom use of a simple, low-cost experimental earthquake simulator suitable for use with children aged approximately 4–8 years. The simulator should be understood as a qualitative classroom analogy rather than as a physically scaled analogy of earthquake ground motion. It does not reproduce seismic-wave propagation, ground acceleration, site amplification, resonance or the dynamic response of real buildings. Accordingly, the concentric circles on the platform are used only as schematic teaching aids for distinguishing relative positions on the analogy and should not be interpreted as isoseismal lines or as a physical representation of the attenuation of earthquake shaking with distance. Built from everyday materials, a paper box, cardboard, rubber bands, toy bricks and an optional 1.5 V electric motor, the device allows young learners to investigate, through guided experimentation, selected factors related to earthquake effects, including distance from the epicentre, the qualitative intensity of ground shaking, the height of a model structure and the use of reinforcement. In doing so, it introduces the concepts of focus, epicentre, intensity and structural resistance in a manner adapted to the cognitive level of the preoperational and early concrete-operational stages of development. The paper should therefore be read as a practice-oriented educational innovation article. Its purpose is to present a reproducible classroom apparatus, explain its pedagogical rationale and report qualitative observations from classroom use. It does not claim to provide a formal experimental evaluation of learning outcomes, and the observations reported are intended to guide future systematic research using structured assessment instruments. More specifically, the article has three aims: first, to describe the construction of a low-cost earthquake simulator that can be reproduced in ordinary kindergarten and primary-school classrooms; second, to present a guided inquiry sequence through which young children can explore basic seismic concepts in an age-appropriate way; and third, to report exploratory classroom observations that may inform future systematic research on early-years earthquake education.

THEORETICAL AND EDUCATIONAL BACKGROUND

The pedagogical case for introducing earthquakes, and indeed any natural-science phenomenon, to children of preschool and early primary age rests on a body of developmental and educational theory that has accumulated steadily since the second half of the twentieth century. The foundational reference point remains Piaget's account of cognitive development, and in particular his characterisation of the *preoperational stage*, which spans roughly the ages of two to seven years and corresponds closely to the age range targeted by the present study (Feldman, 2017). At this stage, children's reasoning is still largely intuitive: they think symbolically and can represent objects and events that are not immediately present, but their judgements tend to centre on a single salient dimension at a time, they have difficulty reversing operations mentally, and their explanations of natural phenomena are often animistic or transductive rather than logical. These limitations have, in earlier generations of educational thinking, been

read as reasons to postpone formal science teaching; the contemporary reading, however, is closer to the opposite. As Feldman (2017) notes, the preoperational years are not a period of cognitive idleness but a phase of extraordinary curiosity, during which children are constantly searching for explanations and behaving, in their own terms, as confident experts on the topics that interest them. The pedagogical task is therefore not to wait until logical thought matures, but to provide concrete experiences through which intuitive thinking can develop the regularities that will underpin later, more elaborate reasoning.

This task is most coherently framed within the constructivist tradition that Piaget himself helped to establish. Constructivism holds that knowledge is not transmitted from teacher to learner but built up by the learner through active engagement with the physical and social world, and that this construction proceeds most effectively when the learner is given opportunities to manipulate objects, formulate predictions and revise expectations in light of observable outcomes. In the early years, the implications of this position are well established: young children learn science most durably through hands-on, play-based and inquiry-driven activities that are matched to their developmental level (Trundle & Saçkes, 2015). Evidence from kindergarten science education also indicates that STEM-based teaching interventions can support young children's engagement with physical-science concepts when activities are concrete, exploratory and developmentally appropriate (Samara & Kotsis, 2023). Recent large-scale evidence has further shown that early and sustained engagement with science in kindergarten is a significant predictor of children's later science achievement in the elementary grades, even after controlling for socio-economic and cognitive variables (Saçkes et al., 2011). The implication is that early-childhood science is not simply enrichment but a foundational investment in scientific literacy, and that the quality of children's first experimental experiences shapes the trajectory of their subsequent engagement with the discipline.

A particular strand of this constructivist tradition that bears directly on the design of the present device is inquiry-based learning. In an inquiry-based approach, children encounter a phenomenon, formulate questions about it, manipulate variables, gather evidence and draw conclusions, with the teacher acting as a facilitator rather than as a source of authoritative knowledge. The successful use of such an approach also depends on teachers' positive attitudes towards experimentation in physics teaching, since experimental activities require teachers to organise materials, guide observation and support pupils' interpretation of evidence (Vlachos et al., 2024). This emphasis is also consistent with research showing that scientific inquiry is regarded as an important component of primary science education and of pre-service teachers' preparation for classroom practice (Stylos et al., 2023). Empirical studies in early-years and primary-school contexts have consistently shown that inquiry-based methods produce stronger conceptual gains, more positive attitudes towards science and more robust development of process skills than didactic instruction (Samarapungavan et al., 2008). In this context, experiments are particularly significant because they allow pupils to observe phenomena directly, test predictions and construct scientific meaning through evidence-based reasoning (Kotsis, 2024). In the specific context of natural hazards, Aksa (2022) has argued that inquiry-based learning is particularly well suited to teaching about phenomena such as earthquakes, floods and landslides, since it allows learners to engage with the causal mechanisms of these phenomena rather than memorising surface facts about them, and to develop the kind of evidence-based reasoning that underpins effective preparedness behaviour. A simple, manipulable physical model, such as the earthquake simulator described in this paper, offers a natural vehicle for this kind of inquiry, since it places the variables that govern earthquake damage (intensity of shaking, distance from epicentre, structural design) within the literal reach of young children.

A complementary dimension of the theoretical framework comes from the Science–Technology–Society (STS) tradition, which emphasises that scientific knowledge does not exist in isolation but is embedded in technological practice and in social decision-making about risk, safety and the built environment. From this perspective, an early-years engagement with earthquakes is not merely an exercise in geological literacy but an entry point into broader questions about how communities prepare for and respond to natural hazards, why some buildings are safer than others, and how scientific understanding informs everyday choices (Korakas, 2020). For children growing up in seismically active regions, these are not abstract questions; they are part of the lived environment, and an STS-informed approach helps children to see themselves as future participants in the collective response to seismic risk rather than as passive observers of an external phenomenon.

A further consideration that is increasingly recognised in the literature on disaster education concerns the affective dimension of children's engagement with hazards. Earthquakes are not emotionally neutral subject matter, particularly for children who have themselves experienced a significant seismic event or who live with the awareness that one is possible. Recent kindergarten-focused disaster-education work has also shown that innovative, age-appropriate approaches can help young children engage with disaster preparedness in ways that are meaningful, participatory and emotionally manageable (Pamaong & Shaw, 2025). Recent work has shown that disaster education for young children is most effective when it integrates cognitive, behavioural and emotional preparedness, and that hands-on, manipulable models can play a useful role in helping children to acquire a sense of agency over a phenomenon that is otherwise large, invisible and frightening (Huang et al., 2024; Raccanello et al., 2020, 2023). The simulator described in this paper is designed with this consideration in mind: by allowing children to *cause* the shaking themselves, to *predict* what will happen to a small wooden structure and to *observe* the consequences in a contained and reversible setting, the device offers a route to the kind of mastery experience that supports both conceptual learning and emotional resilience.

Taken together, these strands of theory, Piagetian developmentalism, constructivist pedagogy, inquiry-based learning, the STS perspective and the recent attention to emotional preparedness, converge on a clear set of design principles for an early-years earthquake-education resource. Such a resource should be concrete and manipulable rather than abstract; it should allow children to vary identifiable parameters and observe the consequences; it should be embedded within a guided inquiry sequence that elicits children's predictions and observations; it should connect scientific concepts to the technological and social practice of building safely; and it should give children a sense of agency over the phenomenon under study. The simple experimental device presented in the following sections has been designed to meet each of these criteria.

These theoretical perspectives informed specific features of the simulator and its classroom use. Its cardboard platform and manipulable wooden blocks translate Piagetian and constructivist principles into a concrete activity suited to children who reason primarily through direct action and observable outcomes. The concentric circles provide a simple visual representation of relative distance, while the prediction, trial, observation and discussion phases operationalise guided inquiry by encouraging children to express an expectation and reconsider it in light of the observed outcome. The comparison of different model structures connects scientific observation with technological design and community safety, reflecting the STS perspective. Finally, allowing children to initiate or control the shaking transforms a potentially frightening phenomenon into a contained and reversible classroom experience, supporting an age-appropriate sense of agency and emotional preparedness.

SEISMICITY AND EARTHQUAKE EDUCATION IN GREECE

Greece occupies one of the most tectonically active regions on Earth. The country lies above the convergent boundary along which the African lithospheric plate subducts beneath the Aegean and Anatolian microplates of the broader Eurasian plate, producing the arcuate structure known as the Hellenic Arc that extends from the Ionian Sea through the western Peloponnese and around Crete to the Dodecanese (Tsapanos, 2008). The geodynamics of the region are further complicated by the westward propagation of the North Anatolian Fault into the northern Aegean, by extensional deformation across the Aegean back-arc basin, and by the southward retreat ("rollback") of the subducting African slab, which together generate a complex pattern of normal, reverse and strike-slip faulting across mainland Greece, the Aegean islands and the surrounding seas (Meng et al., 2021; Moshou, 2024). The Hellenic Subduction Zone accommodates a convergence rate of approximately 4 cm per year, while the Anatolian plate moves southwestward into the Aegean at roughly 3 cm per year relative to Eurasia, making the broader Aegean one of the most rapidly deforming regions of continental lithosphere on the planet (Andinisari et al., 2021).

The seismic consequences of this tectonic setting are substantial. Greece releases approximately half of the annual seismic energy of Europe and ranks among the six most earthquake-prone countries worldwide (Tsapanos, 2008). Although the great majority of seismic events recorded each year are of low magnitude or occur offshore, where their consequences for the built environment are limited, the historical and recent record contains numerous destructive earthquakes that have caused significant loss of life and damage to infrastructure. The 1999 Athens earthquake, the 2017 Lesvos and Kos events, the 2020 Samos earthquake (Mw 7.0) on the Greece–Türkiye maritime border, and a sequence of damaging events in central Greece, Crete and the Ionian Islands during the early 2020s have all served as recurrent reminders that seismic risk in Greece is not a historical abstraction but a continuing feature of contemporary life (Papadimitriou et al., 2020). Each such event renews public attention to the question of how communities, and in particular, how schools, prepare for and respond to seismic hazards.

The Greek state has responded to this reality through a sustained programme of school-based earthquake preparedness, coordinated since the late 1980s by the Earthquake Planning and Protection Organization (EPPO, in Greek OASP). EPPO's educational activities include the publication of teaching materials for pupils, teachers and pupils with disabilities, the development of model school emergency plans, the requirement that schools conduct at least three earthquake drills per academic year, and the training of school principals and teachers in disaster preparedness (Kourou et al., 2025). Empirical assessments of the Greek programme suggest that, by international standards, awareness of earthquake risk and familiarity with response procedures among Greek teachers are comparatively high, and that the long-running EPPO campaign has made a measurable difference to school-level preparedness (Papavasileiou et al., 2022). At the same time, more recent surveys have found persistent gaps between awareness and behaviour: a substantial proportion of the Greek public reports being familiar with the standard prevention messages while simultaneously misunderstanding the recommended protective actions during an earthquake, a finding that points to the limits of awareness-raising in the absence of deeper conceptual understanding (Lekkas et al., 2021).

Within the formal curriculum, the position of earthquakes is more uneven. A recent content analysis of Greek geography curricula from 2003 to 2023 found that disaster risk reduction is integrated almost exclusively through the knowledge dimension, with a strong focus on geological hazards, earthquakes in particular, in Grades 5 and 6 of primary school, but with comparatively little attention to the action, participation and integration dimensions that international frameworks for disaster education identify as essential (Passadelli et al., 2024). At the same time, the recent Greek inquiry-based learning science curriculum for primary education places stronger emphasis on pupils' active investigation of natural phenomena, making low-cost experimental resources particularly relevant for classroom implementation (Kotsis et al., 2025). The curriculum, in other words, tells children what an earthquake is rather more readily than it engages them in reasoning about what they can do, how communities prepare and why certain measures work. Furthermore, while seismic content is reasonably well represented at the upper-primary level, its presence in kindergarten and the first two grades of primary school remains limited, despite the fact that children in these years are already capable of engaging with the underlying concepts when these are presented in age-appropriate, concrete and manipulable forms (Trundle & Saçkes, 2015).

It is precisely this gap, between high public attention to earthquake risk, a well-established but uneven curricular treatment, and a scarcity of resources adapted to the cognitive level of the youngest learners, that motivates the present work. In a country where every child will, at some point in their school career, take part in an earthquake drill, and in many cases will experience a felt earthquake before completing primary school, there is a strong case for introducing the underlying scientific concepts as early as the kindergarten year, in a form that is concrete, engaging and pedagogically sound. The remainder of this paper describes a simple, low-cost experimental device that has been designed and used with this aim in mind.

Table 1. Instruments and materials required for the assembly of one earthquake simulator

Instruments and materials	Quantity	Approximate cost (€)
Scissors	1	already available
Hole puncher	1	already available
Marker pen	1	0.50–1.00
Cardboard paper box (approx. 30 × 40 × 15 cm)	1	reused / no cost
Cardboard sheet (slightly smaller than box opening)	1	reused / no cost
Rubber bands	15	0.50–1.00
Adhesive tape (wide)	1 roll	1.00–2.00
Wooden building blocks (Jenga-type)	≈ 20	3.00–5.00
Thin wire (approx. 20 cm)	1 length	0.50
Small DC electric motor with eccentric cam (optional)	1	5.00–8.00
Battery, 1.5 V LR20 (D-cell) (optional)	1	1.50–2.50
Estimated total without motor		5.50–9.50
Estimated total with motor		12.00–20.00

Note. Costs are approximate and may vary according to local prices and the availability of reused classroom materials.

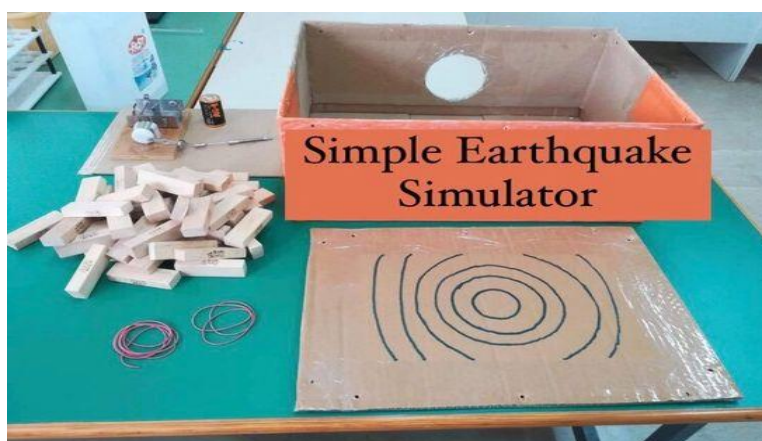


Figure 1. Materials used for the construction of the earthquake simulator, including the cardboard box, suspended platform, rubber bands, wooden blocks and optional motor unit (Source: Authors' own elaboration)

MATERIALS AND METHODS

Materials and instruments

The experimental device described in this study was designed to be assembled from inexpensive, widely available materials that can be sourced in any school setting and that pose no safety risk to young children. The complete list of materials and instruments required for one device is given in **Table 1**. With the exception of the optional electric motor, none of the items requires specialist supply, and the total material cost of a single device, based on retail prices in Greece in 2024–2025, does not exceed approximately ten to fifteen euros. Where the motor is used, the additional cost is of the order of five to eight euros for a small hobby DC motor and a single D-cell battery.

A photograph of all the materials laid out prior to assembly is shown in **Figure 1**. The cardboard sheet that will serve as the suspended “floor” is visible at the front of the image, with the concentric circles representing the epicentre and successive radial distances already drawn on its upper surface; the wooden blocks that will serve as model buildings are stacked to the left, together with the rubber bands, scissors and marker pen used during assembly. The optional motor unit, mounted on its own small plywood base and connected to a 1.5 V D-cell battery, is shown in the upper-left of the photograph.

Assembly Procedure

The device consists of a rigid outer box, a suspended inner platform that represents the ground surface, and a rubber-band suspension system that allows the platform to oscillate in response to an applied disturbance. The assembly procedure is straightforward and can be completed by a single adult, or by older primary pupils working under supervision, in approximately twenty to thirty minutes.

First, the upper flaps of the cardboard box are removed and a circular hole approximately ten centimetres in diameter is cut on the rear face of the box, large enough to allow an adult hand to pass through comfortably (**Figure 1**, right). This hole serves two purposes: it allows the device to be operated manually, by inserting a hand and shaking the suspended platform from below, and, when the motorised version is used, it allows the mechanical linkage from the external motor to pass into the interior of the box and couple to the underside of the platform.



Figure 2. Top view of the assembled simulator. The cardboard platform is suspended inside the paper box by rubber bands, allowing it to oscillate during the simulated earthquake (Source: Authors' own elaboration)



Figure 3. Assembled simulator showing the rear access hole and a three-block tower placed at the epicentre (Source: Authors' own elaboration)

Second, the concentric circles representing the surface point above the earthquake focus, that is, the epicentre, and successive radial distances from it are drawn on the upper face of the cardboard sheet that will serve as the suspended platform. In the device shown in **Figure 1** and **Figure 2**, five concentric circles have been drawn with a green permanent marker, with the innermost circle used as a symbolic representation of the epicentre and the outermost circles extending almost to the edges of the sheet. The exact number and spacing of the circles is not critical, but it is helpful for the subsequent inquiry sequence (Section 4.4) if at least three clearly distinguishable radial zones, near, intermediate and far from the epicentre, are visually identifiable. It should be emphasised that the concentric circles drawn on the cardboard platform serve only as schematic markers of radial distance from the centre of the model. They are not intended to represent isoseismal lines or to imply that all points located on the same circle experience equal shaking intensity. In real earthquakes, isoseismal lines are constructed from observed effects and damage and are generally irregular, because seismic intensity is influenced not only by distance from the epicentre but also by source characteristics, geological conditions, topography and the vulnerability of the built environment. The circles are therefore used solely as a visual and instructional aid that allows children to distinguish locations that are relatively nearer to or farther from the centre of the platform.

Third, holes are punched at the four corners and at the midpoints of the long edges of the cardboard platform, using a standard office hole puncher, and corresponding holes are punched on the inside upper edges of the box. The cardboard platform is then suspended inside the box by passing a rubber band through each pair of corresponding holes and securing it to the box. Eight rubber bands in total are used in the configuration shown in **Figure 2**; additional rubber bands may be added at the midpoints of the short edges if the platform sags excessively. A strip of adhesive tape may be placed over each hole on the cardboard platform before threading the rubber bands, to reinforce the cardboard and prevent the holes from tearing during repeated shaking.

Fourth, the device is checked for free movement of the suspended platform. When the platform is pressed gently and released, it should oscillate visibly for two or three cycles before damping out. If the platform is rigid or barely moves, the rubber bands are likely too short, too stiff or too tightly stretched, and they should be replaced with longer or more elastic bands, or the tension should be reduced. Conversely, if the platform sags so deeply that it touches the bottom of the box, the rubber bands are too long or too slack, and additional rubber bands should be added, doubled, or replaced with shorter ones.

Fifth, model buildings are constructed from the wooden blocks and placed on the platform. A range of configurations is used in the instructional sequence described in Section 4.4, single towers of varying height, multi-column structures with horizontal beams, simple two-storey "houses", and structures reinforced with the thin wire to model the role of reinforcement in real construction. **Figure 3** shows the simplest configuration, with a single three-block tower placed at the epicentre, while **Figure 4** shows a richer arrangement with multiple structures placed at different radial distances from the epicentre, allowing the role of distance to be investigated.

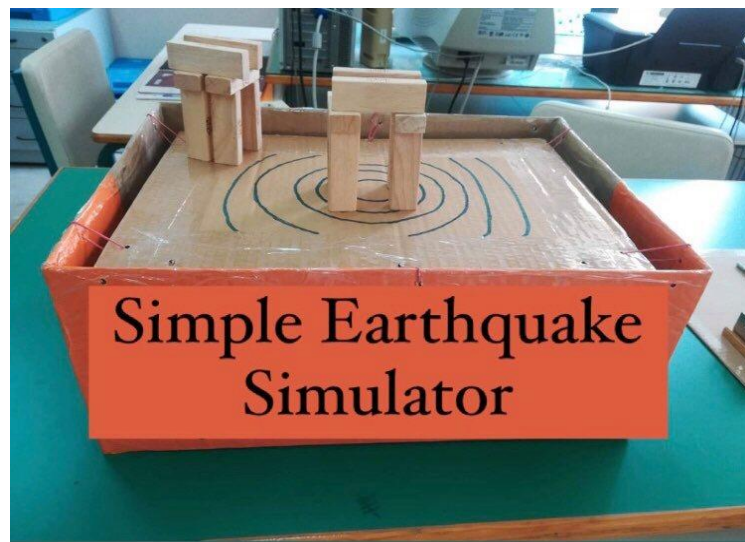


Figure 4. Two model buildings placed at different distances from the epicentre before a trial (Source: Authors' own elaboration)

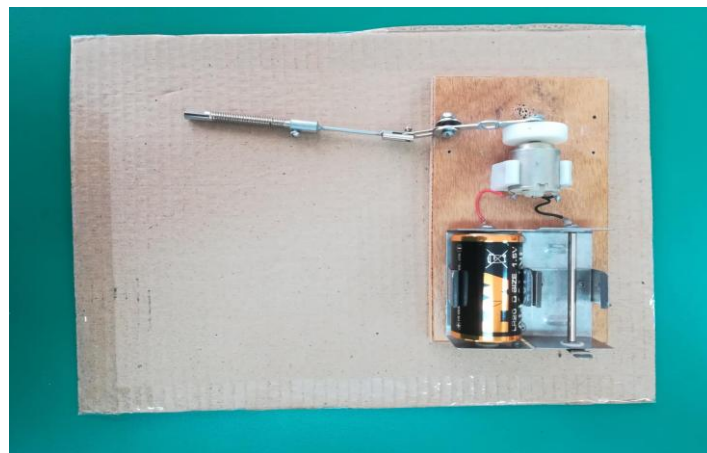


Figure 5. Optional motorised drive used to produce a more regular oscillation of the suspended platform. The motor is powered by a 1.5 V D-cell battery and transfers motion to the simulator through an eccentric cam and linkage (Source: Authors' own elaboration)

The simulator should be assembled and operated under continuous adult supervision. Cutting, hole punching, wiring and installation of the motorised mechanism should be undertaken only by an adult or by older pupils under direct supervision. The battery, motor, eccentric cam, connecting wire, rubber bands and small building components should be inspected before each use and kept out of the reach of unsupervised children. Children should not place their hands inside the box while the motor is operating. The motor should be disconnected from the battery before structures are repositioned or mechanical adjustments are made. Damaged or overstretched rubber bands and exposed or sharp wire ends should be replaced or securely covered. Particular attention is required when the activity involves children for whom the small building blocks may present a choking hazard.

Operating Procedure

The device can be operated in two modes, which differ in the degree of control offered over the intensity, duration and reproducibility of the imposed ground motion. The use of earthquake simulators as didactic tools has been proposed as an effective way to make seismic phenomena more visible and understandable in educational settings (Vanciu-Rău et al., 2020). In the manual mode, the operator inserts a hand through the rear access hole and shakes the underside of the suspended platform directly. This mode requires no additional equipment, is well suited to demonstrations in front of an audience of young children, and allows the intensity of shaking to be varied at will, but it offers limited reproducibility between trials and depends on the operator's fine motor control.

In the motorised mode, the suspended platform is set into oscillation by a small DC electric motor mounted on a separate plywood base and coupled to the underside of the platform by a rigid linkage with an eccentric cam (Figure 5). The motor is powered by a single 1.5 V LR20 (D-cell) alkaline battery, and the eccentric rotation of the cam translates into a reciprocating displacement of the linkage, which in turn drives the suspended platform in a quasi-sinusoidal horizontal oscillation. This mode produces a more uniform, reproducible and visually convincing simulation of seismic shaking, and it frees the operator's hands to point out features of the experiment to the children. It also approximates more closely the operation of professional earthquake simulators used in earthquake-engineering teaching and research (Chen et al., 2024).

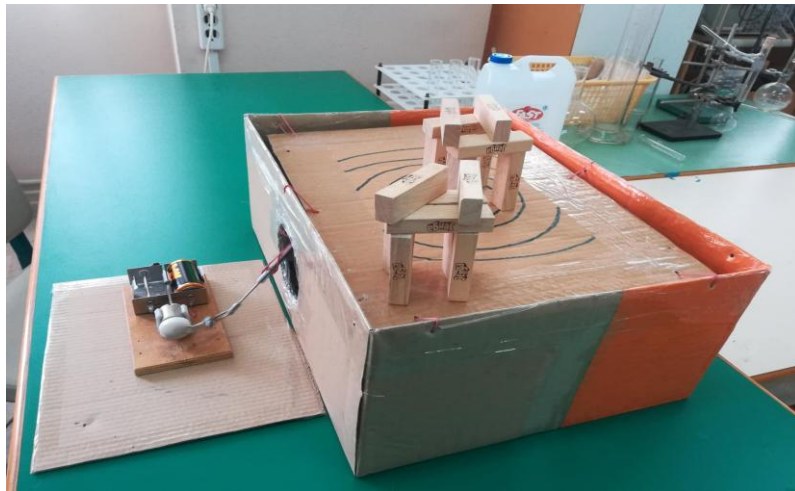


Figure 6. Motorised trial in progress. The external motor produces horizontal oscillation of the suspended platform, causing the model structure to shake (Source: Authors' own elaboration)

The device was developed as a qualitative classroom analogy and was not instrumentally calibrated for displacement amplitude or oscillation frequency. Consequently, these quantities may vary according to rubber-band elasticity and tension, motor speed, eccentric-cam geometry, mechanical coupling and platform loading. The motorised mode provides greater consistency between successive classroom trials than manual operation, but it should not be regarded as producing standardised or quantitatively reproducible ground motion.

In both modes, the duration of each trial is held to between ten and fifteen seconds. This duration is practical for classroom use and is broadly comparable to the order of magnitude of strong shaking in some moderate crustal earthquakes, although real strong-motion duration varies considerably depending on earthquake magnitude, focal depth, rupture process, distance from the source and local ground conditions. It is also a period over which the attention of preschool-age children can reliably be sustained on a single observation task. Longer trials add little pedagogical value and tend to result in the complete dispersal of the block structures, which complicates subsequent observation.

It should be emphasised that the simulator does not reproduce seismic-wave propagation, vertical and horizontal ground-acceleration components, site amplification, resonance or the dynamic response of real buildings. The model is deliberately simplified for early-years education. Its purpose is to make visible, in a safe and manipulable form, selected qualitative relationships among shaking, distance from the represented epicentre, structural stability and reinforcement.

Suggested Instructional Sequence

The device is intended to be embedded within a guided inquiry sequence rather than used as a standalone demonstration. The sequence proposed here has been developed and refined through repeated use in kindergarten and early-primary classrooms in the Region of Epirus, Greece, and is consistent with the inquiry-based and constructivist principles set out in Section 2.

The sequence begins with a brief whole-class discussion, in which the children are introduced to a small number of foundational concepts: that the Earth is made of large pieces of rock that move very slowly; that, when these pieces move suddenly, the ground shakes; that the place where the shaking starts deep inside the Earth is called the focus; and that the point on the surface directly above it is called the epicentre. In the classroom model, the concentric circles are used to show different distances from the epicentre, and children are invited to observe that the effects of shaking are often greater near the centre of the model than farther away. The teacher should explain, in age-appropriate language, that this is a simplified representation. In real earthquakes, the shaking felt at a place, that is, the earthquake intensity, does not depend only on distance from the epicentre. It also depends on the earthquake magnitude, the depth of the focus, the type of ground, the path followed by the seismic waves and the way buildings are constructed. The distinction between magnitude and intensity is therefore introduced qualitatively: magnitude refers to how large the earthquake is at its source, whereas intensity refers to how strongly it is felt and what effects it produces at a particular place. These ideas are introduced in age-appropriate language, with reference to children's own experience of having felt the ground move during an earthquake (almost universal among children of this age in Greece), and they are not presented as facts to be memorised but as questions that the experiment will help to answer.

Following this introduction, the device is presented and the children are invited to predict what will happen when the platform is shaken with a small tower placed at the epicentre, with two towers placed at different distances from the epicentre, with a tower built from many blocks compared with a tower built from few blocks, and with a structure whose blocks have been loosely tied together with the thin wire compared with one whose blocks are simply stacked (**Figure 6**). Each of these comparisons isolates a single variable, distance from epicentre, structural height, presence of reinforcement, and allows the children to formulate predictions, observe outcomes and, with the teacher's guidance, draw inferences.

Until after the trial has been completed, and where possible they are elicited from the children themselves before being summarised by the teacher. To support classroom use, the proposed instructional sequence is summarised in **Table 2**.

Table 2. Suggested inquiry sequence for the classroom use of the earthquake simulator

Phase	Teacher action	Example teacher prompt	Possible child response	Scientific concept
Introduction	Presents the simulator and introduces the idea of ground shaking.	“What do you think happens to the ground during an earthquake?”	Children describe shaking, movement, fear, or previous experiences.	Earthquake as ground motion
Prediction	Places one or more block structures on the model floor.	“Which building do you think will fall first? Why?”	Children predict using everyday ideas about distance, height, balance, or strength.	Prediction and causal reasoning
Trial	Operates the simulator manually or with the motor for 10–15 seconds.	“Watch carefully what happens to each building.”	Children observe which structures move, fall, or remain standing.	Observation of effects
Comparison	Repeats the trial while changing one variable at a time.	“What changed this time? Was the building closer, taller, or stronger?”	Children compare outcomes across trials.	Variables: distance, height, reinforcement
Discussion	Guides children to express the pattern in their own words.	“Why do you think this building fell and the other one stayed standing?”	Children relate the outcome to distance from the epicentre, shaking strength, or building design.	Epicentre, intensity, structural resistance
Preparedness link	Connects the model with earthquake safety at school and home.	“What do we do in our school when there is an earthquake drill?”	Children recall drill procedures and discuss safer behaviour.	Disaster preparedness



Figure 7. Post-shake configuration of the model buildings after a trial. The fallen blocks provide a starting point for discussing, in qualitative terms, how earthquake effects may vary with distance from the epicentre, building design and ground conditions (Source: Authors' own elaboration)

After the trial, the post-shake configuration of the structures is photographed or sketched (**Figure 7**), and the children are invited to comment on which structures fell first, which fell furthest from their starting positions, and what features of the construction appear to have made a difference. A short worksheet of guiding questions, included as an appendix to this paper, is used to structure this final phase of the activity and to support the teacher in eliciting the conceptual content from the children's observations. The complete sequence, introduction, prediction, trial, observation and discussion, typically occupies a single forty-five-minute session for one experimental comparison, or two consecutive sessions when several comparisons are to be explored in succession.

PEDAGOGICAL IMPLICATIONS AND OBSERVED OUTCOMES

This section reports on the implementation of the device in kindergarten and early-primary classrooms in the Region of Epirus, north-western Greece, and on the patterns of children's engagement and conceptual reasoning that were observed during its use. The account given here is qualitative and observational rather than the product of a formal experimental study with pre- and post-intervention measures. It should therefore be read as a description of how the device functions in practice, of the kinds of learning episodes it generates and of the questions it leaves open for more systematic investigation in subsequent work. The main limitation of the present paper is that children's conceptual development was not assessed through a validated instrument, a structured interview protocol or a comparison group. In addition, the classroom observations were conducted in a specific regional and educational context, and the findings cannot be generalised without further investigation. These limitations do not reduce the practical value of the simulator, but they define the article as an educational innovation study rather than as evidence of demonstrated learning effectiveness. The limitations of this evidentiary base are addressed explicitly in Section 7. A further limitation concerns the physical scope of the analogy itself: the simulator does not reproduce real seismic-wave propagation, ground acceleration, site effects, resonance phenomena or the quantitative dynamic response of buildings. Its purpose is

therefore not to model earthquake physics with engineering precision, but to provide young children with a concrete and manipulable representation through which they can reason qualitatively about shaking, distance, stability and reinforcement.

Setting and Participants

The device was implemented in six public schools in the Region of Epirus, north-western Greece: four kindergartens and two primary schools. The implementation involved eight intact classes: four kindergarten classes, two Grade 1 classes and two Grade 2 classes. A total of 148 children participated, comprising 65 kindergarten children and 83 primary-school children. One classroom session was conducted in each class, resulting in eight sessions in total. Each session lasted approximately 30–45 minutes and was facilitated by the author in collaboration with the regular classroom teacher.

During each session, the author recorded free-form contemporaneous field notes focusing on children's verbal responses, participation and interactions with the simulator. After the classroom implementations, two authors jointly reviewed the notes and inductively organised the observations into broad descriptive categories through discussion and consensus. These categories concerned sustained engagement with the activity, the use of everyday experiences and prior knowledge, the verbalisation of observations, comparisons between experimental outcomes, the revision or elaboration of initial responses, and connections with earthquake-preparedness practices. The categories were used solely to organise and describe recurring patterns in the observations; numerical frequencies were not calculated, and the procedure was not intended to constitute a formal qualitative content analysis.

Photographs of the experimental configurations and informal post-session conversations with participating teachers were used only as supplementary contextual sources. Because the field notes were open-ended and no structured observation protocol, independent classroom observer or formal inter-rater reliability procedure was employed, the findings should be interpreted as exploratory qualitative documentation rather than as systematic evidence of learning outcomes.

Formal permission to conduct the classroom activity was obtained from the heads of the participating schools, and informed consent was obtained from the children's parents or legal guardians. Institutional ethics review was not sought because the implementations formed part of regular educational activities and no names, personal data, individual assessment records or identifiable images of children were collected. The field notes contained only anonymised classroom-level observations and were used to provide an exploratory description of the activity rather than to evaluate individual children. All reported observations are aggregated, and the photographs included in the manuscript show only the simulator and classroom materials, with no identifiable children.

Children's Engagement and Observed Responses

The most consistent observation across all classroom implementations was the high level of engagement that the device elicits in children of this age. The combination of an unfamiliar object, a visible and somewhat dramatic outcome, block towers that fall over, and the opportunity to predict and observe at close range proved reliably capable of holding the attention of a full class group for the duration of a session, including the discussion phase that follows the experimental trials. This pattern is consistent with the broader literature on hands-on and inquiry-based learning in the early years (Trundle & Saçkes, 2015), and it offered, in practical terms, the precondition for any subsequent learning: a sustained period of focused attention on a single physical system.

Within this period of engagement, three distinct patterns of children's response could be identified. First, children of all ages in the target range were quickly and confidently able to predict that a tower placed *closer to the centre* of the suspended platform would fall sooner, or fall more completely, than one placed further away. After two or three trials, the language used by the children to describe this regularity moved from purely spatial terms ("this one fell first") to terms approximating the scientific concept of intensity decreasing with distance ("the shaking is stronger in the middle"). The introduction of the formal term *epicentre* during the post-trial discussion was, in most sessions, received without difficulty, with children spontaneously pointing to the innermost concentric circle on the cardboard platform when subsequently asked to identify the epicentre of the experimental earthquake.

Second, the comparison between a tall, narrow tower built from many blocks and a shorter, wider construction built from fewer blocks reliably generated the prediction, frequently before any trial was conducted, that the taller structure would fall first. When asked to justify this prediction, children typically appealed to everyday intuitions about balance and stability rather than to any specifically seismic reasoning. This is consistent with what would be expected at the preoperational and early concrete-operational stages (Feldman, 2017), and it offered a productive bridge between the children's existing knowledge of how objects in the world stand or fall and the new concept of structural resistance to ground motion. The teacher's role at this point in the sequence was to validate the children's existing reasoning while introducing the additional consideration that, during shaking, taller and narrower block structures are often less stable because their centre of mass is higher and they are more easily overturned. The discussion should also clarify that, in real buildings, earthquake resistance does not depend on height alone but also on materials, reinforcement, foundations, stiffness, damping and overall structural design.

Third, the comparison between a stacked tower and a tower whose blocks had been loosely tied together with thin wire proved the most pedagogically challenging of the three principal comparisons. A substantial proportion of children predicted, on the basis of the additional material involved, that the wired structure would be "heavier" and therefore "fall harder", and were genuinely surprised when the wired structure remained standing while the unreinforced tower collapsed. This surprise was, in the author's observation, the single most productive moment in the sequence for introducing the concept of structural resistance and, by extension, the connection between scientific understanding and the design of safer buildings, the science–technology–society dimension discussed in Section 2. Hands-on learning has also been shown to be valuable for teaching earthquake-resistant

structural systems, because it allows learners to connect structural design principles with observable building behaviour under seismic conditions (Karadag & Canakcioglu, 2024).

Anticipated Learning Outcomes

On the basis of these observations, the device appears to support, in a developmentally appropriate form, the following intended learning outcomes for children in the target age range. The framing here is deliberately cautious: these are outcomes that the device is *designed* to support and that the observed patterns of children's engagement are *consistent with*, not outcomes for which formal pre- and post-intervention measurement has been carried out.

At the level of concepts, the classroom observations suggest that the full instructional sequence can support children's initial familiarisation with the terms earthquake, focus, epicentre and intensity in a form appropriate to their cognitive stage. In this early-years context, intensity is treated qualitatively, as the visible and felt strength of shaking and its effects on the model structures, rather than as a formal seismological scale. During the observed sessions, many children identified the marked central area of the platform when asked to indicate the epicentre, distinguish it from more distant locations and describe, in a simplified way, how the observed effects of shaking changed with distance from it. These responses should be interpreted as promising indicators of conceptual engagement, rather than as evidence of measured learning gains. At the level of *causal reasoning*, children become able to identify three factors that influence the extent of earthquake damage, the intensity of shaking, the distance from the epicentre and the design of the building under examination, and to predict the relative outcomes of a small number of simple experimental comparisons in which these factors are varied one at a time. At the level of *process skills*, children gain experience in formulating predictions, observing outcomes systematically and revising their initial expectations in light of evidence, the elementary components of scientific inquiry as it is conceived in the early-years science literature (Samarapungavan et al., 2008).

A further outcome that emerged from the implementation, although it was not among the original aims of the device, concerns the *affective dimension* of children's engagement with earthquakes. In a country in which most children have either felt an earthquake themselves or know an adult who has, the subject is not emotionally neutral, and there is a recognised tension between raising children's awareness of seismic risk and avoiding the cultivation of fear (Raccanello et al., 2023). The simulator appears, in the author's observation, to support a positive resolution of this tension: by allowing children to cause and control the shaking, to predict its consequences, and to observe that the structures most affected are those that have not been built carefully, the device offers a route to a sense of agency over the phenomenon. This interpretation is consistent with recent work showing that earthquake shaking simulations can support youth learning and resilience-building by transforming seismic risk from an abstract threat into an observable and discussable experience (Musacchio et al., 2025). Children leaving the session frequently expressed interest in the construction of their own homes, in what their parents had told them about earthquakes and in the contents of the school's earthquake-drill procedures, indicating that the device functions as a productive entry point into the broader programme of school-based earthquake preparedness coordinated by the Earthquake Planning and Protection Organization (Kourou et al., 2025).

Teacher Response

Informal feedback from the participating teachers, gathered in post-session conversations, was uniformly positive. The most frequently cited strengths of the device were its low cost and ease of replication, the visual immediacy of its operation, and the readiness with which it could be integrated into existing classroom activities on the natural environment, on the local context (most schools in Epirus are within reach of historically active fault zones) and on civic preparedness. The most frequently cited limitations were the dependence of the manual operating mode on the operator's technique, which several teachers reported as a barrier to their independent use of the device after the initial demonstration, and the absence of a structured assessment instrument by which the children's learning could be documented. Both of these limitations point directly to extensions of the work that are discussed in Section 7.

DISCUSSION

The simple earthquake simulator described in this paper, and the implementation experience reported in Section 5, can be situated within three overlapping conversations in the literature on science and disaster education: the conversation about the developmental appropriateness of formal scientific concepts in the early years, the conversation about the design of low-cost classroom apparatus for hands-on seismology teaching, and the broader policy-level conversation about the role of schools in disaster risk reduction. Simulation-based earthquake education has also been shown to help learners connect theoretical knowledge with practical preparedness actions, particularly when the activity allows them to experience and discuss emergency situations in a structured learning environment (Kalanlar, 2026). The remainder of this section considers what the present work contributes, and what it does not contribute, to each of these conversations in turn, and concludes with a reflection on the design principles that have emerged from the implementation experience.

The observed patterns of children's engagement with the device offer modest but real support for a proposition that the early-childhood science-education literature has been advancing for some years: that the concepts traditionally reserved for upper primary and secondary teaching are accessible to children at the preoperational and early concrete-operational stages, provided they are presented in a concrete and manipulable form. The fact that children aged four to eight reliably and rapidly showed emerging reasoning the relationship between distance from the epicentre and intensity of shaking, and articulate this relationship in their own words after only two or three trials, is consistent with a broader pattern in which young children, when given an

appropriate physical analogy, are capable of considerably more sophisticated causal reasoning than the standard developmental account would predict (Samarapungavan et al., 2008; Trundle & Saçkes, 2015). The implication is not that Piagetian stage descriptions are wrong, but rather that the *content* a child can engage with at any given stage is a function of the form in which it is presented, and that the apparent inaccessibility of seismological concepts at early ages is in many cases an artefact of the abstract verbal form in which they are typically introduced rather than of any developmental impossibility.

This observation has practical consequences for curriculum design. The recent content analysis of Greek geography curricula by Passadelli et al. (2024) found that earthquake content is concentrated in Grades 5 and 6 of primary school, with comparatively little presence in earlier years; the present work suggests that this distribution reflects historical convention rather than any developmental ceiling, and that a substantial part of the seismological content currently delivered to ten- and eleven-year-olds in a primarily verbal form could be delivered earlier and more effectively in a primarily experimental form. The case is not for replacing the upper-primary material but for laying the groundwork for it in the kindergarten and early primary years, in the same way that early-mathematics curricula now routinely introduce the precursors of formal arithmetic during the kindergarten year (Saçkes et al., 2011).

A second strand of the relevant literature concerns the design of physical apparatus for classroom earthquake simulation. A spectrum of devices has been described in the published record, ranging at one extreme from the elaborate uniaxial earthquake simulator marketed for university-level structural-engineering teaching, which can cost several thousand euros and require dedicated laboratory space, through medium-cost classroom ones suitable for upper secondary and undergraduate teaching (Chen et al., 2024), to simple inexpensive devices comparable to the one described here (Savasci, 2011; Mendoza et al., 2008). Within this spectrum, the present device occupies a niche that has been comparatively under-served: it is simpler and less expensive than even the simplest of the previously published classroom earthquake simulators, it is explicitly designed for use with children below the age at which most such devices are targeted, and, importantly, it incorporates radial markings on the platform that allow the role of *distance from the epicentre* to be investigated, a variable that is absent or implicit in most other classroom devices.

The decision to suspend the platform on rubber bands rather than on, for example, marbles or wheels, a choice that distinguishes the device from several alternative DIY designs in circulation, has implications worth noting. The rubber-band suspension produces a simplified horizontal oscillation with a clear dominant frequency and a visible amplitude, which makes the relationship between the applied disturbance and the motion of the platform transparent to a young observer. It also damps quickly when the driver is removed, so that successive trials can be conducted with minimal delay. The main limitation of this design is that it does not reproduce the complex, multi-directional and multi-frequency motion of real seismic waves, nor does it allow quantitative analysis of ground motion, attenuation or resonance. For the target age range, however, this simplification is pedagogically appropriate. The purpose of the device is not to simulate earthquake dynamics with physical precision, but to support qualitative reasoning about shaking, distance, stability and reinforcement.

The optional motorised drive (Figure 4) is a relatively minor extension to the basic device but it merits separate discussion. The principal advantage of the motorised mode over the manual mode is reproducibility: the same input is delivered on each trial, which allows the teacher to make defensible comparisons between successive trials in which only the structure under test has been changed. The principal disadvantage is the reduced operator control over the imposed motion, which is determined by the geometry of the eccentric cam, the coupling between the motor and the suspended platform, and the rotational speed of the motor. In practice, this limitation can be partly mitigated by running the motor at a lower voltage or by inserting a series resistance, both of which reduce the rotational speed and therefore the frequency of the imposed motion. Depending on the coupling and load, this may also reduce the observed severity of shaking of the suspended platform. Teachers reported that the manual mode was harder to operate consistently than they expected, which suggests that the motorised mode should be presented as the default rather than as an optional extension in future iterations of the design.

A third conversation within which this work belongs concerns the broader role of schools in disaster risk reduction. The Sendai Framework (UNDRR, 2015) and subsequent international guidance have established that DRR education is most effective when it is integrated across multiple dimensions, knowledge, action, participation and integration, rather than treated as a purely cognitive matter (Passadelli et al., 2024). The Greek school system, through the long-running activities of the Earthquake Planning and Protection Organization, has developed a particularly strong tradition in the *action* dimension, with mandatory drills and emergency-plan training (Kourou et al., 2025; Papavasileiou et al., 2022); but, as recent surveys have documented, awareness and preparedness behaviour can diverge substantially, with members of the public reporting familiarity with the standard messages while simultaneously misunderstanding the recommended protective actions (Lekkas et al., 2021).

The simulator described here is best understood as a contribution to the knowledge dimension of this multi-dimensional framework, and, more specifically, as a contribution to the conceptual underpinnings of the knowledge that the EPPO drills already convey behaviourally. Its practical contribution lies in translating abstract ideas about earthquakes, distance from the epicentre, shaking intensity and structural resistance into a concrete classroom experience that can be implemented with minimal cost, limited preparation time and no specialised laboratory equipment. In this sense, the device functions as a bridge between school earthquake-preparedness activities and early-years science education. A child who has seen, on the experimental device, that buildings closer to the epicentre suffer more damage than buildings further away, and that buildings whose elements are connected are more resilient than buildings whose elements are merely stacked, is in a substantially better position to make sense of the procedural instructions delivered during an emergency drill, to ask coherent questions about her own school building, and to engage with adult conversations about seismic safety. In this sense the device does not duplicate the work of the EPPO programme but provides the conceptual scaffolding on which that work can rest more securely.

The emotional dimension of children's engagement, mentioned in Section 5.3, also bears on this wider context. Raccanello and colleagues (2020, 2023) have argued, on the basis of substantial empirical evidence from primary-school populations in Italy, that effective earthquake education for young children must integrate cognitive, behavioural and emotional preparedness, and that interventions which address only one of these dimensions risk being either ineffective (when the cognitive content is decoupled from the children's lived experience) or counter-productive (when behavioural training is delivered without the cognitive scaffolding that would allow children to make sense of it). The simulator, by allowing children to *control* the shaking themselves and to *observe* its effects in a contained and reversible setting, offers a route into the emotional dimension that is consistent with this multi-component view and that complements both the cognitive content delivered in the formal curriculum and the behavioural content delivered through the EPPO drills.

Five design principles have emerged from the development and implementation of the device, and they are offered here both as a summary of what the present work has learned and as a starting point for the development of comparable resources in other domains of early-childhood science teaching. *First*, the device should permit a single experimental variable to be manipulated at a time, with the others held constant, the radial markings on the platform and the use of standardised wooden blocks are both consequences of this principle. *Second*, the outcome of each trial should be visible, reversible and rapid, so that children can observe, predict and re-test within the attention span of a single session. *Third*, the device should allow children to *cause* the phenomenon being studied rather than merely to watch it, since the experience of agency is what supports both the cognitive and the emotional dimensions of learning. *Fourth*, the materials should be cheap, widely available and replaceable, so that the device can be replicated by any teacher in any school and so that breakage during use is not an obstacle to continued teaching. *Fifth*, the device should be embedded within a structured inquiry sequence, introduction, prediction, trial, observation, discussion, rather than presented as a self-contained demonstration. None of these principles is novel in itself, but their combined application in a device designed specifically for the kindergarten and early-se years is, to the best of the author's knowledge, comparatively unusual in the published seismology-education literature.

LIMITATIONS AND FUTURE WORK

A clear-eyed account of the limitations of the present work is a prerequisite for situating its contribution accurately and for identifying the most productive directions for subsequent research. The principal limitations fall into four categories, which are considered in turn below, and each is paired with a concrete proposal for follow-up work.

Evidentiary Base

The most significant limitation of the present work is the qualitative and observational character of the evidence reported in Section 5. The implementation experience drawn upon in this paper consists of contemporaneous field notes by the author, photographs of experimental configurations, and informal post-session conversations with participating teachers; it does not include systematic pre- and post-intervention measurement of children's conceptual understanding, structured comparison with a control group, or independent observation by a second researcher. As a consequence, the claims advanced in Sections 5 and 6 about the device's effects on children's learning are best understood as hypotheses that the implementation experience renders plausible, rather than as conclusions for which the present study provides direct empirical support.

The natural next step is the design and execution of a small-scale quasi-experimental study, in which children in two or more matched class groups are assessed for their understanding of a focused set of seismological concepts, at minimum, the concepts of *epicentre*, *intensity-as-function-of-distance*, and *structural resistance*, both before and after a controlled implementation of the device. Such a study would require the development of an age-appropriate conceptual instrument, ideally consisting of a small number of picture-based items administered as a short individual interview rather than a written test, since the target age range includes pre-readers. The recent literature on early-childhood science assessment offers several precedents for instruments of this kind (Samarapungavan et al., 2009), and the adaptation of such an instrument to the seismological content addressed by the present device is a tractable piece of work that could be carried out within a single academic year.

Scale and Context

The implementation reported here has been confined to kindergartens and early-primary classrooms in a single Greek region (Epirus), with a single facilitator (the author) and a relatively small number of class groups. This restricts the generalisability of the observations in two directions. *Internally*, it leaves open the possibility that the patterns of children's engagement reported in Section 5 reflect features of the facilitator's practice, his familiarity with the device, his rapport with the participating teachers, his disciplinary background as a science-education advisor, at least as much as features of the device itself. *Externally*, it leaves open the question of how the device performs in other regional, national or linguistic contexts, particularly in countries with different baseline levels of public familiarity with earthquakes and different curricular treatments of disaster topics.

The natural next step is a multi-site implementation study, in which the device is used by class teachers, not by the device's developer, in schools across two or more regions and ideally in two or more countries. Such a study would address both the internal and external generalisability questions, and it would also generate the kind of practical feedback about classroom logistics, teacher confidence and material durability that no single-site study can produce. A cross-national implementation between Greece and one or more comparator countries with similar seismic exposure (Italy, Türkiye, Albania) would be particularly valuable, both for the comparative evidence it would yield and for its potential contribution to the international networks on school safety and DRR education established under the Sendai Framework (UNDRR, 2015).

Apparatus

The device as described in this paper has three apparatus-level limitations that bear acknowledgement. *First*, the rubber-band suspension that gives the device much of its pedagogical accessibility is also a source of long-term wear: rubber bands degrade through repeated stretching and through exposure to light, and a device that has been in use for several months may require replacement of one or more bands. This is a minor practical issue for an individual classroom but a meaningful one for any institutional implementation, and a future version of the device should consider replacing the rubber-band suspension with a more durable equivalent, light springs, or elastic cord of the kind used in archery, without sacrificing the visual clarity that the present suspension provides. *Second*, the manual operating mode proved harder for participating teachers to use consistently than was initially expected (Section 5.4), and the motorised mode should accordingly be presented as the default in future iterations, with the manual mode demoted to an optional simplification. *Third*, the device produces qualitative outcomes, buildings fall over, or they do not, but it produces no quantitative output that could be used for older or more advanced learners. An obvious extension would be the addition of a low-cost accelerometer module (the small breakout boards now widely available for educational use cost only a few euros) coupled to a simple display, which would allow upper-primary and secondary classes to relate the magnitude of the input to the response of different structures and to introduce, in age-appropriate form, the elementary concepts of acceleration, frequency and resonance.

Pedagogical Scope

A fourth limitation concerns the conceptual scope of the device. The simulator addresses the relationship between earthquake intensity, distance from the epicentre, and structural response, but it does not address several other concepts that are central to the seismological content of upper-primary and secondary curricula, most notably, the distinction between body waves and surface waves, the relationship between magnitude and intensity, and the time-dependent character of seismic risk. The device is not intended to address these concepts, and it would be misleading to claim that it does; but the boundary between what the device can support and what it cannot should be drawn clearly for any teacher considering its use, and a future paper or accompanying teaching guide should make this boundary explicit. A complementary line of development would be the design of a small family of related devices, each focused on a different aspect of seismology, wave propagation, fault rupture, the relationship between deep focus and surface intensity, that could be used in sequence across the years of primary schooling to build up, by stages, the integrated understanding that the upper-primary curriculum currently attempts to deliver in a single block of teaching.

An Integrated Programme of Follow-Up Work

Taken together, the four limitations above suggest a concrete programme of follow-up work that could be carried out over a period of two to three years. The first phase would consist of the design and validation of the age-appropriate conceptual instrument described in Section 7.1, in collaboration with one or more research-active colleagues in early-childhood science education. The second phase would consist of a quasi-experimental study with the instrument, conducted in a small number of schools in Epirus and one or more comparator Greek regions, with the device used by class teachers after a short training session. The third phase, contingent on the results of the second, would consist of a cross-national multi-site implementation in collaboration with colleagues in one or more neighbouring earthquake-prone countries, in the framework of an existing or new project on school-based DRR. The author would welcome contact from colleagues interested in collaborating on any phase of this programme.

CONCLUSIONS

This paper has described the design, construction and classroom use of a simple, low-cost experimental earthquake simulator intended for children aged approximately four to eight years. Built from a paper box, a sheet of cardboard, rubber bands and wooden building blocks, with an optional small DC motor for more reproducible operation, the device can be assembled by a teacher in a short time and at low material cost. It allows young learners to investigate, through guided hands-on inquiry, selected factors related to earthquake effects, including distance from the epicentre, qualitative intensity of shaking and structural design.

The classroom observations reported here suggest that the device can support children's engagement with the concepts of epicentre, qualitative intensity and structural resistance when these are presented through concrete and manipulable experience. However, these observations should be interpreted as exploratory rather than as evidence of formally measured learning gains. The contribution of the paper therefore lies primarily in the design of the device, the inquiry sequence proposed for its classroom use and the practical design principles that emerged from its implementation.

Future research should examine the educational impact of the simulator through a more systematic design. Such work could include pre- and post-activity assessment, structured observation protocols, interviews with children and teachers, and comparison with more traditional earthquake-preparedness instruction. A multi-site study involving different age groups, school contexts and teachers would also help determine whether the device can be reliably implemented beyond the classrooms in which it was initially developed. In this way, the simulator may serve not only as a practical classroom resource, but also as the basis for more rigorous research on early-years earthquake education and disaster-risk-reduction learning.

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Ethical statement: The authors stated that the study was conducted anonymously, and no personally identifiable or sensitive personal data were collected. Permission to conduct the study was obtained from the participating schools' principals and teachers, and informed consent was obtained from the parents or legal guardians of the participating students prior to data collection. Participation was voluntary, and the data were collected and analyzed in a manner that did not allow individual participants to be identified. The authors further stated that formal approval by an institutional ethics committee was not obtained, as the study involved an anonymous educational research procedure, did not collect identifiable or sensitive personal data, and posed no foreseeable risk to the participants. All procedures were conducted in accordance with the ethical principles applicable to educational research.

AI statement: The authors stated that generative AI tools were used solely for language editing, including grammatical, syntactical, and stylistic improvements. These tools were not used to generate scientific content, analyze data, interpret results, or formulate conclusions. All AI-assisted revisions were critically reviewed and approved by the authors, who take full responsibility for the final content of the manuscript.

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