

New Trends and Issues Proceedings on Humanities and Social Sciences



Volume 6, Issue 1 (2019) 304-312

www.prosoc.eu

Selected Paper of 11th World Conference on Educational Sciences (WCES-2019) 07-10 February 2019, Milano Novotel Milano Nord Ca' Granda Convention Center, Italy

GeoGebra application, used in the determination of the magnitude of an earthquake

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Suggested Citation:

Chiriacescu, B., Chiriacescu, F. S., Barna, V. & Miron, C. (2019). GeoGebra application, used in the determination of the magnitude of an earthquake. *New Trends and Issues Proceedings on Humanities and Social Sciences*. [Online]. 6(1), pp 304–312. Available from: www.prosoc.eu

Selection and peer review under responsibility of Prof. Dr. Jesus Garcia Laborda, University of Alcala, Spain.

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Abstract

In this paper, the authors tackle the earthquakes study with the aim of determining the magnitude. By means of a GeoGebra program (an open source programme), we encourage the secondary school scholars in modelling the data obtained from an actual earthquake. We intend to obtain the magnitude of an earthquake by a method that can be easily comprehended by the students. The model is based on Richter's approach. In order to facilitate the process, a GeoGebra application was created that allows for an accurate calculus. The instrument presented in this paper assists in a better understanding of the Richter scale (including how it was built) and the correlation between the energy released by the earthquake, the amplitude of the waves and the epicentral distance. The students will be able to analyse a seismogram, to identify its main elements and to determine the magnitude of a simulated earthquake.

Keywords: Earthquake, GeoGebra, seismogram, STEM, Richter scale.

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1. Introduction

A major problem encountered when teaching physics in upper secondary school is the fact that the presented phenomena are often detached from reality. Although normally it should be dealt with natural phenomena, it is a very common practice to excessively mathematise the notion in working with templates when solving problems as well as during the teaching process. As a result, the students are no longer attracted to science and, especially to physics study. Forbus (1997) (Learning Sciences, Northwestern University) pleads for a qualitative study of physics. He starts by denying the stereotype that natural sciences and 'engineering' should be very mathematised and reasons that such an idea is in fact deeply counterproductive. The students are required to memorise formulae or ways of solving the problems without a true understanding of the principles that rest behind the concepts. Developing an educational software that shapes and illustrates the phenomena from the qualitative point of view could be a key solution to this problem.

The preoccupation for the study of earthquakes at high school level is not a new trend. In France, for example, we find the 'EduSeismo' project since 2006. In the frame of this project, seismic stations were installed in 60 schools and under the guidance of teachers and seismologists, and the students were given the opportunity to collect and interpret seismic data (Berenguer, Courboux, Tocheport & Bouin, 2013). In addition, a website of the project was created (<http://www.eduseismo.org>), where information and data about earthquakes are at public disposal (Virieux, 2000). A similar program was implemented in USA in 1996. With the so called IRIS program simple seismographs were installed in schools, the collected open data being used either by students or other people interested in the study of earthquakes (Braile, Hall-Wallace, Taber & Aster, 2003). In Romania, a country with a high level of seismic activity, 'The Romanian Educational Seismic Network' program is present (Tataru, et al., 2016). The project was implemented in nine schools. The resulting website (<http://www.roeduseis.ro/ro/>) contains informative materials, flyers, brochures, worksheets and evaluation sheets, resources that are in the reach of anyone interested in earthquakes' study and, moreover, in including this topic in the teaching process.

In this paper, we want to show that by using the GeoGebra program, while involving methods specific to the science, technology, engineering and mathematics (henceforth, STEM) and instruments from inquiry-based learning and project based learning, a proper way of determining and explaining the Richter scale magnitude can be introduced to the upper secondary school students. Starting from a spectacular natural phenomenon, the earthquake, by using computer modelling, the students can be explained the manner in which this phenomenon occurs and how it is further studied. Being such a dramatic phenomenon, there are a lot of myths, incomplete or false information that are spread through the mass media and other sources (internet and other). Even the expression 'Magnitude on the Richter scale' sounds hollow as long as someone does not know the real significance. Using the method presented in this paper, we can take a step forward in clarifying some things about this phenomenon and the concepts describing it.

The application presented below is mainly addressed to students from the upper secondary school and can be connected both with the study of the mechanical waves and some sciences classes or extracurricular activities. Starting with the analysis of an educational seismogram (a simplified seismogram that can be easily 'read' by students which do not have extended knowledge in seismology) by employing the graphics mode of the GeoGebra application, the authors prepared an application that eases the finding of an earthquake's magnitude. In this manner, the students can focus on the qualitative interpretation of the phenomenon, on the meaning of the numbers, on the way in which different factors may influence the manifestation of an earthquake.

2. The Richter scale magnitude

The famous scale in discussion, that it's worldwide used, was presented for the first time by Richter (1935). In his paper, Richter shows that until then seismic intensity scales were used for expressing the

locally observed effects of an earthquake. It is the case with the Rossi-Forel or Mercalli-Cancani scales. For a better interpretation of an earthquake, a new point of view is needed, in a way that the focus should be moved from the local effects towards the energy released in the Hypocenter, in the moment of the earthquake occurrence. This way of studying the earthquake presents multiple advantages regarding the statistic study of the phenomenon. Therefore, Richter proposes the term ‘magnitude’ in order to make the difference from the previously used ‘intensity’. Richter studied the dependence of the amplitude logarithm in the seismic wave with the epicentral distance. Thus, he states that: ‘The magnitude of any shock is taken as the logarithm of the maximum trace amplitude, expressed in microns, with which the standard short-period torsion seismometer ($T_0 = 0.8$ seconds, $V = 2800$, $h = 0.8$) would register that shock at an epicentral distance of 100 km’.

The calculations are shortly presented in Shearer’s (2009) course:

$$M_L = \log_{10}A(x) - \log_{10}A_0(x) \quad (1)$$

where A_0 is the reference amplitude (Richter considered it equal to 1 micron) and X is the epicentral distance. The reference level is given by an earthquake that at 100-km distance produces a displacement of 1 mm—for such an earthquake it was given the magnitude of 3° on the Richter scale. Taking a step forward, a 4° earthquake would give a displacement of 10 mm at 100 km or 1 mm at 300 km, a 5° one would create a 100 mm displacement at 100 km, or 1 mm at 600 km and so on. Obviously, the variation is not a linear one (as we can expect according to Eq. (1) above). Using a large number of measurements, Richter and Gutenberg achieved the nomogram below (Figure 1) (Gutenberg & Richter, 2010; Hyndman & Hyndman 2010; Richter, 1958).

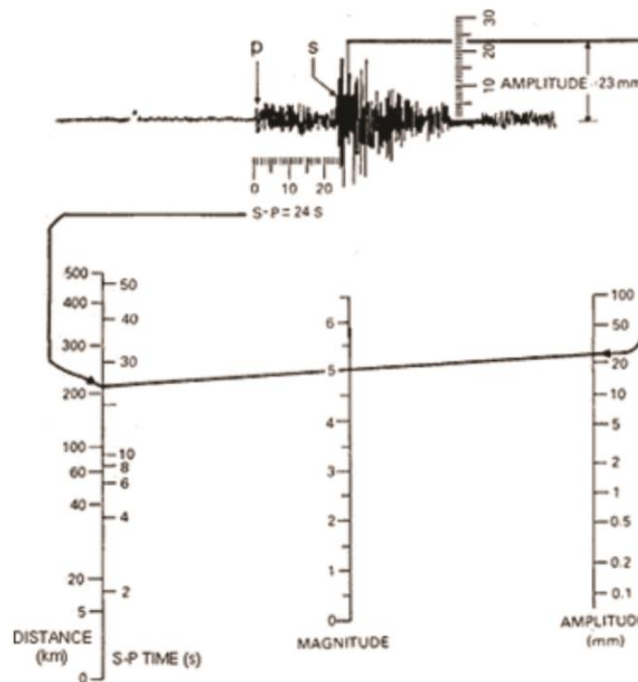


Figure 1. Magnitude (Richter Gutenberg) nomogram with the explanation of how the data from the seismogram can be used in practice

The magnitude on the Richter scale can be determined, considering the S-P interval and the amplitude of the S wave, while using the above nomogram. The S-P interval can be related to the epicentral distance, meaning the distance between the epicentre of the earthquake and the location of the seismic station. The amplitude can be read on the seismogram, as shown in Figure 1. (and later in Figure 4). With this data and using the Richter-Gutenberg nomogram, one can find the magnitude of

the earthquake by drawing the segment that connects the point indicating the epicentral distance (the left axis in Figure 1) with the point indicating the amplitude of the earthquake (the right axis in Figure 1). The point where this segment crosses the middle axis indicates the magnitude of the earthquake. We can verify the accuracy by taking data from more than one station—if the determinations were right, all the segments will intersect on the same point on the magnitude axis (as later shown in Figure 7).

3. Finding the magnitude by using the new GeoGebra built application

GeoGebra is a free, Open Source application, used, especially for geometric constructions and/or algebra calculus. The program allows building animations that can be used in the physics teaching process (Lalingkar, 2018; Marciuc & Miron, 2014; Marciuc, Miron & Barna, 2016a; Marciuc, Miron & Barna, 2016b; Walsh, 2017). Taking into consideration, the versatility of the program and the fact that it is able to run on any kind of device—computer, laptop, tablet and smartphone—it emerges as a very useful tool for the construction of an application for determining an earthquake magnitude.

For start, we use as background image a map of the Romanian seismic network downloaded from the National Institute of Earth Physics (INF) (<http://helitool.infp.ro/>). On this map, we label several seismic stations located at different distances and with different azimuths from the seismic region (marked with a red star). Even though for finding the earthquake magnitude the data from one station would suffice, in order to have a more accurate determination we chose to use records from three stations. In Figure 2, each station is marked on the map with a Boolean switch that, when ticked will show the following information: a slider for introducing the epicentral distance, a slider for introducing the amplitude, the seismogram obtained at the station and one switch that, when ticked, will draw the segment that will lead to resolving the magnitude. We chose the stations in various regions (and at different distances) from the seismic centre that is labelled with a red star: Cluj (CJR), Cernavoda (CVD) and drobeta turnu severin (RMGR). We chose also stations that are quite far from the seismic area, as Richter method works better with this kind of stations.

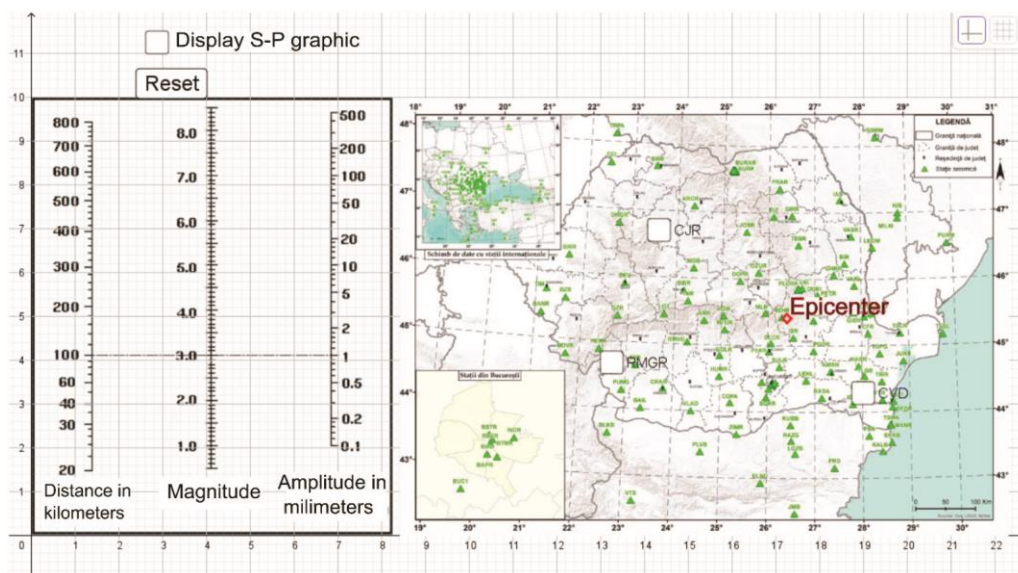


Figure 2. The application's start image

The nomogram (Figure 2—left side of the workspace) shows three axes:

- The right side axis shows the amplitude of the S wave. This value and the previous one (S-P interval) are determined from the seismogram.
- The middle indicates the magnitude on the Richter scale.
- The left one is for the epicentral distance that is directly connected with the S-P interval. The epicentral distance is determined according to the S-P interval that is on the seismogram and using the diagram from Figure 3 (this diagram was made according to the data published on the Romanian Institute of Applied Seismology website http://www.fotonsas.ro/principiu_avertizarii_seismice.htm).

According to the published data, the velocity of primary waves is $v_p = 7.8 \text{ km/s}$ and that of the secondary waves is $v_s = 4.6 \text{ km/s}$. So, knowing the S-P interval between the arrival times of the S (t_s), and P waves (t_p) [see Eq. (2)], the epicentral distance (δ) can be calculated as following:

$$t_p = \frac{\delta}{v_p} \dots, \dots, t_s = \frac{\delta}{v_s} \dots \Rightarrow A = \pi^2 \dots \Delta t = t_s - t_p = \frac{\delta}{v_s} - \frac{\delta}{v_p} \quad (2)$$

Results:

$$\delta = \frac{\Delta t}{\frac{1}{v_s} - \frac{1}{v_p}} \Delta \delta = \frac{v_p v_s}{v_p - v_s} \cdot \Delta t \quad (3)$$

With the above numerical values, it results the linear dependency $\delta = 11.21 \Delta t$ Starting from here, we can build the diagram from Figure 3 (that can be brought in front by using a check button).

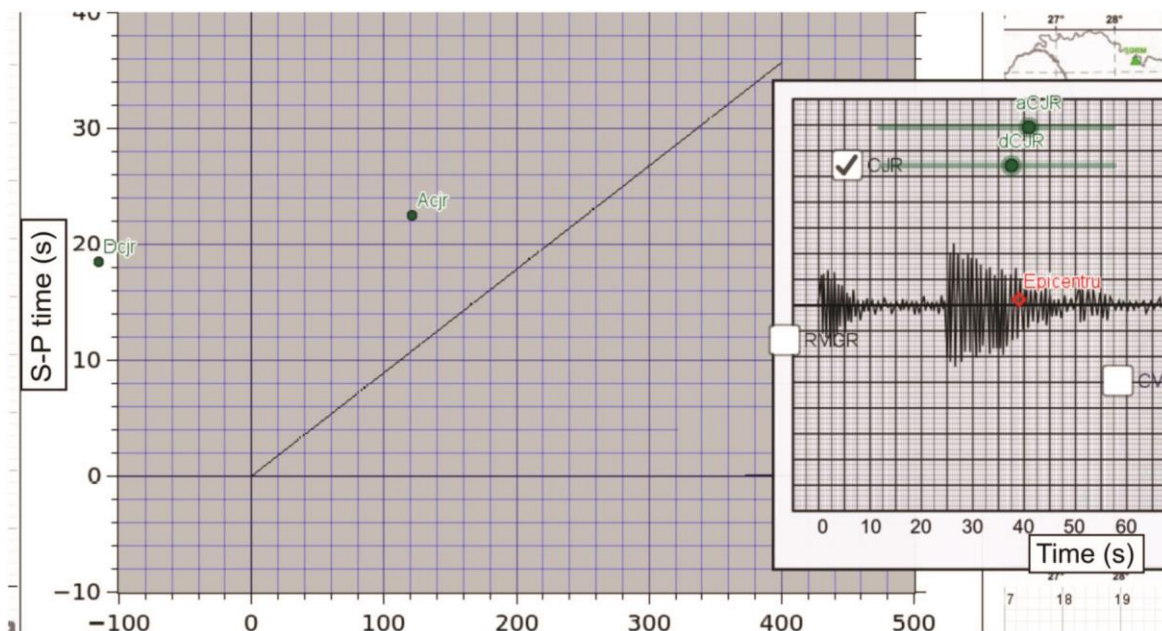


Figure 3. Epicentral distance diagram according to the S-P interval. On the right side, we can observe a seismogram that can give us this interval

In the beginning, as shown in Figure 4, the user will bring to the front an example seismogram where the main information is explained: the S-P interval between the arrival times of P and S waves and the amplitude of the S wave. This seismogram is in fact much simpler than a real one and it can definitely help to a better understanding from the students.

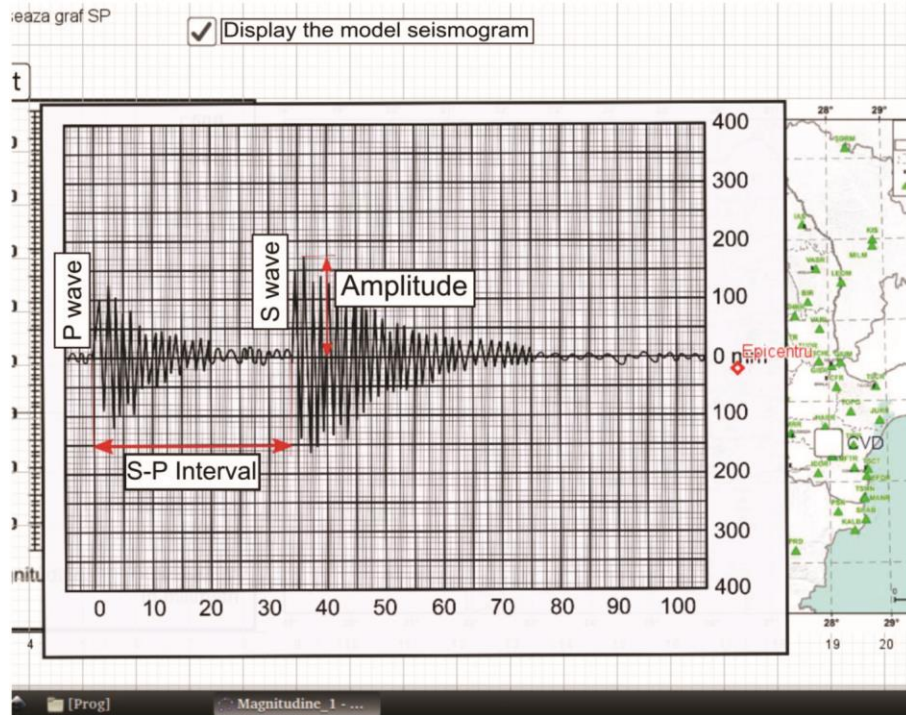


Figure 4. Didactic seismogram—with its help the reading of the main seismogram is explained

After explaining the work stages and which determination should be done, we send the model seismogram and, one by one, we bring to the front the data from each station. The S-P interval and the amplitude of the S wave will be read and, using the records sliders, the user will introduce the data. By using a slider, a point will be moved on the respective axis in the nomogram. The corresponding position will be chosen (see Figure 5).

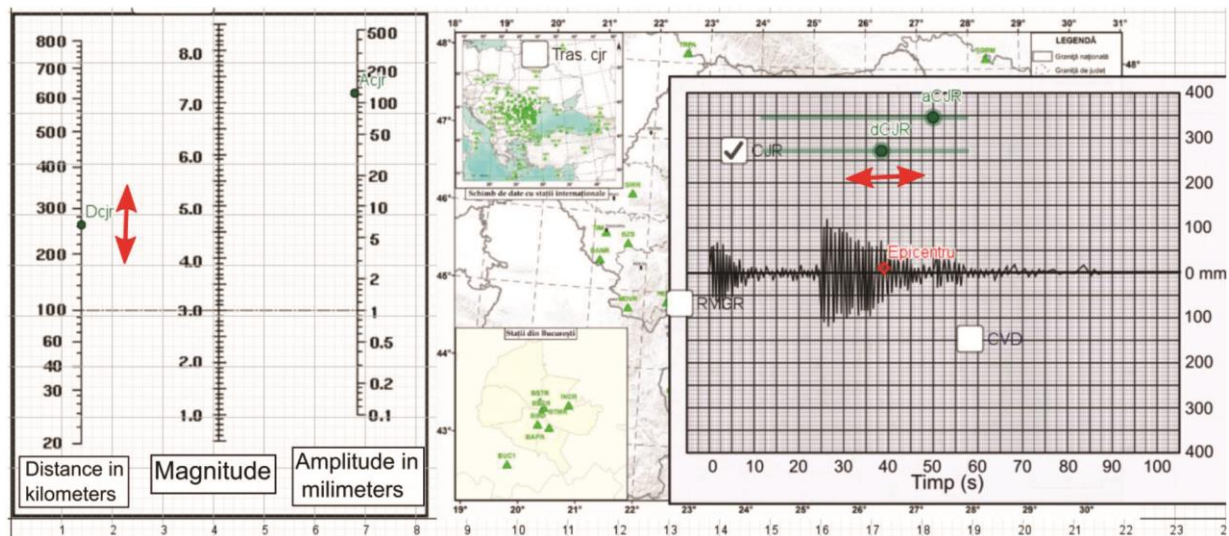


Figure 5. The information brought in the first plane by ticking the CJR button. The double arrows indicate how, the corresponding point moves in the nomogram in order to show the corresponding epicentral distance (by moving the slide input button dCJR)

Once here, by ticking the 'Tras' button, we shall obtain a segment that connects the distance point and the amplitude one. The point where the segment intersects the magnitude axis will reveal the magnitude of the earthquake (as shown in Figure 6).

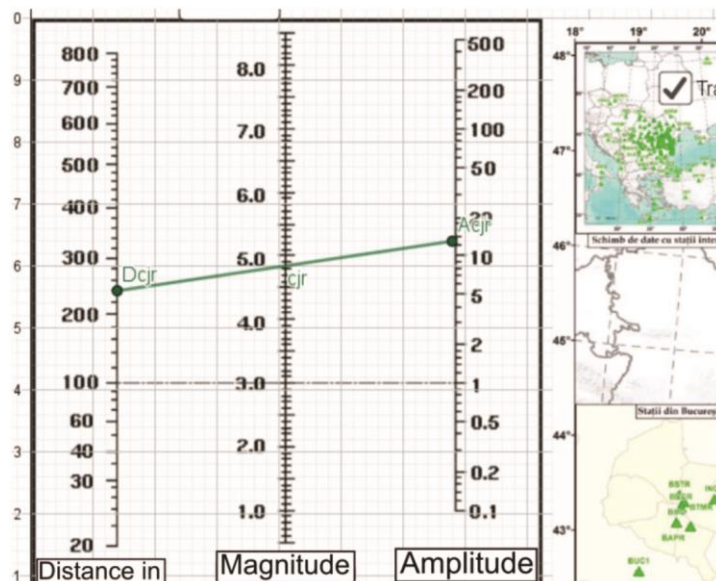


Figure 6. Drawing of the line that connects the position (Dcjr) with the amplitude (Acjr). The magnitude of the earthquake is obtained as being the value where the segment intersects the middle scale.

This process can then be repeated for the other stations. If the procedure was correct, the segments corresponding to the other stations will cross in the same point on the middle magnitude scale of the nomogram (indicating the same magnitude, as we can observe in Figure 7).

Even if this thing does not fully happen, it will then be a very good opportunity to discuss with the students about the errors and the factors that can influence the measurements. Afterwards, the process can be started another time in order to obtain better results. This can be done by clicking the RESET button.

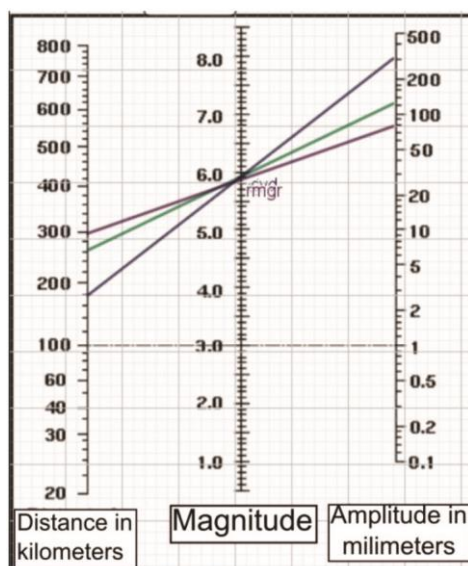


Figure 7. The lines from three seismograms indicating the same magnitude (5.9° on Richter scale).

4. Conclusion

The described instrument and procedure allow the students to find the magnitude of a virtual earthquake and to understand the principles that stand at the base of the Richter scale and the way in which a seismogram is used in order to obtain the needed seismographic information. The GeoGebra application yields the necessary calculus and graphically draws the segments used for finding the magnitude and that allows focusing the discussion on two ideas:

- the qualitative study and the considered concepts;
- the errors that may occur during the measuring process (how we can reduce them and how the results are influenced).

Meanwhile, by having a 'reliable helper', the teacher can dedicate more time and attention to the students, spend more time monitoring their activities, offering more explanations, following the individual progress. This clearly leads to a better quality of teaching and better consequential results. Moreover, the mathematical calculus is reduced to the minimum, the students being encouraged to appreciate the phenomenon from the qualitative point of view, without being discouraged by mathematics that very often is above their understanding level. The fact that the graphical drawings are done by the application reduces the human error and increases the precision of the determinations.

As we emphasised from the start, the earthquakes are part of our daily life—in a country with relatively high seismic activity such as Romania. In this way, studying a daily life phenomenon, with implications for everyone, the motivation of the students for STEM studies will increase and they will acquire a better understanding of concepts as mediated as those related to the earthquakes.

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