TOPICS OF PHYSICS IN VIRTUAL EXPERIMENTATION

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Abstract

The use of information and communication technologies in education for different school levels is becoming an usual practice. Concepts that many times are presented to the students from a static point of view are more easily apprehended when adequate technologies are used to give them greater dynamism.

Bearing in mind the real difficulties in the implementation of an experimental teaching of Physics, it is possible nowadays to present to the students activities inserted in a context of new technologies that encourage the experimentation and the sense of discovery, two essential teaching aspects of the Experimental Sciences.

The project "Topics of Physics in Virtual Experimentation" intends to promote the virtual experimentation in the classroom, through the exploration by the students of computational applications and the development of small investigation projects. All the materials will be available in the project site http:// fisicaexpvirtual.com.

Keywords: Technology, Scratch, Excel, experimentation, Ssreadsheet, computational application, astrolabe.

1 INTRODUCTION

Relationships between mathematics and observable physical phenomena are important for an understanding of the experimental aspects of mathematics, and the validation of hypotheses and modeling techniques developed to simulate observed phenomena.
The potential of computational resources available in schools allow students to develop projects inter-relating various branches of knowledge in a fast and efficient manner.
The work described in this article is a project undertaken at a school in Lisbon as part of a contest sponsored by the Foundation Ilidio Pinho under the theme "The Arts of Physics" and provides some examples of activities implemented with the students within the classroom environment. Considering further developments, we present a proposal for a project to be performed with varying degrees of depth depending on the level of education targeted, related to the XV and XVI centuries Portuguese discoveries and with the orientation in the high seas. This is an overarching subject that runs through several different areas of knowledge from astronomy to mathematics and physics. We use the astrolabe as an example and present an application developed in MS Excel to validate our work.

2 THE PROJECT "TOPICS IN VIRTUAL EXPERIMENTATION"

The use of information technology (IT) in the teaching and learning at different levels of schooling, is an increasingly common and irreversible practice.
Concepts that were previously often presented in a static manner, are easier to grasp by students when adequate technologies are used to introduce greater dynamics.
Given that there are real-life difficulties for implementing experimental approaches to several topics in Physics, it is possible to introduce students to activities in new technologies that encourage *virtual hands-on* experimentation and the sense of discovery - two essential aspects for the teaching of Experimental Sciences. This can be, somewhat paradoxically, referred to as Virtual Experimentation.

The project Topics in Physics on Virtual Experimentation was conducted in an elementary school in Lisbon during the 2009/2010 school year.
The activities covered some topics presented in Physics courses through the 3rd cycle of basic education (7th to 9th grade), in which students explored computer applications and developed small research projects.
The activities took place within the classroom environment, in the Math Club throughout the school year and entailed a significant experimental component. All the materials are available to be consulted online at http://www.fisicaexpvirtual.com (Fig.1)[1].

Figure 1 - Homepage for www.fisicaexpvirtual.com.

The choice of the appropriate software for the simulations was fundamental and included always computer programs of easy and free access in schools. MS Excel, with its programming component in Visual Basic, as well as Geogebra, a dynamic geometry freeware, were natural options since the students already had experience working with these programs from the previous year.

We exemplify some of the themes discussed:

To study direct proportionality, a mathematical concept introduced on 7th grade, we used applications developed in MS Excel.
The application corridadecarros.xls allows to initially enter the distance that the two cars will cover and the speed of each car. Upon clicking on the "Animation" button it is possible to observe the progress of the two cars and the time each car takes to cover the designated distance. This application was built with students during the same period when the mathematical and physical concepts involved were formalized during the classroom lectures (Fig. 2). What we studied was simply the function $d = vt$ where d refers to the distance, v the speed and t, time.

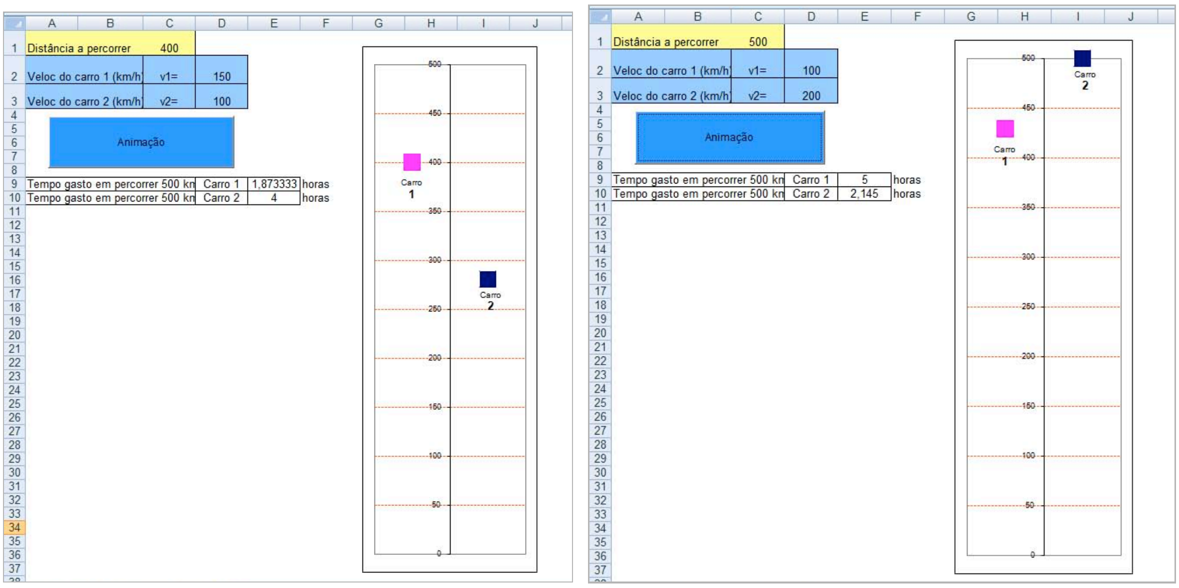


Figure 2 - Application corridadecarros.xls. In the first instance the cars travel 400 km at a speed of 150 km / h for one car and at 100 km / h for the other. In the second example car 1 and 2 travel 500 km at speeds of 100 km / h and 200 km / h, respectively.

Another example investigated was the mathematical relationship between weights suspended on a spring and its elongation. For this we developed an application, using MS Excel, that allows for the visualization of a scheme of a spring and a graphic that expresses the stretching of the spring versus the weight applied. The application also allows for changes on the spring rigidity. The students used this application to see whether the relationship between the elongation of the spring and a weight applied is one of direct proportionality (or correlation). We also carried out experiments to determine the weight that must be suspended on the spring to evoke an elongation of 15 cm, for example, or vice versa- to determine the stretch on the spring caused by a weight of 1.5 kgf. Furthermore, the students changed the spring rigidity and registered what happened on the chart (Fig. 3).

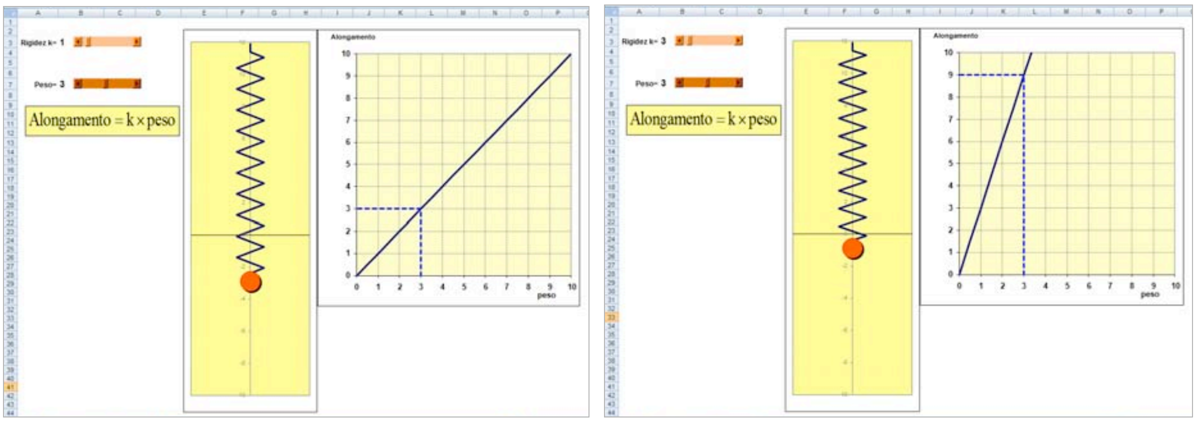


Figure 3 - Application mola.xls. The spring rigidity is altered between the two experiments.

For the first time, we used Scratch, a programming language developed at MIT. Scratch is a pleasant and intuitive programming environment. With a simple graphic interface, it allows students to explore and experiment with programming concepts. Notwithstanding is the fact that it can be used from very basic programs to projects of great complexity, and has several mathematical functions available.

With this programming language it is possible to create simulations and interactive applications. What makes it very accessible is also its block structured programming feature, a syntax common to many programming languages.

Finally, to complement the learning process using Scratch we connected the virtual to the physical world. This was possible with Picoboard, an external sensor kit that when plugged into the USB port of any computer, starts immediately downloading data that can be used in programs such as Scratch.

This device is a circuit board that includes a microcontroller, a button, a scrollbar, a light sensor, a microphone and four ports to measure circuit resistance (Fig. 4).
What happens is that, depending on the sensor, the circuit resistance will vary as a function of a particular property, such as temperature, for instance. In reality, a Scratch project can detect what happens in the physical environment around it and be programmed to react in a particular way.

Figure 4 - Picoboard Scratch

The students' enthusiasm was notorious when they saw their programs "react” to what was happening outside the computer. As examples:
• When the signal detected in a certain "port" indicated that the temperature decreased (the sensor was placed under an ice cube) a recorded voice was heard saying "Ouch, it’s cold!"
• A car in a Scratch program moved to the right, because a student stirred a wheel on which four mercury switches sensors were placed to allow the car to move in four directions.
• Using Scratch we indicated to a bee which flower to land, by putting on the flower a light sensor.
• We calculated the distance traveled by a ring that spins with a magnet placed on it which, when it passed by a certain point, triggered a magnetic sensor. A picture filled with colors and shapes changed dynamically, depending on the sound or the light detected by a sensor (Fig. 5).

Figure 5 - Pictures of some projects done with students.

3 FUTURE PROJECTS

We intend to continue this type of work, by either specifically created applications for teaching certain topics in mathematics and physics, or by encouraging the development of such applications by students themselves, depending on the level of education in which we operate on.
The next section presents a methodology that we consider adequate to develop a project using IT within the field of celestial navigation and nautical instruments used by navigators. It aimed at the development of a MS Excel application to simulate the operation of an astrolabe. Along this section we addressed aspects of astronomy considered essential for a full understanding of this navigation tool of great importance for orientation at high sea. Without going into great detail, in the following paragraphs we will present requisites needed for the simulation of an astrolabe in a Excel-like spreadsheet, from the astronomical to the computational aspects, including the mathematical requirements and some procedures deemed as necessary to build the application.

This project, aimed for students from 9th grade onwards and it does not replace the construction of an astrolabe using a protractor and a cardboard. This crafty model may be used in more junior contexts (grade 7, for example) to determine the height of the building a school, for example.

4 THE PROJECT "ORIENTATION IN THE HIGH SEAS"

For many years, navigating the high seas was regarded as too risky an activity and fraught with life-threatening dangers for the sailors.

During the Middle Ages western world sailors encountered numerous difficulties and, therefore, mainly sailed along the coast. For this type of navigation, guidance was provided using reference points on land. Due to this limitation, the discovery of new territories was very difficult.

It was the careful and meticulous study of the skies for many years, that allowed for the accumulation of knowledge and the development of Celestial Navigation. These astronomy studies led to the discovery of cyclical phenomena such as the succession of days and nights, the existence of the celestial sphere when in the evening the stars appear to be fixed inside a big ball [2], and to verify that the position of the sun on the horizon varies causing the changes in seasons.

Throughout the XV Century there was a significant advance in the explorations of the Atlantic Ocean with expeditions that would last months in the sea. It was, hence, necessary to develop techniques and instruments for the sailors to know their positions and which direction to follow. The long Portuguese journeys of discovery would not have been possible without the genius and ingenuity of the mathematicians and cosmographers of that time who placed in the hands of the adventurous navigators tools as simple and effective as the astrolabe [3]. This instrument can measure the zenith distance at noon, which gives sufficient information to determine the latitude of the place.

4.1 Localization of the starts

4.1.1 Position of the Stars based on the horizon line: horizontal coordinates

On a clear night, from a non illuminated place on Earth, one can easily see the stars. Since the distances between the Earth and the stars are very large, we can imagine them projected on the inner surface of a huge hollow sphere called the celestial sphere. This apparent sensation, does not correspond to reality, but the representation of the celestial sphere with the Earth occupying its center is rather useful when we want to position stars in the sky [2].

However, from a given location on Earth, it is not possible to see the whole sphere. Only one half. This finding led us to realize that each place on Earth has its own horizon- an imaginary plane below which nothing can be seen.

Figure 6 is a schematic representation of a cut of the Earth through one of its meridians, with two observers at different locations. For each observer, A and B, there is a different zenith. The zenith corresponds to the highest point in the sky over the head of the observer (Fig. 6).

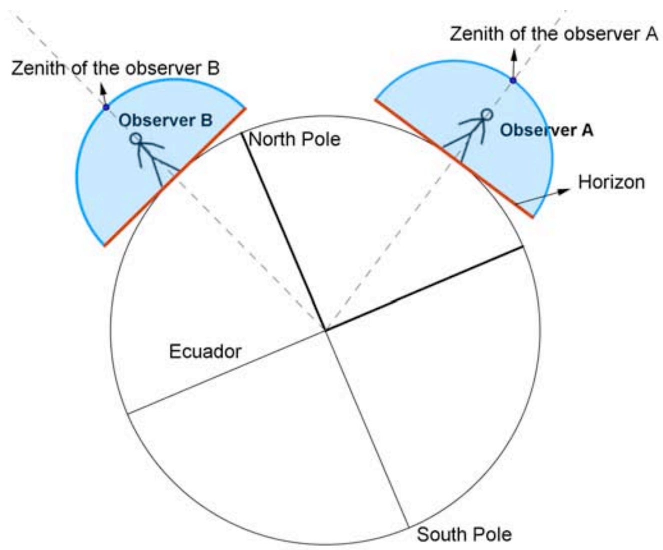
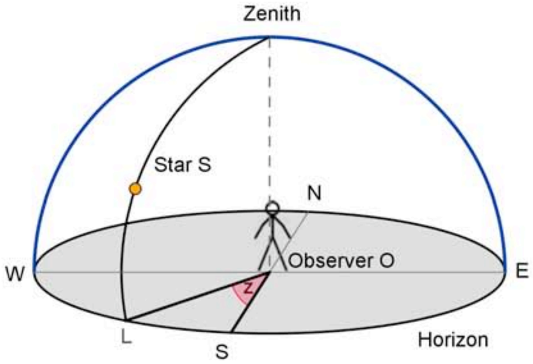
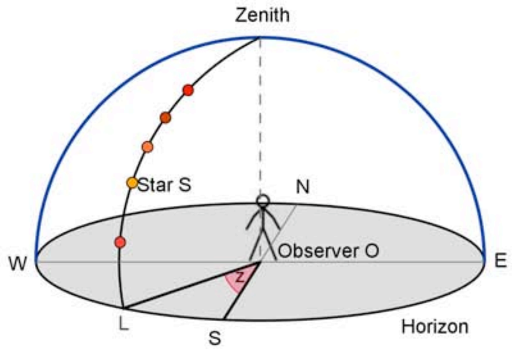


Figure 6 – Meridional cut of the Earth. Representation of the celestial sphere and the horizon for two observers placed at different locations.

We can locate any point on the celestial sphere using the horizontal coordinates. This way of referring to the position of a star refers to the horizon line. The horizontal coordinates are the height h and azimuth z, as illustrated in Figures 7 and 8.
For the azimuth (see Figure 7 (a)) we drew a half-line with its origin at the point where the observer is located (O) and that passes through the point designating as the South Pole (S). Then we drew a line joining the zenith and the point that represents the position of the star, extending it until it intersects the horizon line. Letting L be that point of intersection, the angle formed by two half-lines OS and OL is the azimuth (z).
From figure 7 (b) it can be seen that all the stars that are on the line connecting the zenith and the start S have the same azimuth, therefore the need to define another coordinate, the height, to be able to differentiate one star from another.



(a)



(b)

Figure 7 – Azimuth of a star.

To determine the height we plot a half-line joining the observer to the star and a half-line joining the observer to the point of intersection of S-star line zenith with the horizon line (point L, figure 8). The angle formed by these two half-lines is the height of the star.

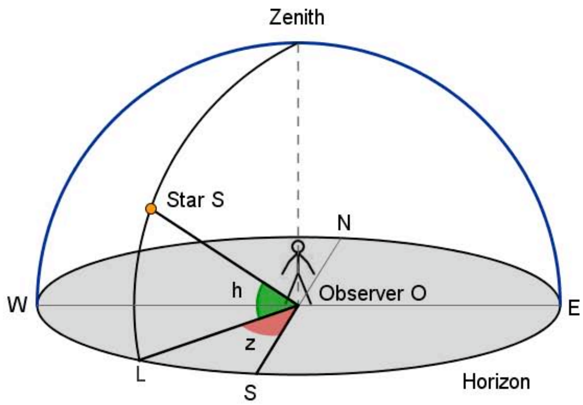


Figure 8 - The horizontal coordinates: height (h) and azimuth (z).

4.1.2 Annual variation of the angle between the rays of the sun and the Earth's axis. The declination of the Sun.

It is known that the Earth moves around the Sun (translational motion) so that its center describes an elliptical orbit in which the center of the Sun is one of the focuses of the ellipse. Given the small eccentricity of this ellipse it is possible, for many purposes, to assume it as a circumference centered on the Sun and that the movement is uniform.
Figure 9 depicts the Earth's orbit around the sun. The Earth is represented in four positions along its orbit. The plane of the Earth's equator is tilted about 23,50 in relation to the plane of the Earth's orbit.

As shown in Figure 9 the angle between the Earth's axis and the rays of the sun varies throughout the year from a peak of 90o+η during the Winter Solstice to a minimum of 90 o -η in the Summer Solstice, going through the mean point of 90° at the Equinoxes (Fig.9).

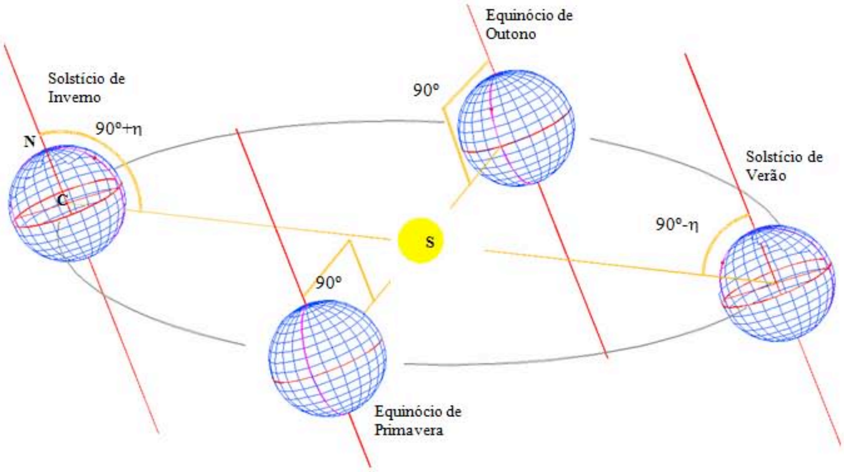


Figure 9 - Translation of the Earth.

The declination is the amplitude of the angle that the sun's rays make with the celestial equator (Fig. 10).

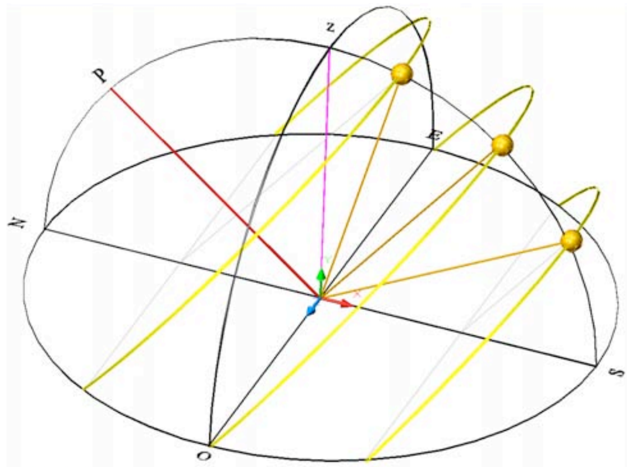


Figure 10 - Celestial Sphere as can be seen by an observer in Lisbon, Portugal

The declination angle, referred to as d, varies seasonally, due to the tilt of the Earth over its axis of rotation. Should the Earth not be tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted circa $23^0$45' and the angle of declination varies, plus or minus this value. Only during the Spring and Autumn equinoxes is the angle of declination 0°.

4.2 Determining the latitude by calculating the meridian altitude of the sun and its declination

The geographic latitude of a place is the angle formed between the meridian of that place and the half-line with origin at the equator and that passes by the zenith of the place. It varies between -90 ° and 90°. Negative latitudes refer to the southern hemisphere and positive latitudes to the northern hemisphere.

During the first half of the XV century, while returning from Guinea-Bissau, the Portuguese developed a technique for navigation to circumvent winds and currents. They'd sail off for about one to two months without sight of land, hence needing to know the location and height of Polar Star in its meridian passage. Comparing this height with the star height in Lisbon or Lagos, they'd easily deduced the number of leagues they had to sail before reaching their destination harbor. The height of

the Polar Star in relation to the horizon directly indicated the latitude of the place. But the navigators faced a problem. When they'd reach the equator line the Polar Star was no longer visible. And there was still the fact that the sun could not be considered a "fixed" celestial body relatively to the Earth. The latitude started to be calculated based on the meridian altitude of the sun and its declination on the day of the observation, for which solar declination tables were built. The first solar declination letters date from 1483, and the Portuguese sailors used the one compiled by an astronomer from Salamanca, Abraham Zacutto[5].
The diagram depicted on Figure 11 shows a meridional cut of the Earth in Winter and the angle X corresponds to the latitude of the place. On that location is an observer. For this location a diagram is shown of the celestial sphere and an indication of the direction of the sun rays at noon, the zenithal distance z which corresponds to the measurement of an arch between the observer-zenith line and the observer-star line. It also shows the declination d. The declination assumes a negative value because the sun is located south of the equator. Applying their knowledge about angles of parallel sides the students can conclude that the angle λ is the sum of the values corresponding to the zenith distance and the declination.

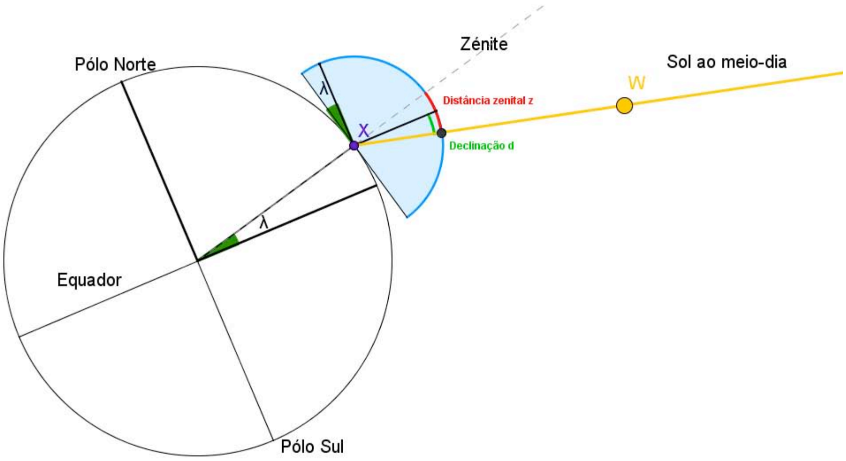


Figure 11 - Latitude of the place X and its relationship with the zenith distance z and declination d.

4.3 The Astrolabe

The Portuguese navigators used the astrolabe to measure the zenith distance of the Sun at noon. The astrolabe that existed at the beginning of the Portuguese Discoveries was a planispheric astrolabe, which was introduced in the Iberian Peninsula by the Arabs and resulted from an original idea from the Ancient Greek (IX Century BC) [3].
The mariner's astrolabe results from a simplification of the former and simply consists of a ring, graduated in degrees with a rotating alidade for sighting the Sun or a star. The ring was cast brass, quite heavy and cut away to keep it from blowing around in the wind. Errors of four or five degrees were common with this rudimentary instrument (Fig. 12).

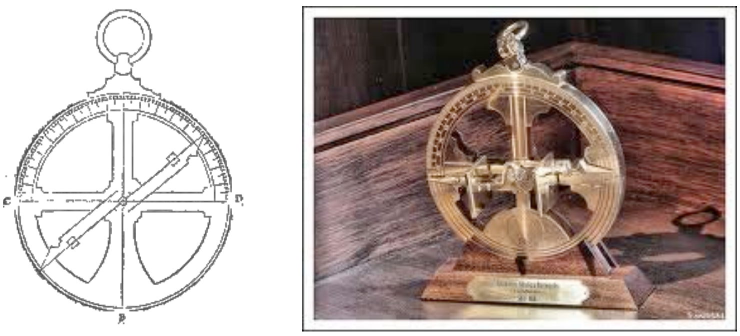


Figure 12 – Mariner's Astrolabe (http://astrolabes.org/pages/mariner.htm).

The mariner's astrolabe was used to measure the altitude of stars, including the Polar Star or the sun at noon.

For that, the medeclina had two small plates, pinnules, with holes in the central parts to peer at the stars or project the light from the sun, to align the cross hairs with the direction of the star. The scheme in Figure 13 shows a cut by a plane south of the celestial sphere at solar noon and a diagram of a mariner's astrolabe, at particular location.

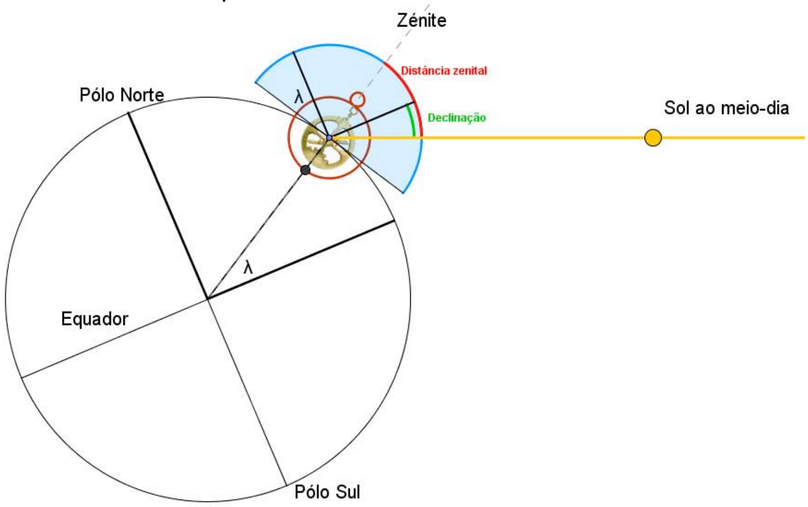


Figure 13 - Latitude.

4.4 Simulation of an astrolab in MS Excel. The application astrolabio.xls

The application astrolabio.xls is available online at http://matematicainteractiva_dm.fc.ul.pt and allows the simultaneously views of the following schemes:

1. The annual motion of the Earth and the variations of the angle of the sun rays with the Earth's axis, over the year.
2. A view from a cut south of the celestial sphere at solar noon and
3. A plan of a mariner's astrolabe (ring, graduated in degrees with a rotating alidade for sighting the Sun or a star).

The positions of the sun at the solstices and equinoxes, and a view from a meridional cut of the Earth and the celestial sphere, on a given location are also represented on Fig. 14 [4].

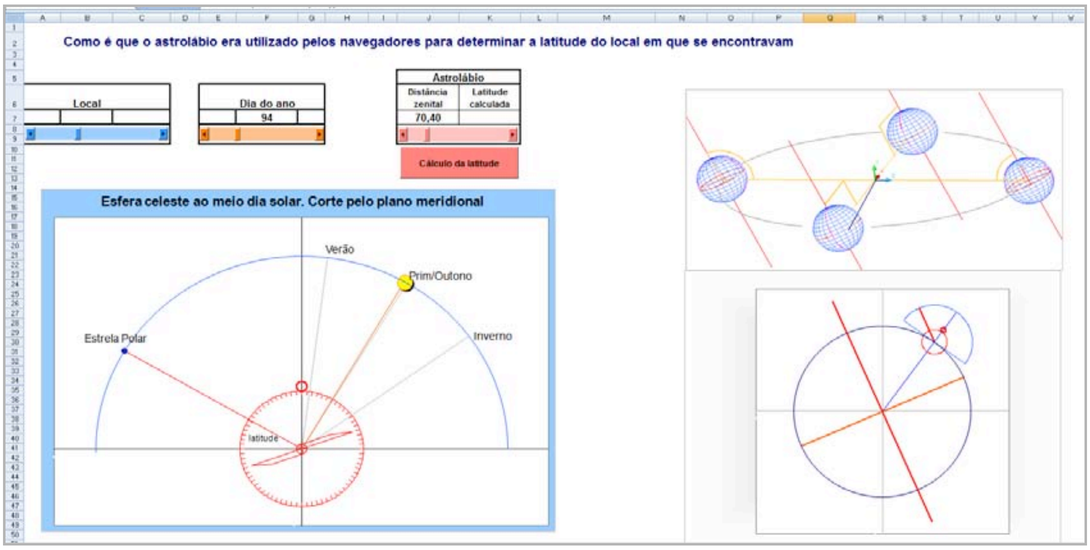


Figure 14 – View of the astrolabio.xls application.

Using the application one can choose a location on Earth in the northern hemisphere (the blue scroll bar), choose the season of the year (orange scroll bar) and simulate a measurement, with an astrolabe, of the zenith distance (red scrollbar).

The zenith distance of the Sun is the angle that the sun rays make with the vertical of the place.

When pointing the alidade to the sun, one just clicks on the "Calculation of Latitude" button and the

resulting measurement value arises.
We now reveal some relevant points for the construction of this application.
Basically, it is necessary to introduce three scrollbars, one to choose a location, another to choose the day of the year and the last to simulate measurements with the astrolabe (Fig. 15)

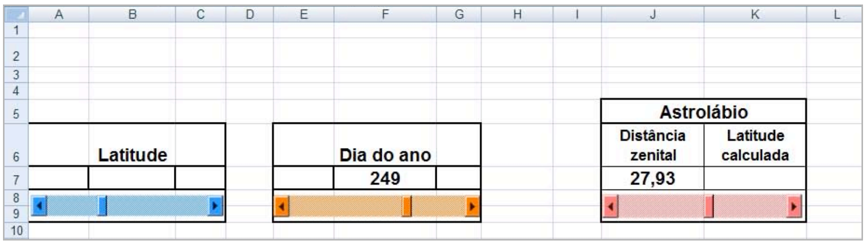


Figure 15 – Data input for the application astrolabio.xls.

Next, we introduce a command button which will perform the calculations of the latitude. An approximate value of declination can be obtained from the formula

d = 23.43 x sin [360 / 365 x (284 + N), where N stands for the number of the day taking into account that the latitude is equal to the sum of the declination with the zenith distance.

5 CONCLUSIONS

These interactive and dynamic models can be a strong motivation for students who want to get a deeper understanding of their possible dynamic behaviors.
By simply using software tools available on most computers we have the shown that mathematical examples can be experimented without relying on specialized software.
From a computational standpoint, all applications we needed were simple and intuitive. Therefore, it is possible to focus on the "conceptual mechanism" of these examples and make it easily accessible to those who want to learn mathematics and its applications deeply.

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