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Planetarium software in the classroom

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Abstract

Students often find astronomy and astrophysics to be most interesting and exciting, but the Universe is difficult to access using only one's eyes or simple equipment available at different educational settings. To open up the Universe and enhance learning astronomy and astrophysics different planetarium software can be used. In this article we discuss the usefulness of such simulation software and give four examples of how such software can be used for teaching and learning astronomy and astrophysics.

1. Introduction

Astronomy and astrophysics are subjects that tend to spark interest in pupils and students. Being one of the oldest sciences it is still a relatively unexplored area, with a huge number of new questions to be answered. Fascinating pictures and TV shows in addition to famous presenters has kept the interest alive and reaching new generations. While books, pictures, and TV shows, give one aspect, the possibility to observe the sky has becoming increasingly difficult due to light pollution [1]. And, to do your own systematic observations are even more difficult. However, the development of planetarium software, such as *Stellarium* [2], *Starry Night* [3] and *Celestia* [4], to mention a few, opens up possibilities to be able to do systematic studies in the classroom in a comparably short time. This cannot replace proper observations but serve as a supplement. The planetarium software computes the position of the stars, planets, moons and the Sun using proper algorithms, making it a suitable tool to study different aspects of the Universe.

The aim of this paper is to discuss and demonstrate some of the possibilities planetarium software has in finding interesting teaching projects to enhance teaching and learning astronomy and astrophysics.

2. Background

As a way to help students come to understand the grandeur and complexity of the multidimensional Universe, different learning environments can be used. A learning environment could be any environment where learning can take place: in lecture-rooms, laboratories, at home, etc. *Virtual* learning environments (VLEs) are powerful learning environments created using multimedia tools. These environments offer potential for learning through their use and way of presenting different disciplinary-specific representations using visualisations [5]. These have been found to offer new possibilities for students to learn about the Universe in ways that otherwise would be difficult [6] by offering the experience of 3D.

Learning astronomy and astrophysics demands to be able to think spatially [7], or in ones' mind conceptually extrapolate three-dimensionality from a 2D input [8], but this have been found very difficult for students and is furthermore an often taken-for-granted ability or competency [7, 9–13]. However, only little is known about the learning possibilities that such a collection of representations can present to 'reflective learners' [14] and how the ability to extrapolate three-dimensionality is related to the level of disciplinary knowledge of the students. Furthermore, having access to such learning environment does not automatically make learning possible, since a fluency in understanding and using the disciplinary-specific representations [15] used in such environment is prerequisite to be able to interpret the displayed information [6].

Learning to understand the Universe has been shown to involve learning to 'Read the Sky', a metaphor for learning to understand and communicate via the 'language' of astronomy and astrophysics [16]. This 'language' involves not only words, but all the different disciplinary-specific and highly specialized representations, tools, and activities, that are used within the disciplinary discourse of astronomy and astrophysics [15].

With this background, planetarium software, as interesting examples of VLEs, offers many possibilities for learning astronomy and astrophysics in potentially new and beneficial ways, as they dynamically introduce students to the details, structure and complexity of the Universe in pseudo-3D, which is otherwise impossible using other representations [17–19]. Indeed, research has found such simulations, for example planetarium software, to be beneficial for learning astronomy and astrophysics [16, 20–29].

3. Planetarium software

The use of practical exercises in astronomy is often restricted by the impractical time requirements associated with observations. The use of planetarium software makes this possible using a realistic simulated environment with no limitations on time or location. This is especially useful for example when teaching the phases of the moon [24, 37]. If done in practice using real observations, one has to be able to perform systematic observations over a period of 28 d, with all constrains due to weather conditions and other factors. By illustrating different astronomical concept with realistic simulations instead of static figures or textual descriptions it is easier for pupils and students to overcome misconceptions [13, 38–40]. It is also possible to set up a hypothesis, for example how the stars move on the north pole or the equator, and test it with planetarium software [23].

There exists a multitude of different planetarium software [2–4], with similar representations and disciplinary affordances. The differences are mainly in the degree of sophistication and the intended user-groups. Our aim is to use software that is both cheap and easy to use for students, yet advanced enough to provide the disciplinary affordances needed. Popular commercial software (for example *StarryNight* [3]) has in principle the same features as available open source software (*Stellarium* [2] and *Celestia* [4]) why we have chosen to use *Stellarium* as the software to be referred to in this article, as it is easy to use, a freeware, and available in a number of languages. It should be noted that the discussion in general is not dependent nor restricted on using a specific planetarium software.

Below, we give four examples of what information obtained from using planetarium software can be used for. By navigating such software, students can extract information that can be used for further investigations in astronomy.

By positioning oneself on Earth, (1) information about the apparent path of the Sun over the sky can be obtained and used for finding the Equation of time (difference between sidereal (relative to the stars) and synodic time (relative to the Sun)), (2) determining the distance to the Sun similar to the method used by Aristarchus of Samos, (3) elongation of the planets as observed from the Earth, and (4) the HR-diagram, fundamental to all of astronomy and astrophysics.

3.1. Here comes the Sun

One of the oldest astronomical instruments used is the sundial. With it you can measure the height of the Sun in the sky, which is the altitude of the Sun. It is quite easy to construct a sundial and measure the altitude during one day [30]. Even more interesting is to study how the altitude changes over a year. To do this experimentally

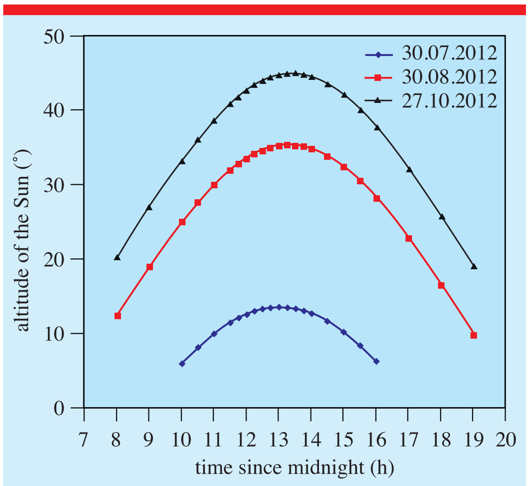

Figure 1. Obtained solar altitude in Trondheim (latitude: N63°26′24″) for three different days using *Stellarium*.

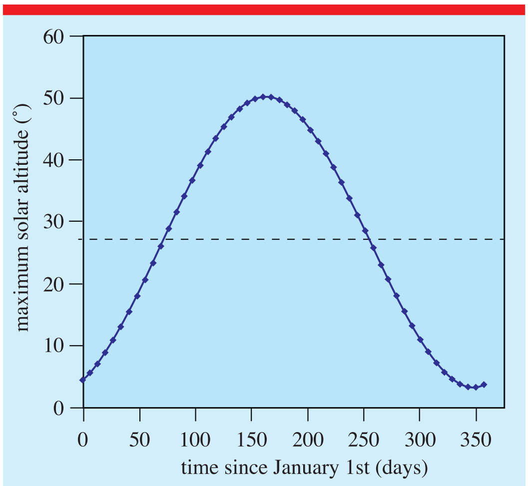

Figure 2. Obtained maximum solar altitude in Trondheim using data from *Stellarium*.

would take at least three months. But by using planetarium software it is possible to get enough data in less than hour. By selecting a specific day each pupil can obtain the solar altitude by reading the value for different times during his/her day, for example every 15 min close to midday and 30 min otherwise. The angle can then be plotted as a function of time (since midnight). By choosing suitable days the pupils will clearly see the differences. One must be cautious with daylight saving time. Figure 1 shows the Sun's altitude for three different dates in Trondheim, Norway. Note that one is not bound to one's own location, but can do this for any location on Earth.

The use of solar altitude in navigation can be an interesting subject in combination with geography and history. For example has it been established that the Vikings used a solar compass [31, 32] based on the principle of solar altitude. It is possible to test the accuracy of such a navigational device using the data obtained, and answer the question on how the Vikings managed to reach Iceland, Greenland and ultimately America.

By studying the altitude of the Sun during one day, one will notice that the maximum altitude changes during a year. Figure 2 shows the maximum solar altitude during a year in Trondheim.

It is possible to use data on the maximum solar altitude collected during a year to determine (a) the latitude (λ) of the observation location, (b) the obliquity (φ) of the Earth's axis, (c) the length of a year (T) and (d) the date of the vernal equinox (t_0), as have been shown in the excellent article by Lahaye [30]. The maximum altitude can to a good approximation be shown to be:

$$\theta_{\max} = 90° - \lambda + \varphi \sin\left(\frac{2\pi}{T}(t - t_0)\right)$$

Using this expression to fit to the data it is possible to determine the different parameters and get semi-experimental values of them.

Pupils paying attention will possible find that the maximum altitude does not occur at 12.00 (unless they place themselves on the Greenwich meridian or at any meridian at n * 15° E/W; $n = 1, 2, 3, \ldots, 24$) and that the time changes during the year. This is due to the concept of local noon, and that the Earth is divided into time zones. The variation of the time for maximum altitude is due to the eccentricity of the Earth's orbit, which gives rise to the *equation of time*, the difference between the time of maximum altitude at that specific longitude and the observed time:

$$E(t) = T_{\max(\text{longitude})} - T_{\max(\text{observed})}$$

Figure 3 shows the *equation of time* for Trondheim.

The *equation of time* can be shown as [30]:

$$E(t) = \frac{d}{2\pi}\left[\frac{1 - \cos\varphi}{2}\sin\left(\frac{4\pi}{T}(t - t_0)\right) - 2\varepsilon\sin\left(\frac{2\pi}{T}(t - t_1)\right)\right]$$

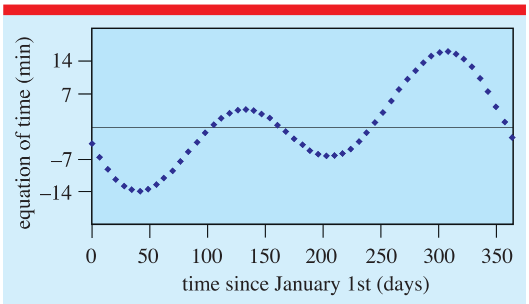

Figure 3. Obtained *equation of time* for Trondheim from *Stellarium*.

Where d is the length of the day, ε the eccentricity of the Earth's orbit and t_1 is the time for perihelion. By fitting data it is possible to determine the parameters.

3.2. Distant Sun

Aristarchus of Samos was an ancient Greek astronomer and mathematician who presented the first known model that placed the Sun at the center of the universe with the Earth revolving around it. He is mostly known for this determination of the distance between Earth and the Sun. We will use data taken from *Stellarium* and show how this was done.

Aristarchus used a simple geometrical construction based on when the moon is half lit, which is when the angle formed by the Sun–Moon–Earth is 90° (figure 4). All you have to do is determine the angle between the Moon and the Sun, which turns out to be rather challenging a task. In addition, one has to determine when the Moon is half lit.

Using a planetarium program you can find the illumination in the object information, why it is relatively easy to find the moment when the Moon is half lit. With this information it is possible to go out and determine the angular distance between the Sun and the Moon with a suitable tool, such as a sextant. While this is easy in theory it is challenging in practice. Using planetarium software it is possible to measure the angular distance in the software. *Stellarium* has an angular measuring feature making it possible to measure the angle directly (figure 5). One must observe that this method uses the local quarter, the local time when the moon is half lit from that position, on the surface of the Earth, while in general astronomical calendars the quarters are normally calculated from the centre of the Earth, so the time will be different as the position will give rise to a difference.

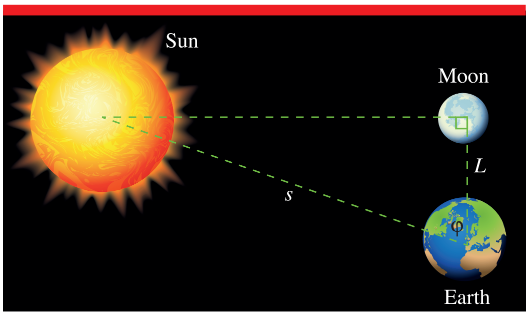

Figure 4. Sun–Moon–Earth system when the Moon is half lit.

Using the local quarter and measuring the angular distance gave a value of $89°51'30'' = 89,86°$. Using Aristarchus relation,

$$\cos\varphi = \frac{L}{S}$$

one obtain that the distance to the Sun $S = 409L$, in fair agreement with more accurate results.

3.3. The planets

The planets move in quite complicated patterns over the sky. This was a problem in the old geocentric picture of the solar system, where the only acceptable movements were circular, thus giving rise to epicycles. Copernicus based his heliocentric picture on circles, why his system was also complicated with epicycles. Kepler found a solution to this by using elliptical orbits. Kepler was also able to use the distances from the Sun to the different planets in his third law, stating that

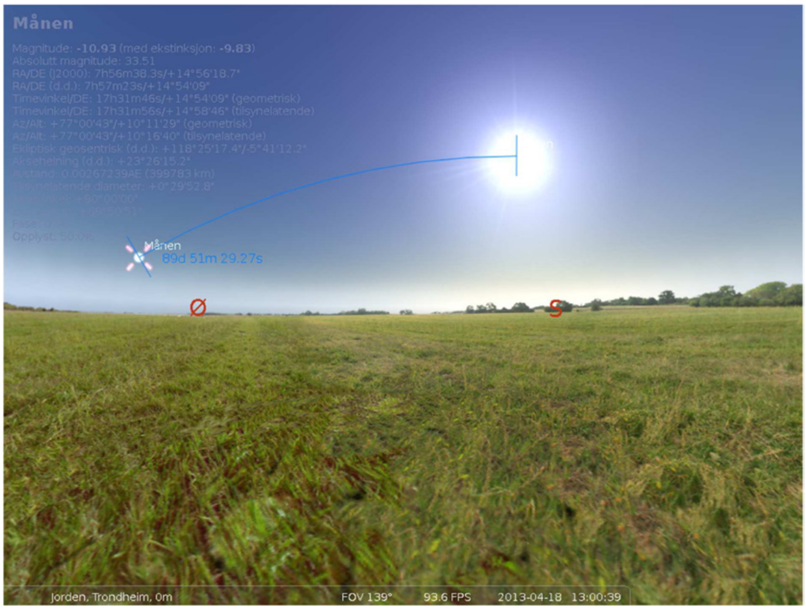

Figure 5. Screen dump from *Stellarium* with angle measurement between the Sun and the Moon. 18 April 2013, 13:00:39 (local quarter in Trondheim).

$$\frac{T^3}{r^2} = \text{constant}$$

where T is the orbital period of the orbiting body and r is the radius of the orbit, i.e. the semi-major axis of the ellipse.

It is possible to determine the radius of the orbit to the inner planets by studying the greatest *elongation*. A planet's elongation is the angle between the Sun and the planet, with the Earth as the reference point. The greatest elongation of a given planet occurs when this inner planet's position, in its orbital path to the Sun, is at tangent to the observer on the Earth (figure 6).

From figure 6 we find that the greatest elongation gives:

$$\sin\theta_{\max} = \frac{r_{\mathrm{P}}}{r_{\mathrm{E}}} \rightarrow r_{\mathrm{P}} = r_{\mathrm{E}}\,\sin\theta_{\max}$$

If we determine the greatest elongation we will be able to express the radius of the inner planets expressed in the Earth's distance to the Sun, i.e. one Astronomical Unit (AU). This can be done with observations or using planetarium software. However, since the orbits are ellipses we will find that the greatest elongation varies, especially for Mercury, which has an eccentric of 0.20. Depending on when you determine the greatest

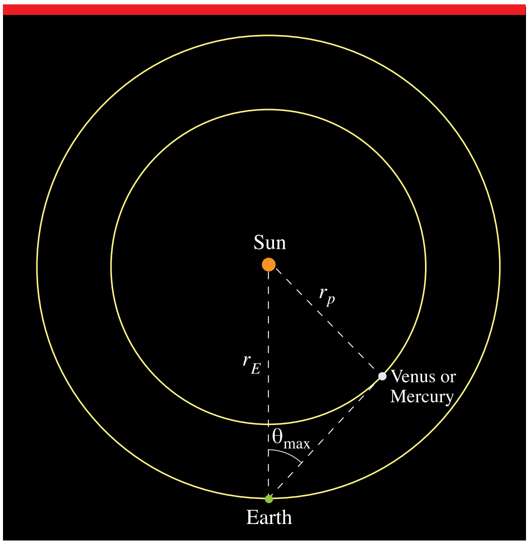

Figure 6. Diagram showing the elongations of the inner planets from the Earth's position.

elongation the value will fall between 18 and 28 degrees. Using these values we find that the radius of Mercury's orbit vary between $0.309r_{\mathrm{E}}$ and $0.469r_{\mathrm{E}}$, compared with $0.307r_{\mathrm{E}}$ and $0.467r_{\mathrm{E}}$ from accurate measurements [33]. The difference is due to the eccentricity of the Earth's orbit. Venus has a much smaller eccentricity, smaller than the Earth's, which gives a larger uncertainty. The values obtained are close to the real value. It is possible to obtain acceptable results using planetarium programs and having the possibility to 'observe' over a long time.

The situation with the outer planets are more complicated, at least if we stay on Earth. However, with planetarium software it is possible to travel in space, and observe the Earth from an outer planet, with offers more learning possibilities for the students, see above. From these traveling and new positions it is then possible to use the same principle as we did with the inner planets from Earth.

3.4. HR-diagram

Hertzsprung–Russel (HR) diagrams are graphs of stellar properties showing the relationship between stars' absolute magnitudes, or luminosities, versus their effective temperatures, classifications, spectral types, or colour index. Historically, the diagram played an important role towards an understanding of stellar evolution. HR-diagrams are neither maps of the location nor movement of stars during their life, something that is a common belief. The information needed to construct an HR-diagram is readily available in planetarium software, why it is not necessary to access that information in tables. However, disciplinary discernment from such diagrams are very difficult for pupils and students since the diagrams can be seen as being constructed in non-intuitive ways, with the axes pointing in reversed directions and using logarithmic scales [41–43]. One advantage is that the pupils/students will see that the position of a star in a HR-diagram does not depend on its location in the sky.

3.4.1. Construction of HR-diagram. Even if HR-diagrams are widely used there does not exist any common nomenclature, as there are lots of options as to the quantities on the axes. The vertical axis show the absolute magnitude, or the luminosity, while the horizontal axis show the color index, surface temperature, spectral type or classification, the latter two not being numerical quantities. In addition will the surface temperature give a non-linear, reversed, scale. However, it is important to choose the same quantity in the HR-diagrams as the one you have as reference.

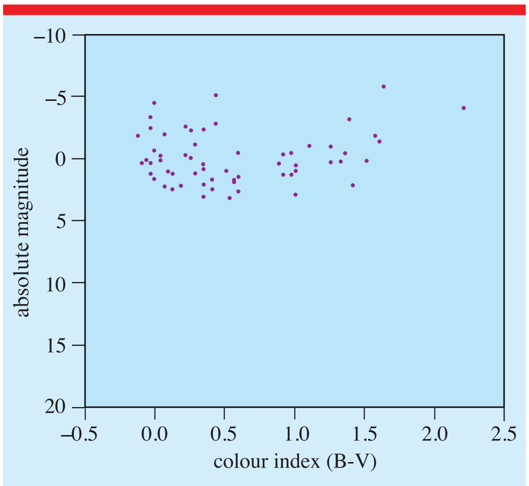

Figure 7. HR diagram for a limited area of the sky (decl. 20°–25°, RA 6h00m–6h30m, data from *Stellarium*).

If you choose colour-index and absolute magnitude, that information is available in *Stellarium* together with other information of a selected star. To have the absolute magnitude one must know the distance to the star, something that limits the number of stars with available information. The data of a significant number of randomly selected stars can then be analysed in a spreadsheet program. If one chooses absolute magnitude pupils and students will have to discern that the scale is inverted. A small selection of stars, as seen in figure 7, will not give an HR-diagram as we know it. This is due to that we randomly select the brighter or more luminous stars (Malmquist bias [34]), thus only representing the upper part of the HR-diagram. This can thus be used to discuss how you sample your stars. A better way is to let different pupils/students select a part of the sky (determined by the coordinates), or a constellation, and note every star within this region. However, open clusters, e.g. the Pleiades, are most suitable for this exercise, since they include many stars of approximately the same age but in different stages of stellar evolution, see below. If you get a larger number of stars a better HR-diagram will be obtained, as seen in figure 8.

3.4.2. Use of HR-diagrams. In addition to obtaining an HR-diagram, one can use it to determine the age of a star cluster (e.g. [44]). As mentioned earlier, open star cluster is a group of stars that

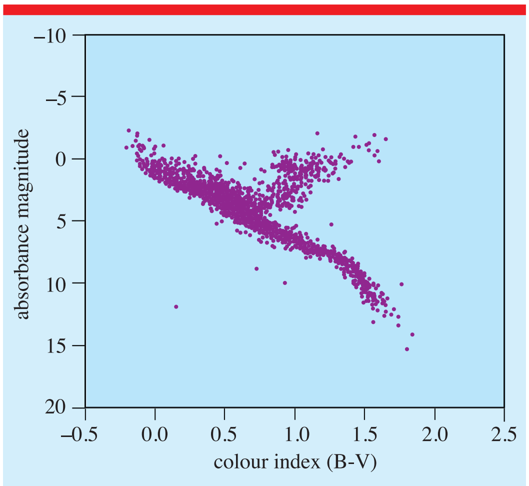

Figure 8. HR diagram constructed from 5000 stars with data from the Hipparcos catalogue [35].

formed at approximately the same time. Since we know that the lifetime of stars in the main sequence is dependent on their absolute magnitude, it is possible to see the turnoff-point in a self-constructed HR-diagram to discuss and assess the age of the cluster [36]. For example, if one finds a small number of stars with high absolute magnitude one can tell that the cluster is older than the lifetime of those stars. The open star cluster Pleiades can be studied in this way and the obtained HR-diagram can be compared with theoretical models of stellar evolution, giving an age between 75 and 150 million years.

4. Discussion and conclusions

The aim of this paper was to discuss and exemplify the possibilities of using astronomical simulation software in teaching and learning astronomy and astrophysics in the classroom. Recent research has shown that students are struggling with their understanding of the Universe and our argument, based on recent literature, is that by exploring a VLE, such as a planetarium software, students are better equipped to learn fundamental aspects of the Universe. From the same software, it is then possible to design tasks and extract information that uses students' prior knowledge and experiences to enhance learning at a more advanced level, in accordance with the ADD hierarchy [6]. The given examples represent tasks that we have tested in classrooms over the years and found useful, doable, and, most importantly, educationally important for the students. In these we connect observations with experience and data collection, i.e. disciplinary discernment, and use this to increase the learning opportunities, hence increase the disciplinary knowledge by the students.

The first example (Solar height) can in principle be done without planetarium software, but it becomes more practical to use such software. The goal is to understand variations in height of the Sun in relation to latitude for the observer and exemplify this by studying the solar height from different locations on the Earth. This example also opens up possibilities for studying the equation of time, and as such taking the exercise to an ever higher level concerning both disciplinary discernment and disciplinary knowledge. The second example replicates very old observations of the Moon and the Sun to determine the relative distance to the Sun. This exercise is very difficult to do from real observations but using the software it is much easier and potentially leads to a deeper understanding of the lunar orbit, its motion and, perhaps most importantly, the relative size and arrangement of the celestial bodies involved. Research have repeatedly shown this to be very difficult to understand for students and pupils of all ages ([7, 8], and references therein). The third exercise continues to challenge the students in their development of extrapolating three-dimensionality competency [7], hence their understanding of the arrangement of the celestial bodies in our planetary system. Finally, the fourth example, exploring properties of stars, have the potential in helping students enhance their understanding concerning astrophysics on stellar evolution. The HR-diagram, very central to all of stellar astrophysics, is a representation that has been show to be difficult for students to 'read' or understand [16]. By challenge them to develop such representations themselves [45], it may be possible to enhance their disciplinary discernment and knowledge.

In all of these examples the role of the teacher is central [46] as one providing the necessary scaffolding needed to help students crossing the boundaries in the ADD and by then helping the students becoming their own teachers in the process of teaching and learning astronomy and astrophysics. Only then will the students/pupils develop representational competency and be able to fully 'read the sky'.

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