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Programming Ozobots for teaching astronomy

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Abstract

Experimental teaching is essential for a good understanding of science, especially on Physics. Practical activities play an important role for engaging students with science, mainly when they interact directly with equipment, collect experimental data with computers and/or use interactive software for data analysis. In this work, we present the use of low-cost mini-robots as an 'object-to-think-with' for teaching and learning with technology. The activity concerns programming the robots to make them run in circular paths, record videos of their trajectories and analyse them with Tracker Software, to boost the study of Astronomy contents. This kind of practical activity develops multiple skills in students and is usually very well accepted because it involves robots, programming, manipulating technology and for raising topics that are difficult to understand in real-life observations, making them cognitively accessible to the vast majority of students. In this practical activity, students are asked to create the robot programming code and make a video recording (with a smartphone) of the robots' trajectories, mediated by the teacher, who assists in the construction of the experimental activity and analysis of the data obtained. The results will allow students to understand Kepler's laws of planetary motion and why some planets seem to have an apparent retrograde motion as seen from the Earth, a problem that arose in IV BC and was only officially solved by the Copernicus heliocentric model, published in 1543, the year of his death.

Keywords: block programming, robots in science, kinematics, astronomy, apparent retrograde motion, Kepler's laws

1. Introduction

Experimental teaching is essential for a good understanding of science, especially on Physics [1, 2]. Practical activities play an important role for engaging students with science, mainly when they interact directly with equipment, collect experimental data with computers and/or use interactive software for data analysis [3–6].

Astronomy is an observational science. Many astronomical phenomena can be observed from Earth with the naked eye, such as Moon phases or eclipses. One other phenomenon observed with the naked eye is the so-called retrograde motion of the planets. During the year, planets will generally drift slowly eastward (direct motion) relative to the 'fixed' stars. At very specific times, this drift stops and the planet starts moving westward (retrograde motion) for a few days/weeks, after which it resumes its direct motion. This particular unusual motion of the planets is the reason why they are called as such: the word planet comes from ancient Greek and means 'wanderer'. Several Greek philosophers addressed this phenomenon. Plato (c. 428–c. 348 BC) challenged his students and contemporaries to find a model combining circular motions that would explain this retrograde motion. One such description gave rise to the epicycle model proposed by Apollonius of Perga (c. 240–c. 190 BC), Hipparchus of Nicaea (c. 190–c. 120 BC) and later used by Ptolemy (90–168 AD) to describe the geocentric model of the Universe [7, 8]. However, this description using epicycles has always been controversial among astronomers. Almost 14 centuries after Ptolemy's death, the apparent motion of the planets was once again explained, but now in a very simple way by Copernicus (1473–1543). In his book 'On the Revolutions of the Celestial Spheres', published in 1543, the year of his death, Copernicus used the Aristarchus of Samos (c. 310–c. 230 BC) heliocentric model for the Solar System, although not citing Aristarchus in the final published manuscript, but only in an early unpublished version of the same book. The apparent retrograde motion of a planet as seen from the Earth was simply the result of both of them orbiting the Sun with different periods.

Understanding the reasons why the apparent retrograde motion is observed is, then, very important for the students' knowledge of the evolution of physical models and the understanding of planetary motion in the Solar System.

In this work, we present the use of low-cost mini-robots called Ozobots as an 'object-to-think-with' [9] for teaching and learning Astronomy with technology. The projected activity concerns programming the robots to make them run in circular paths, record videos of their trajectories and analyse them with Tracker Software [6], to boost the study of Astronomy contents. Students are asked to create the robot programming code for the robots representing four planets and make a video recording (e.g. with a smartphone) of the robots' trajectories. The aim of this educational activity is to allow students to recognize why some planets seem to have an apparent retrograde motion as seen from the Earth and to confirm Kepler's third law for planetary motion, contents that are usually taught theoretically only with drawings.

2. Educational, low-cost and mini-robots

The Ozobot® bit is a robot that identifies lines and colours. It is small and very versatile and is programmable with sequences of coloured lines (red, blue, green and black) or using programming blocks with dedicated online software called Ozoblockly. To make the robot move with very specific speeds, we may have to use block programming code. The mini-robot can have speeds between 20 and 120 mm s^{-1}. In this study we chose the speed of the robot representing the Earth as 60 mm s^{-1} to guarantee that the speed of the other robots, representing the different planets, will be within the robot limits. The block programming codes for the Ozobots representing Mercury and Earth are shown in figure 1.

3. Preparing trajectories and robot speeds

Table 1 shows the average orbital distances of the inner planets to the Sun and their equivalent values in Astronomical Units (au). The data was imported from https://solarsystem.nasa.gov/planet-compare/website.

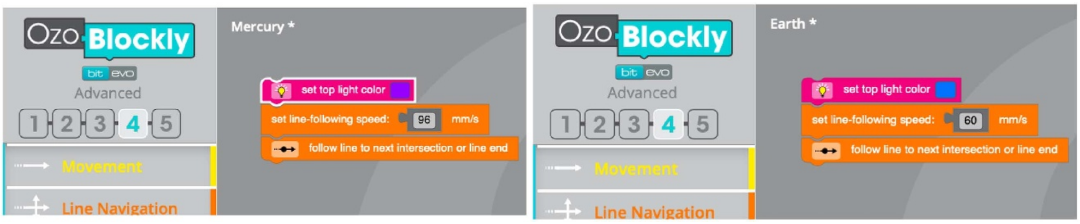

Figure 1. Block programming from Mercury and Earth Reproduced with permission from Ozobot.com (2021).

Table 1. Average distances of planets to the Sun. The data was imported from https://solarsystem.nasa.gov/planet-compare/website.

Distance to Sun	Mercury	Venus	Earth	Mars
(km)	57 909 227	108 209 475	149 598 262	227 943 824
(au)	0.387	0.723	1.000	1.524

Table 2. Average orbit speed of planets in km h^{-1} and in relative speed to the Earth. The data was collected from https://solarsystem.nasa.gov/planet-compare/website.

Speed	Mercury	Venus	Earth	Mars
(km h^{-1})	170 503	126 074	107 218	86 677
Relative to the Earth	1.590	1.176	1.000	0.808

As the orbit eccentricity of the planets is relatively small (except for Mercury), for simplicity we shall consider the trajectories of planets as circular orbits. Therefore, the planets move at nearly constant speeds. The average speed of each planet and the corresponding relative speed to the Earth are presented in table 2.

For the representation of the circular planets' paths, the sun (yellow) is at rest at the centre while the planets are depicted by Ozobot Bit robots, acting as Mercury (violet), Venus (yellow), Earth (blue) and Mars (red) (figure 2).

For convenience, we programmed the robot representing the Earth to move at a speed of 60 mm s^{-1} and the radius of its trajectory corresponding to 1 unit of length. The speed of the other planets was programmed accordingly to table 2 and the corresponding circular path radius were calculated from table 1.

Each robot representing a planet was then recorded with a smartphone at 60 frames per second (fps) and the respective speeds calculated with Tracker software [6], as shown in figure 3.

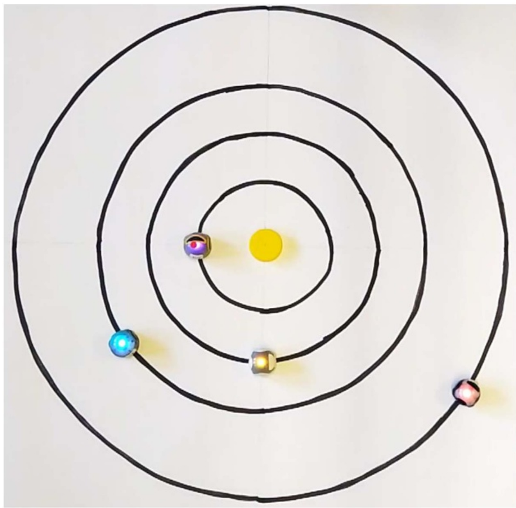

Figure 2. Circular paths representing the trajectories of the inner planets in the Solar System.

The values of the programmed, experimentally measured and relative speeds of each planet to Earth's speed, are presented in table 3. Note that the real speed of the Ozobot Bit does not match exactly with the one programmed. The experimental speeds obtained for the planets relative to Earth's speed (table 3) are close to those found in the literature (table 2) with very small errors, except for 'Mercury' for which we obtained an error of about 13%.

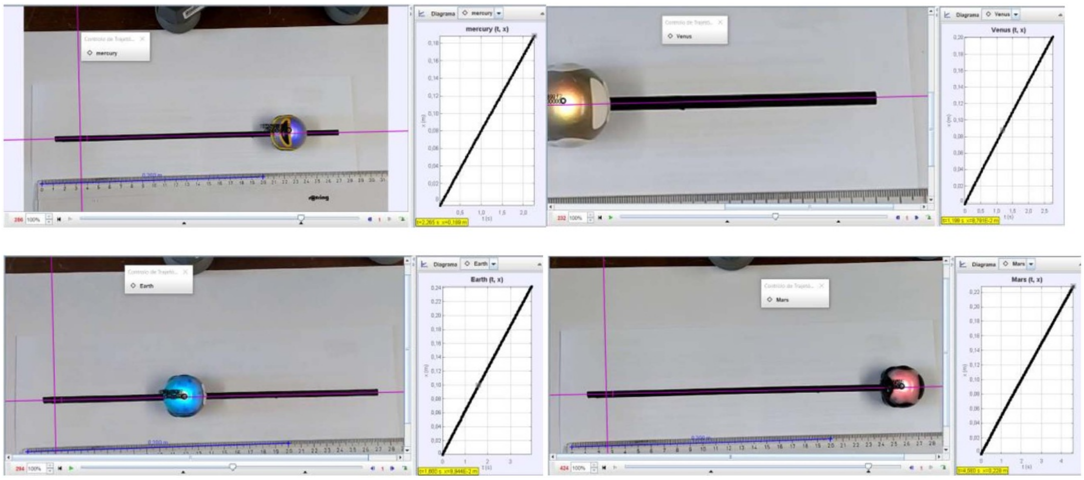

Figure 3. Snapshot of Tracker software for calculating the speed of robots representing the planets. On top, Mercury (violet) and Venus (yellow); on bottom, Earth (blue) and Mars (red).

Table 3. Programmed, measured and relative speeds of each planet to Earth's speed. The radius of each circular path is presented in arbitrary units (au) considering the Earth trajectory radius as 1 unit of length.

Speed	Mercury	Venus	Earth	Mars
Programmed (mm s^{-1})	95	71	60	49
Measured (mm s^{-1})	86	73	61	50
Relative to Earth's speed	1.410	1.197	1.000	0.820
Radius				
Measured (au)	0.40	0.69	1.00	1.49

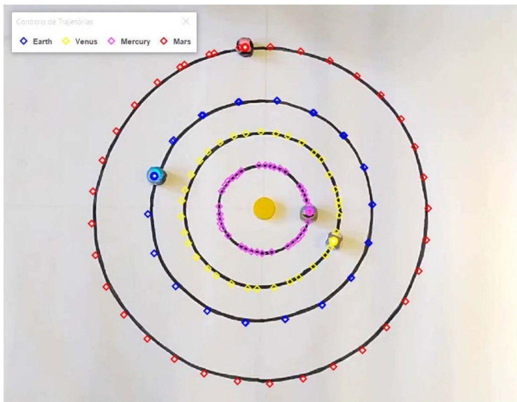

Figure 4. Circular trajectories of the inner 'planets'. The Sun is represented at the centre.

The radius for each circular path were also measured with Tracker and are presented in table 3 in arbitrary units.

The reason why we present these results is to alert teachers that the programming of Ozobot Bit robot is not extremely accurate. Moreover, when the circular paths are drawn, there will always be small deviations in the radius in relation to the intended one. This situation is part of an experiment and must not be discarded from discussion with the students. Nevertheless the limitations of this representation, we will show, in the following, that this activity is suitable to conceptually explain astronomical phenomena and precisely enough to confirm Kepler's third law of planetary motion.

4. Apparent retrograde motion

The apparent retrograde motion of planets is an astronomical phenomenon that is only observed in a local reference frame, such as the Earth. To explain this effect on the light of a Sun centred planetary model, we start by recording the robots moving around the Sun in circular paths as shown in figure 2.

The video was recorded by a smartphone at 60 fps and analysed with Tracker. It can be downloaded from the URL: https://youtu.be/Q_Rl3e-9Zjg. Figure 4 shows the circular trajectories for the several 'planets' at 0.5 s of time intervals.

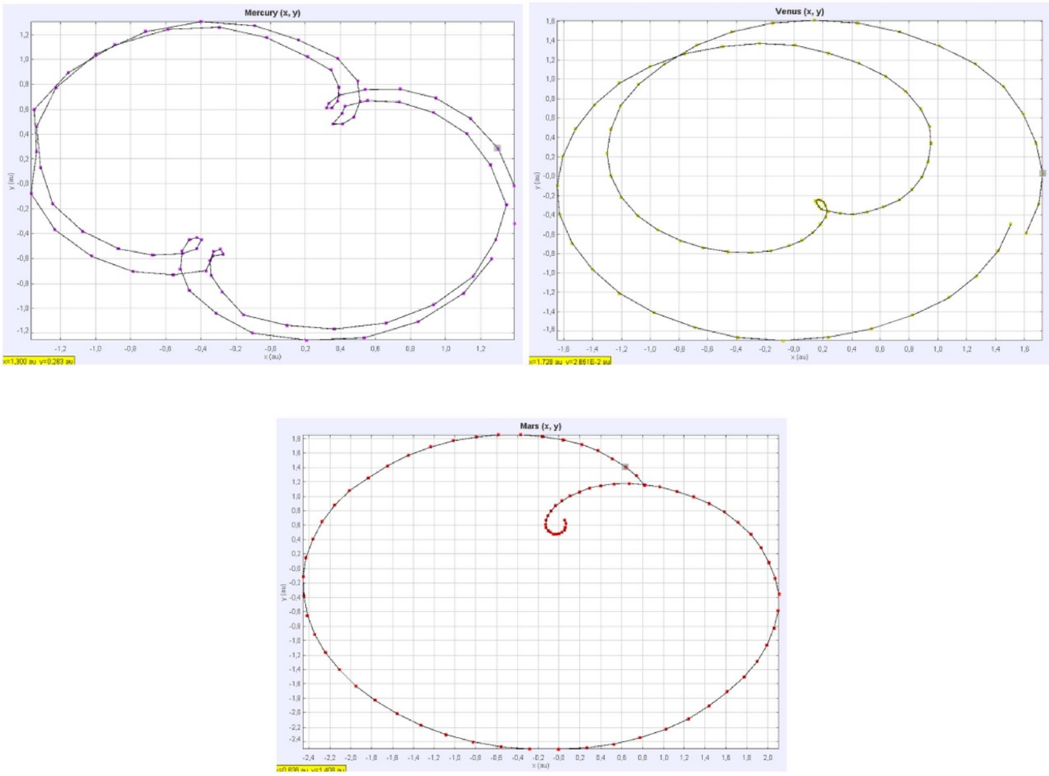

Figure 5. Trajectories of the different 'planets' Mercury (top left), Venus (top right) and Mars (centre) as seen from the Earth. The loops represent the apparent retrograde motion of the planet.

An almost circular trajectory for a planet is relative to the star around which the planet revolves. This also happens between planets and satellites—that is how we observe the Moon from the Earth. But what is the path in the sky of other planets as seen from one planet in particular, if all of them turn around the Sun at speeds that decrease with the distance to the Sun? The software allows to change the reference frame to any of the moving robots[6]. Figure 5 represents the motion as seen from the Earth. We can identify, for the different 'planets', small loops that represent a change in the moving direction of the planet: it goes forward, slows down and starts moving backwards for a while, and then slows down again and returns to move forward again. This motion as seen from the Earth is called the apparent retrograde motion. This phenomenon, which was known by the ancient Greeks and was recently photographed by Cenk E. Tezel and Tunç Tezel (https://apod.nasa.gov/apod/ap120809.html) between late October 2011 and early July 2012, can be easily predicted from computing simulations [10], but undoubtedly a real-time observation in a video-based experiment is more suitable for students with low abstract reasoning.

A similar behaviour can be predicted in other planets, as we see in figure 6 where Mercury is observed from Mars. This might be observed after astronauts land in Mars and observe the yearly drift of other planets.

[6] To change the reference frame to a moving object in software Tracker, go to the 'Coordinate System' menu, choose 'Reference Frame' and select the object to which you want to move the reference frame.

5. Kepler's third law

Kepler enunciated his third law in 1619 in an attempt to quantify the planetary motion in the Solar System to rigorous laws. This law can be

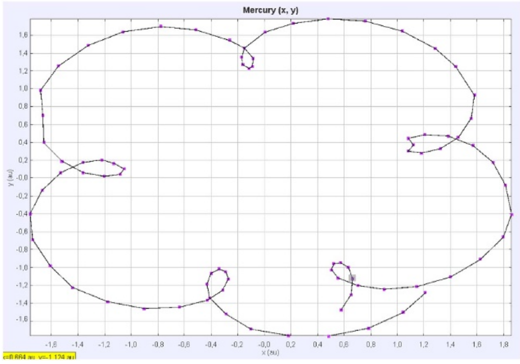

Figure 6. Prediction of the trajectory of Mercury as seen from Mars.

derived from Newton's gravitation law. Assuming that the planet describes a circular orbit, the centripetal force corresponds to the gravitational force acting on the planet:

$$mr\omega^2 = G\frac{mM}{r^2} \tag{1}$$

where m is the mass of the planet, M the mass of the Sun, G the gravitational constant, ω is the angular speed of the planet around the Sun and r is the average radius of the planet's circular trajectory. Rewriting (1) in terms of the period T of the circular motion of the planet we obtain:

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3 = Kr^3. \tag{2}$$

This equation corresponds to Kepler's third law for a circular orbit, where K is a constant for the Solar System.

We can work on equation (2) without the need to use the numerical value of K. Dividing equation (2) by the same equation applied to the Earth orbit around the Sun, we find a new equation that relates orbital periods and average radius of circular trajectories to their values for the Earth's orbit (T_{E} and r_{E}, respectively):

$$\left(\frac{T}{T_{\mathrm{E}}}\right)^2 = \left(\frac{r}{r_{\mathrm{E}}}\right)^3. \tag{3}$$

In an attempt to introduce Kepler's third law as a practical activity, students can use the measured orbital periods of the various robots and the corresponding orbital radius measured from their circular orbits in units of r_{E}. Table 4 presents the measured values from the video recording.

Table 4. Orbital period and radius of the different robots representing the planets. The values were measured from the video recording using the Tracker software.

	Mercury	Venus	Earth	Mars
Orbital period (s)	6.81	13.26	21.00	38.24
Radius (r/r_{E})	0.40	0.69	1.00	1.49

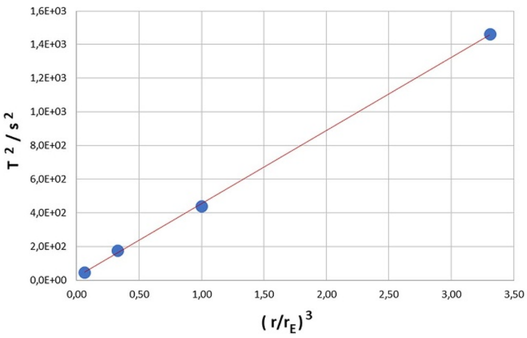

Figure 7. Plot of orbital period T^2 as a function of the ratio of radius $\left(\frac{r}{r_{\mathrm{E}}}\right)^3$. A linear relationship can be fit in accordance to Kepler's third law.

Finally, equation (3) can be verified plotting T^2 as a function of $\left(\frac{r}{r_{\mathrm{E}}}\right)^3$ as we see in figure 7.

As intended, a linear behaviour is obtained in accordance to Kepler's third law. Moreover, the slope of the curve fit corresponds to $T_{\mathrm{E}}^2 = 435 \pm 5$ (s^2), and therefore, $T = 20.9 \pm 0.1$ s, which encloses the experimentally measured orbital period of the Earth robot.

The advantage of this practical activity is that students only need to use the video recording for collecting data. No need to buy or program Ozobots is required. The video analysis allows students to study experimentally the motion of the planets using conversion scales for time and distance. Kepler prediction of the proportionality between the orbital period and the radius of the planet's trajectory can be confirmed with dimensionless functions which come from measures easily obtained from the video recorded.

An alternative to this activity might be to give to the students the orbital radii of planets as provided by NASA (table 1) and use equation (3), derived from Kepler's third law, to calculate the orbital period for each planet, taking one planet (e.g. the Earth) as a reference. From them and their drawn circular paths, students can calculate the scaled speeds for themselves and use those to programme the robots. The results could then be used as a confirmation that the experimental setup is 'accurate' (i.e. the Ozobots match the scaled movement of the real planets). This activity is more complex and expensive as the Ozobot need to be bought, therefore it should be considered as an alternative for more advanced students.

6. Conclusion

With this work, we present a new and creative approach to engage students in understanding Astronomy. The planets are represented by small robots that can be programmed to run at constant speed while paths for their circular trajectories, representing the planet's trajectories in Solar System, are drawn in white paper.

Resources for teaching Astronomy are not easy to build because of the scale of planetary systems and time. We show that this problem can be overcome with convenient simplifications and scaled representations of planetary motion.

The activities here described can be implemented either in person in the laboratory or at distance learning, in the following way:

(a) For the low secondary level, teachers can provide the video of the Ozobots moving in circular paths around the 'Sun'. An explanation of the basic functions of Tracker software (video calibration including writing the number of fps, placement of the reference frame and the use of measuring tools) must be provided to the students. With only this information, they can study the retrograde motion of planets and verify Kepler's third law. The activity should be done at home, individually or in groups, but the discussion of the results must occur with the whole class. It can be done for distance education and therefore, it is a good alternative in pandemic times. This is a cheap solution for a heads-on activity, and it works both conceptual and procedure skills manipulating digital apps. Manipulating Ozobots requires buying the robots but has the advantage of additionally developing programming skills in the students.

(b) For high school, students can actually build the board with the circular paths and program the robots to move at constant speed, taking into account the values of distances of planets in the Solar System and corresponding speeds, in the way explained in the paper. This approach enables hands-on and heads-on engagement of the students. A video should also be recorded, but not necessarily. With this approach, the activity needs to be done in person and students may feel some difficulty working on their own. Therefore, it may not be adequate for pandemic times, although it is possible to be done by students with good skills.

In one way or the other, the most important idea to retain is that teachers have in robots (Ozobots or similar devices) educational tools to give their students the opportunity to experience the study of astronomy contents at reduced scale, measuring easily physical parameters and verifying phenomena that usually are only provided in school textbooks.

This is also a great occasion for the teachers to motivate their students for science and discuss with them the importance of prototypes and setups that allow the study and understanding of physical sciences in controlled environments, being one of the basic pillars of experimental work that begun with Galileo nearly 400 years ago.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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References

[1] Brasell H 1987 The effect of real-time laboratory graphing on learning graphic representations of distance and velocity *J. Res. Sci. Teach.* **24** 385–95
[2] Hofstein A and Lunetta V N 2004 The laboratory in science education: foundation for the 21st century *Sci. Educ.* **88** 28–54
[3] Christian W and Belloni M 2001 *Physlets: Teaching Physics with Interactive Curricular Material* (Englewood Cliffs, NJ: Prentice Hall)
[4] Redish E F 2003 *Teaching Physics with the Physics Suite* (Hoboken, NJ: Wiley)
[5] Sokoloff D R, Laws P W and Thornton R K 1999–2004 *RealTime Physics, Active Learning Laboratories* Modules 1–4 (Hoboken, NJ: Wiley)
[6] Brown D and Cox A J 2009 Innovative uses of video analysis *Phys. Teacher* **47** 145–50
[7] Carrol B W and Ostlie D A 2014 *An Introduction to Modern Astrophysics* 2nd edn (London: Pearson)
[8] Hoskin M (ed) 1996 *The Cambridge Illustrated History of Astronomy* (Cambridge: Cambridge University Press)
[9] Papert S 1980 *Mindstorms: Children, Computers and Powerful Ideas* (New York: Basic Books)
[10] Guerra A G C and Carvalho P S 2016 Orbital motions of astronomical bodies and their centre of mass from different reference frames: a conceptual step between the geocentric and heliocentric models *Phys. Educ.* **51** 055012

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