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ARTICLE

Visualization of Mercury's Orbital Path Around the Sun Using Matlab for Astronomic Distance Learning

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Abstract: Physics phenomena that are macro and micro size often cannot be captured directly by the five senses of man. This study aims to present an alternative astronomical learning activity about the orbital trajectory of the planet Mercury around the sun using MATLAB assistance. Visualization of the orbital trajectory of the planet Mercury begins by describing the appropriate mathematical equations. Next, visualize mathematical equations in graphical form with the help of MATLAB. In this study, students can visualize the orbital trajectory of the planet Mercury around the sun using MATLAB by varying the components of the coordinate equation. Through this visualization, it is hoped that it can help students understand the movement of the planet Mercury around the sun in its orbit independently and creatively. Students can also develop mathematical representation skills and visual representations of the orbital trajectory of the planet Mercury around the sun.

Keywords: Astronomic, Distance Learning, MATLAB, Mercury, Orbit.

Introduction

The demands of technological progress because of the creation of the industrial revolution 4.0 cannot be avoided by every country. It is characterized by several countries competing in researching and exploring natural resources on Mercury and Mars [1]. For some countries, research, and exploration of planets in the Solar System is a necessity that has been scheduled by the governments of these countries [2]. However, for developing countries, these activities cannot be carried out on a massive scale. One of the causes is low income and the budget spent is prioritized for people's welfare, education, health, and expanding employment opportunities. However, developing countries can still research the field of astronomy, one of which is studying the planets in the Solar System by continuing to innovate in the fields of education and research [3].

In carrying out innovations in the fields of education and research, every educator and researcher needs to instill awareness of the importance of cooperation to continue to develop the science of astronomy. One of the innovative efforts that can be done is to apply the concept of astronomy with the help of technology that is cheap, easy to obtain, accessible, and operated by students [4, 5]. This needs to be done so that the quality of students in developing countries is not inferior to students in developed countries. In addition, this is done so that the results of research in the field of astronomy are not only enjoyed by high-income countries but are expected to be enjoyed by all countries.

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Meanwhile, one of the interpretations of astronomical concepts with the help of technology to make it easier for students to understand is the visualization of rocket motion using MATLAB [6]. However, students need to be given flexibility in constructing the visualization of astronomical concepts.

The visualization of astronomical concepts that exist in most schools is in the form of a set of teaching aids to help visualize basic astronomical concepts such as the concept of the revolutionary movement of the planets in the Solar System [7]. However, visualization for the concept of astronomy specifically as well as the orbital paths of each planet in the solar system is not widely owned by schools. The form of visualizing the astronomical concept is in the form of physical objects which are not efficient and effective when used by large numbers of students. Besides, this form of visualizing the astronomical concept is not integrated with the help of technology which causes its use in schools to be limited [8,9]. Unlike the case with visualization of astronomical concepts that integrate technology such as MATLAB which can be used anytime and anywhere without an internet network. Thus, with the help of technology such as MATLAB, which is used in visualizing the astronomic concept, astronomic learning is expected to run effectively.

Through activities that visualize astronomical concepts that are integrated with MATLAB, it can provide an alternative to distance learning. Furthermore, this statement is also supported by the results of research conducted by Yu et al. [10] that the visualization of astronomical concepts regarding the design and analysis of the tertiary mirror system of a thirty-meter telescope at the conceptual stage can be done interactively with the help of MATLAB. The results of this study are supported by research results which reveal that the visualization of the trajectory of a two-stage launch vehicle for low-earth orbit applications assisted by MATLAB obtained visualization results from direct experimental results [11]. MATLAB is a computational software used to easily visualize mathematical equations of astronomical phenomena that do not require an internet connection [12].

MATLAB is a graphical computing software that is used to visualize mathematical equations with two- and three-dimensional graphic visualization results [13]. Using MATLAB, users can manipulate matrices, plot mathematical functions, and equations, implement algorithms and create user interfaces. MATLAB is also a computational software that can analyze simple to complex algebraic equations. MATLAB can be used to support astronomical research activities, especially in analyzing and visualizing mathematical equations of complex astronomical phenomena [14]. In addition, MATLAB software can also be used to assist in distance learning of astronomy.

The application of MATLAB in astronomy learning can support the simple visual construction of each astronomical equation [15]. The application of MATLAB in learning physics also has a positive impact on students' abilities. This is based on the results of research that reveal that learning astronomy that integrates graphic visualization produced from MATLAB can improve students' visual representation abilities [16]. Students' mathematical and graphic representation abilities can also be developed by applying MATLAB-assisted astronomy learning [17]. Once students have good visual representation skills, they can use MATLAB to visualize the mathematical equations of other astronomical phenomena. This is because MATLAB is a graphical computing software that can visualize simple to complex astronomical phenomena [18,19]. Furthermore, some findings reveal the application of MATLAB software in astronomy learning.

MATLAB software has been used to visualize and analyze the gravitational signal from a core-collapse supernova (CCSNe) [20]. The use of MATLAB in astronomical research is used to help extract the Earth's orbital period from the CO_2 concentration in the atmosphere by using the Fourier transform [21]. Using MATLAB, educators and students can visualize and analyze the impact of infrasonic atmospheric noise on gravity detectors [22]. Although MATLAB software has been widely implemented in astronomy research and learning, the implementation of MATLAB is on the topic of the Mercury revolution. This can happen because some researchers, educators, and students focus more on discussing the orbital trajectory of the Earth's revolution [23]. Therefore, with the various uses of MATLAB in astronomy and the lack of visualization of the orbital trajectory of Mercury's revolution using

MATLAB, it is necessary to innovate the development of visualization of the orbital trajectory of Mercury around the planet with the help of MATLAB.

Theory

The state of the orbit of each planet when it evolves will affect the conditions on the planet's surface. Changes in seasons and weather, as well as changes in the length of time day and night, are some of the consequences of this [24]. The changes that occur are of course different from those that occur on Earth and other planets. The movement of Mercury's orbital trajectory around the sun will be easier to learn through visualization activities through software assistance [25]. Currently, many visualization activities have been carried out to support the understanding of concepts related to the movement of the earth around the sun, but many simulations ignore the movements of other planets, especially Mercury around the sun. Besides, there are still several visualizations made with the assumption that the orbits of the planets in the Solar System are circular so they do not adequately describe the actual orbits of the planets [26]. However, let's first recall the characteristics of the planet Mercury.

The planet Mercury has a diameter of about 4862 000 km. Its mass is about 0.055 times the mass of Earth, and its density is about 5400 kg/m^3. The distance from the Sun is 0.39 AU.

The revolutionary period for the planet Mercury is 88 days, while the rotation period is 59 days. Mercury's gravitational acceleration is 0.38 times the acceleration of Earth's gravity [27]. The planet Mercury has a weak magnetic field, and its core contains a lot of iron alloys (iron-nickel) and a thin layer of silicate material [28,29]. The surface temperature of this planet during the day is very high, it can reach 700 K at sunset Mercury's surface temperature drops to 425 K, and the lowest temperature occurs at midnight, which is around 100 K. This is the largest temperature range compared to the temperature range occurs on other planets in the solar system [30]. On Earth, the temperature variation between day and night rarely exceeds 20 K. Long hot days and a very rapid rate of decline in temperature mean that Mercury has no atmosphere [31]. Mercury only reflects 6 percent of the sunlight it receives and on the planet Mercury a giant valley is also found which is evidence of the formation of a basin on the surface because the planet is shrinking more and more [32].

Astronauts have also found evidence that Mercury's crust and upper mantle are tectonically active even though they are not as active as the layers on Earth [33]. However, based on the explanation of this simple theory about the planet Mercury, what needs to be known fundamentally for students in high school or early students in astronomic courses is the shape of the trajectory of the planet Mercury's orbit around the sun. This needs to be known from the start, considering that many educators only focus on conveying the orbital trajectories of the planets in general, which are elliptical [34]. When going to visualize the orbital trajectory of a planet, especially a planet Mercury when it circles the Sun, then assume in advance that the planet has mass (m). Assume the mass of the planet as (m), then the mass of the Sun is assumed to be (M) so that $(M \gg m)$. Meanwhile, the relationship between the sun and the planets will produce a gravitational force according to Newton's law of universal gravity as shown in Eq. (1) below.

$$F = G\frac{Mm}{r^2} \tag{1}$$

Eq. (1) shows the equation for the gravitational force between the sun and a planet or between a planet with G as the gravitational constant and r as the distance between the sun and a planet or the distance between the two planets [35]. If the components of the gravitational force in Eq. (1) are represented in cartesian coordinates and viewed on the x-axis and y-axis, then some components can be represented as in Eqs. (2) and (3).

$$F_x = F\frac{x}{r} = \left(G\frac{Mm}{r^2}\right)\left(\frac{x}{r}\right) = G\frac{Mmx}{r^3} \tag{2}$$

$$F_y = F\frac{y}{r} = \left(G\frac{Mm}{r^2}\right)\left(\frac{y}{r}\right) = G\frac{Mmy}{r^3} \tag{3}$$

Eqs. (2) and (3) can also be written in other forms by substituting them into Newton's second law equation as shown in Eqs. (4) and (5) below.

$$m\frac{dv_x}{dt} = -G\frac{Mmx}{r^3} \tag{4}$$

$$m\frac{dv_y}{dt} = -G\frac{Mmy}{r^3} \tag{5}$$

Eqs. (4) and (5) which are the result of substitution with Newton's second law equation can be simplified by eliminating the components m on both sides of the equation so that the equation can be written as in Eqs. (6) and (7) below.

$$\frac{dv_x}{dt} = -G\frac{Mx}{r^3} \tag{6}$$

$$\frac{dv_y}{dt} = -G\frac{My}{r^3} \tag{7}$$

Furthermore, because this study will only analyze the orbital trajectories of planets, especially the planet Mercury when they circle the Sun, it is determined that $GM = 1$. Besides, it is assumed that the planet Mercury's starting position is at coordinates $(x, y) = (0.5,0)$, and its initial speed i.e., $v_x(0) = 0$ and $v_y(0) = 1.63$ [36]. If it is assumed that $v_x = \dot{x}$ and $v_y = \dot{y}$, then the equations for the motion of the planets, especially the planet Mercury when they circle the Sun, can be written as in Eqs. (8) and (9) below.

$$\ddot{x} = -\frac{x}{(x^2 + y^2)^{3/2}} \tag{8}$$

$$\ddot{y} = -\frac{y}{(x^2 + y^2)^{3/2}} \tag{9}$$

Eqs. (8) and (9) can be used to visualize the orbits of the planets in the Solar System in general when they circle the Sun [37]. The steps that need to be done are writing them as a set of linear ordinary differential equations as shown in Eq. (10) below.

$$\begin{pmatrix} x_1 = x \\ x_2 = \dot{x} = \dot{x_1} = v_x \\ x_3 = y \\ x_4 = \dot{y} = \dot{x_3} = v_y \end{pmatrix} \tag{10}$$

Furthermore, Eq. (10) can be simplified again by substituting it into Eqs. (8) and (9), so that the equation can be written as shown in Eq. (11) below.

$$\dot{x_1} = x_2 \tag{11}$$

$$\dot{x_2} = -\frac{x_1}{({x_1}^2 + {x_3}^2)^{3/2}} \tag{12}$$

$$\dot{x_4} = -\frac{x_3}{({x_1}^2 + {x_3}^2)^{3/2}} \tag{13}$$

Eqs. (11), (12), and (13) are equations used to visualize the orbital trajectories of the planets in the Solar System in general when circling the Sun in MATLAB software. In addition to using Eqs. (11), (12) and (13), visualizing the orbital paths of the planets in the Solar System in general when circling the Sun can also be done using the wave inference equation as shown in Eqs. (14) and (15) following.

$$x(t) = 2\cos(1.63 \times t) \tag{14}$$

$$y(t) = 2\sin(1.63 \times t) \tag{15}$$

Meanwhile, to visualize the orbital trajectory of the planet Mercury when it surrounds the Sun, the MATLAB software is also done using the wave inference equation as shown in Eqs. (16) and (17) below. This is done because the planet Mercury has a very strange orbit around the Sun [38].

$$x(t) = 93\cos t + 36\cos 4.15t \tag{16}$$

$$y(t) = 93\sin t + 36\sin 4.15t \tag{17}$$

Materials and Methods

Visualization of the orbital trajectories of the planets in the Solar System in general when around the Sun and the orbital trajectory of the planet Mercury when circling the Sun is carried out in this article using the help of MATLAB software. The purpose of using MATLAB is to determine the visualization of the orbital trajectories of the planets in the Solar System in general when around the Sun and the orbital trajectories of the planet Mercury when around the Sun. With this, a way to visualize the orbital trajectories of the planets in general when circling the Sun and the orbital trajectory of the planet Mercury when circling the Sun is obtained, which is easy to do in helping study astronomy. MATLAB software is used to help visualize the orbital trajectories of the planets in general when around the Sun and the orbits of the planet Mercury when around the Sun because it can strengthen the mathematical understanding of the concept of astronomy and produce smooth visualizations [39]. Besides, MATLAB also has a feature to visualize graphs with a variety of shape choices, both two-dimensional and three-dimensional, so that it can be used to plot the visualization of the orbits of the planets in general when around the Sun and the orbits of the planet Mercury when circling the Sun based on the Eqs. (14) to (17). Simulating the orbital trajectories of the planets in general when around the Sun and the orbital trajectories of the planets Mercury when circling the Sun with the help of the MATLAB software, is carried out with several steps that need to be done to obtain a visualization of the orbits of the planets in general when around the Sun and the orbits of the planet Mercury. when circling the smooth Sun.

The steps that need to be done are starting with determining the time interval to be inputted in Eqs. (14) to (17). This is done so that the mathematical equations of the orbital trajectories of the planets, in general, when around the Sun and the orbital path of the planet Mercury when circling the Sun which is inputted in the MATLAB workspace can be processed properly and produce smooth visualizations. Thus, the syntax that is inputted into the MATLAB workspace to visualize the orbital paths of the planets in general when circling the Sun which contains Eqs. (14) and (15) can be presented as follows:

```
% Orbit of a planet around the Sun
% By Himawan Putranta
t = (0:pi/360:2*pi*22/3);
x = 2*cos(1.63*t); % x-coordinate.
y = 2*sin(1.63*t); % y-coordinate.
figure;
plot(x,y); %2D plot
colormap(gray)
shading interp
xlabel('x'), ylabel('y')
str=cat(2,'Orbit of a planet around the Sun'),... num2str(kz,'%4.3f'));
title(str)
axis([-t t -t t min(min(x)) max(max(y))])
```

The workspace display of the MATLAB software that has been inputted with Eqs. (14) and (15) which are needed to visualize the orbits of the planets in general when circling the Sun can be shown in Fig. 1.

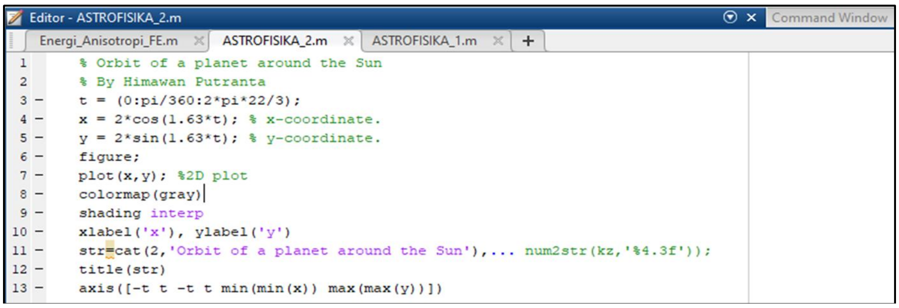

FIG 1. The MATLAB workspace view for visualizing the orbits of the planets around the Sun.

Meanwhile, the syntax that is inputted into the MATLAB workspace to visualize the orbital path of the planet Mercury when it circles the Sun which contains Eqs. (16) and (17) can be presented as follows.

```
% Mercury's orbit around the Sun as seen from the Earth
% By Himawan Putranta
t = (0:pi/360:2*pi*22/3);
x = 93*cos(t)+36*cos(4.15*t); % x-coordinate.
y = 93*sin(t)+36*sin(4.15*t); % y-coordinate.
figure;
plot(x,y); %2D plot
colormap(gray)
shading interp
xlabel('x'), ylabel('y')
str=cat(2,'Mercurys orbit seen from the Earth'),... num2str(kz,'%4.3f'));
title(str)
axis([-t t -t t min(min(x)) max(max(y))])
```

The workspace display of the MATLAB software that has been inputted with Eqs. (16) and (17) which is needed to visualize the orbital path of the planet Mercury when it circles the Sun can be shown in Fig. 2.

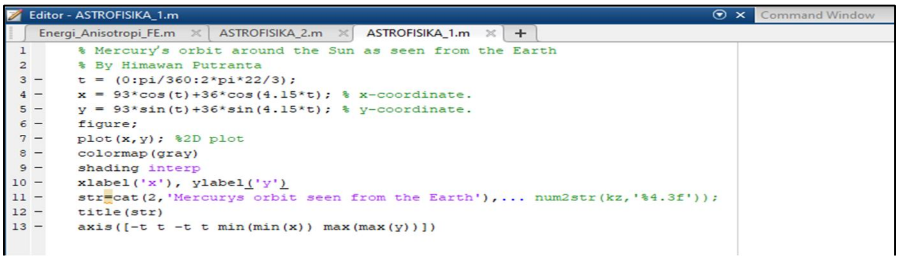

FIG 2. MATLAB workspace view to visualize the orbital trajectory of the Mercury around the Sun.

After inputting Eqs. (14) to (17) which are needed to visualize the orbits of the planets and planets Mercury around the Sun as shown in Figs. 1 and 2, the next step is to visualize the orbits of the planets and planets, Mercury, when they circle the Sun. The steps that need to be taken to bring up the visualization of the orbital paths of the planets and planets Mercury when circling the Sun in MATLAB can be shown by the red circle in Fig. 3. After visualizing the orbits of the planets and planets Mercury as they circle the Sun, the next step is to analyze the visualization.

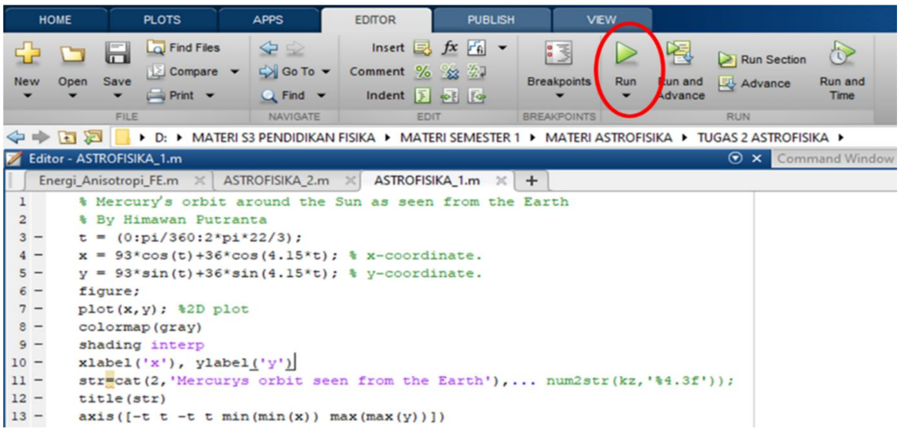

FIG 3. Run the option on the taskbar Editor to display a visualization of the orbits of the planets and Mercury around the Sun.

Results and Discussion

In this article, we demonstrate the process of visualizing the orbits of the planets and planets Mercury as they circle the Sun using the help of MATLAB. visualization of the orbits of the planets and planets Mercury when circling the Sun is done by varying the time value, namely between 0 to $\frac{2\pi\times22}{3}$ with an interval of $\frac{\pi}{360}$. In this study, four equations are used to see the visualization generated from the orbital trajectories of the planets in general and the orbital paths of each planet, especially Mercury, as it surrounds the Sun. One of the reasons why the planet Mercury is used in the study of this article is because the planet Mercury has a very strange orbit around the Sun [40]. This is also done to determine the input and output processes in the form of visualizing the orbits of the planets and the orbits of the planet Mercury around the Sun using MATLAB software. Meanwhile, the results of the visualization of the orbits of the planets in general and the planet Mercury when circling the Sun using MATLAB can be shown in Fig. 4.

Based on Fig. 4, shows that the visualization of the orbits of the planets around the Sun does not form a full circle, but is like a circle with both sides compressed. This is to research which shows that the orbital trajectories of the planets in the solar system do not form a circle but form an elliptical path [41]. Based on Fig. 4 (a) shows that the elliptical blue line is the orbital path of the planets in the Solar System with the sun acting as the center which is at one of the focal points. Fig. 4 (a), only consists of one blue line which is elliptical because it represents the eight planets in the Solar System whose orbital paths are generally elliptical. This is by the first Kepler law that the sun acts as the center of the solar system, which is positioned at one of the focal points of the ellipse [42]. Based on Fig. 4 (a), the planets in the solar system circle the sun in an elliptical path, so that the planets can one time be at the farthest and closest distance to the sun. The closest distance between the planets to the sun is known as perihelion and the farthest distance between the planets is known as aphelion. If the planets are closer to the sun, the orbital speed is higher [43]. Although in general the orbits of the planets around the sun are elliptical, each planet has different trajectory characteristics. This of course will affect the conditions on the surface of each planet, changes in seasons and weather, as well as changes in the length of time day and night. The most obvious thing is the difference in rotation and revolution times for each planet in the solar system.

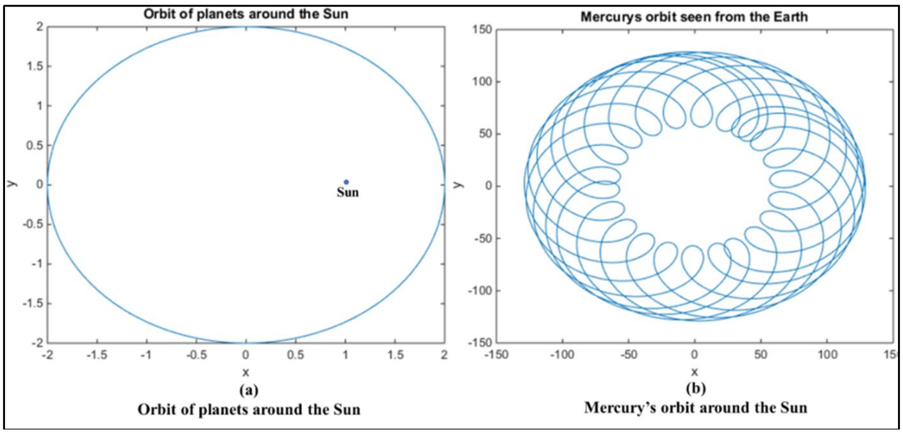

FIG 4. The orbits, (a) the planets around the Sun and (b) Mercury around the Sun.

This is also proven as shown in Fig. 4 (b) that the orbits of the planets in the solar system especially the planet Mercury, are elliptical. However, the path of the planet Mercury's orbit when it circles the Sun is not only an ellipse but, a spiral, -like a coil of wire or a hair tie. Based on Fig. 4 (b), the orbital trajectory of the planet Mercury when it circles the Sun as seen from Earth appears to circle the Sun in a spiral pattern with a close distance to the sun. This is to the statement which states that Mercury is the closest planet to the Sun which is 57909050 km or 0.387 AU [44]. Meanwhile, the perihelion distance of the planet Mercury is as far as 46001200 km, and its aphelion distance is 698169900 km [45]. Besides, the trajectory of the planet Mercury's orbit around the Sun as shown in Fig. 4 (b) shows a pattern of adjacent spiral curves. This shows that the orbital period of the planet Mercury is fastest than the orbital period of the other planets in the solar system. The planet Mercury certainly moves fastest when it is closest to the Sun and the slowest when it is farthest from the Sun. This is by the results of research which shows that the average orbital velocity of the planet Mercury is 47,362 km/s, meaning that Mercury takes approximately 88 days to complete one orbit of the Sun [46]. The duration of the fast orbit of the planet Mercury also affects the time on Earth, if the time of the two planets is compared, then one day on the planet Mercury lasts two years on Earth [47]. Based on Fig. 4 (b), it is also shown that the path of the planet Mercury's orbit around the Sun is in the form of a spiral pattern which is visible when it shrinks and expands. This shows the typical behavior of the planet Mercury that at one time the planet Mercury appears to be shrinking when its core cools and looks very dark [48]. This is influenced by the position of the planet Mercury farthest and closest to the sun.

Furthermore, this visualization of the orbits of the planets in general and the planet Mercury around the Sun has an important purpose in the astronomical. In the field of astronomical research, the benefits obtained from this visualization activity are to find out the characteristics and content of the natural resources of the planet Mercury [49]. Besides, the purpose of this visualization is to determine the pattern of orbital movements of the planet Mercury when it circles the Sun. This is by the need that technological advances, especially in the field of astronomy, require a broad study of the characteristics and phenomena of the universe [50]. This visualization certainly opens a perspective for every researcher to study more about the characteristics of the planets around Earth. Through this visualization, it is hoped that the researchers will be able to determine the physical characteristics of how nearby planets cope with the ultraviolet radiation emitted by the sun. Visualization of orbital trajectories of the planets in general and the planet Mercury when circling the sun also supports the implementation of astronomical learning activities [51].

This can be done by asking students to analyze the characteristics of the orbital trajectories of the planet Mercury when it circles the Sun. Students were then asked to explore the mathematical equations of the orbits of the planets in general and the planet Mercury around the Sun. Furthermore, the students are asked to visualize the mathematical equations in MATLAB software. Visualization of the orbits of the planets in general and the planet Mercury when they circle the Sun can be a link between mathematical equations and astronomic experiments cheaply, easily, and can be done anytime, anywhere. This visualization activity is also able to make it easier for students to apply the mathematical equations of an astronomical phenomenon [52]. The activity of visualizing mathematical equations of astronomical phenomena can support the implementation of learning astronomy in the early years remotely.

Astronomic learning that implements visualization activities can be carried out well if students can be actively involved in understanding the mathematical equations of astronomical phenomena and virtual experiments with the help of MATLAB. Furthermore, through visualizing the orbital trajectories of the planets in general and the planet Mercury using MATLAB assistance, students can develop mathematical representation skills and creative visual representations. Besides, students' science process skills and critical thinking skills also improve. This is because the students need to explore the characteristics and mathematical equations of the orbits of the planets in general and Mercury. With the current global condition that is being hit by the COVID-19 pandemic, astronomical learning that implements this visualization process can support distance learning astronomy [53]. This is because astronomical learning is carried out based on virtual projects and students can be motivated to learn astronomical concepts.

Conclusions

In this research, the orbital trajectories of the planets and the planet Mercury, in general, have been visualized using the help of MATLAB software. MATLAB software is used to simulate the orbits of the planets in general and the planet Mercury when it circles the sun. The MATLAB software was chosen to simulate the orbital trajectories of the planets in general and the planets Mercury when they circle the Sun because it is one of the computational software that is easy to operate, capable of visualizing mathematical equations of complex astronomical phenomena, and producing graphical visualizations in two and three dimensions., making it easy to use by high school or college students in the early years of learning or novice programmers. This visualization activity can make it easier for students to understand and implement mathematical equations of an astronomical phenomenon, especially regarding the orbits of the planets in general and the planet Mercury when circling the Sun in a virtual experiment. This activity of visualizing the orbital trajectories of the planets in general and the planet Mercury when circling the Sun can support the implementation of learning astronomy in middle school or college in the early years remotely. Furthermore, the results of this study can also be used as a reference source for researchers or students in the future to be able to visualize the orbits of the planets in general and the planet Mercury when circling the Sun from planets other than those in the galactic solar system. Milky Way.

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