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RESEARCH ARTICLE

ORBITAL ECCENTRICITY STUDY OF PLANETS: A COMPARATIVE ANALYSIS OF MANUAL SIMULATION AND DIGITAL VISUALIZATION

Thoriqi **FIRDAUS**[1], Listiawan[2] , Riski **DEWANTO**[3] , Ihza Risky **WINEDAR**[4]

[1]Natural Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia. thoriqifirdaus.2023@student.uny.ac.id

[2]Natural Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia. listiawan.2023@student.uny.ac.id

[3]Natural Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia. riskidewanto.2023@student.uny.ac.id

[4]Natural Science Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta, Yogyakarta, Indonesia. hzarizky.2023@student.uny.ac.id

Abstract

Understanding planetary orbits is a fundamental concept in astronomy. Many secondary school students encounter difficulties comprehending the shape and characteristics of orbits, which are not perfect circles but ellipses with varying degrees of eccentricity. These challenges are particularly evident when students are tasked with sketching or calculating the eccentricity of a planet's orbit, a measure of how elongated the orbit is. This study aims to explore and compare the efficacy of two pedagogical approaches manual simulation and digital simulation—in enhancing students' understanding of planetary orbit shapes and the concept of eccentricity. A descriptive-comparative research design is employed to depict and contrast the effectiveness of these two teaching methods. The experiment, crafted based on expert design, involves four qualified astronomy educators to apply both approaches. The manual simulation requires students to draw orbits and compute eccentricity manually, whereas the digital simulation leverages software to visualize the motion of planetary orbits. Evaluation is conducted through Focus Group Discussions (FGD) with four subject matter experts to provide feedback on the effectiveness of the two methods, the challenges faced by students, and the level of comprehension achieved. The results from the manual experiment indicate that the orbital eccentricity ranges between 0.2 and 0.4, suggesting that the planets' orbits are elliptical. These findings align with Kepler's laws, which state that planetary orbits are elliptical, with the Sun at one of the foci. Results from the NASA Eyes application further corroborate this, showing that the orbits of planets in the solar system are indeed elliptical, both at perihelion (the point closest to the Sun) and aphelion (the end farthest from the Sun). In conclusion, this research substantiates that the orbits of planets in the solar system are elliptical, consistent with Kepler's laws.

Keywords: Orbital eccentricity, planets, manual simulation, digital visualization

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ARAŞTIRMA MAKALESİ

GEZEGENLERİN YÖRÜNGE EKSANTRİKLİĞİ ÇALIŞMASI: MANUEL SİMÜLASYON VE DİJİTAL GÖRSELLEŞTİRMENİN KARŞILAŞTIRMALI ANALİZİ

Öz

Bu çalışma, gezegen yörüngelerinin anlaşılmasının astronomi eğitimindeki temel kavramlardan biri olmasına rağmen ortaöğretim düzeyindeki öğrencilerin yörüngelerin biçimini ve özelliklerini kavramada önemli güçlükler yaşadığını vurgulamaktadır. Özellikle yörüngelerin kusursuz birer çember olmayıp değişen dışmerkezlik derecelerine sahip elipsler şeklinde olması, öğrencilerin hem çizim yaparken hem de dışmerkezlik hesaplamaya çalışırken zorlanmalarına neden olmaktadır. Bu araştırma, gezegen yörüngelerinin biçimi ve dışmerkezlik kavramının öğretiminde iki pedagojik yaklaşımın —manuel simülasyon ve dijital simülasyon— etkililiğini incelemeyi ve karşılaştırmayı amaçlamaktadır. Çalışmada, iki yöntemin etkililiğini betimlemek ve karşılaştırmak üzere betimsel-karşılaştırmalı araştırma deseni kullanılmıştır. Uzman görüşü doğrultusunda yapılandırılan deneysel uygulama kapsamında dört nitelikli astronomi eğitimcisi her iki yöntemi de gerçekleştirmiştir. Manuel simülasyon sürecinde öğrencilerden yörünge çizimleri yapmaları ve dışmerkezlik değerlerini elle hesaplamaları istenirken, dijital simülasyon sürecinde gezegen hareketlerini görselleştiren yazılımlar kullanılmıştır. Her iki yaklaşımın etkililiği, öğrencilerin karşılaştığı güçlükler ve kavrama düzeyleri dört uzmanla gerçekleştirilen odak grup görüşmeleri aracılığıyla değerlendirilmiştir. Manuel uygulamanın sonuçlarına göre yörünge dışmerkezliği 0,2 ile 0,4 arasında değişmekte olup gezegen yörüngelerinin eliptik olduğunu göstermektedir. Bu bulgular, Güneş'in odaklardan birinde yer aldığı eliptik yörüngeleri tanımlayan Kepler yasalarıyla uyumludur. NASA Eyes uygulamasından elde edilen sonuçlar da gezegenlerin hem Güneş'e en yakın noktaları olan günberi konumlarında hem de en uzak noktaları olan günöte konumlarında eliptik yörüngelere sahip olduğunu doğrulamaktadır. Sonuç olarak, bu çalışma Güneş Sistemi'ndeki gezegenlerin yörüngelerinin Kepler yasalarıyla tutarlı biçimde eliptik olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Yörünge dışmerkezliği, gezegenler, manuel simülasyon, dijital görselleştirme

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Geniş Özet

Giriş

Güneş sistemi ve gezegenlerin hareketlerinin anlaşılması, astronomi eğitiminin temel konularından biridir. Bu alandaki en temel kavramlardan biri ise gezegenlerin Güneş etrafında izlediği yörüngelerdir. Ancak, pek çok öğrenci bu yörüngelerin biçimlerini ve özelliklerini kavramakta zorlanmaktadır. Özellikle yörüngelerin tam bir daire değil, belirli derecelerde basıklığa (eksantrikliğe) sahip elipsler olduğu bilgisi, öğrenciler tarafından sıklıkla yanlış anlaşılmaktadır. Eksantriklik, yörüngenin ne kadar uzamış olduğunu belirten bir ölçüttür ve gezegenin Güneş'e en yakın olduğu nokta (günberi) ile en uzak olduğu nokta (günöte) arasındaki farkı etkiler. Öğrenciler, eksantriklik gibi soyut bir kavramı zihinde canlandırmakta ve bu değeri hesaplamakta zorlanmaktadır. Teorik bilgiye sahip olsalar bile, bu bilgiyi görselleştirmeye veya grafiksel olarak ifade etmeye çalıştıklarında yetersiz kalabilmektedirler. Geleneksel eğitim yaklaşımlarında bu tür kavramlar genellikle sözel açıklamalarla aktarılmakta, ancak bu yöntemler gezegen hareketlerinin dinamik yapısını öğrencilere yeterince aktaramamaktadır. Statik görseller ve açıklamalar çoğu zaman soyut kavramları açıklamada yetersiz kalır. Bu nedenle, öğrencilerin kavramları doğrudan deneyimleyebileceği daha etkileşimli öğrenme yöntemlerine ihtiyaç duyulmaktadır. Bu yöntemler arasında hem manuel (el ile çizim ve hesaplama) simülasyonlar hem de dijital görselleştirmeler öne çıkmaktadır. Manuel yöntemler öğrenciyi sürece aktif olarak dahil ederken; dijital simülasyonlar ise daha doğru ve gerçekçi temsiller sunabilmektedir. Ancak her iki yöntemin de tek başına bazı sınırlılıkları bulunmaktadır. Araştırmalar, öğrencilerin gezegen yörüngeleri konusunu özellikle eksantriklik hesaplamaları ve yörünge şekillerini görselleştirme konularında anlamakta zorlandığını göstermektedir. Bu konu sadece astronomi için değil, aynı zamanda yerçekimi, mevsimlerin oluşumu, gök cisimlerinin konumlarının hesaplanması gibi birçok doğa olayının anlaşılması için de temel teşkil etmektedir. Bu nedenle, bu kavramların öğrencilere etkin bir biçimde kazandırılması büyük önem taşımaktadır. Teknolojinin eğitimde artan rolüyle birlikte, son yıllarda dijital simülasyonların soyut kavramların öğretiminde etkili bir araç olduğu ortaya konmuştur. Öğrenciler bu simülasyonlar sayesinde gezegenlerin yörüngelerini gözlemleyebilmekte, eksantriklik gibi değişkenleri değiştirdiğinde nasıl sonuçlar doğduğunu anlık olarak görebilmektedir. Bu tür uygulamaların teorik bilgiyi pekiştirdiği, gözlem ve analiz becerilerini geliştirdiği belirlenmiştir. Bu çalışmada, daha önce çoğunlukla ayrı ayrı ele alınan manuel ve dijital simülasyonların birlikte kullanıldığı bir yaklaşım önerilmektedir. Öğrenciler önce yörüngeleri elle çizecek, ardından dijital ortamda bu yörüngeleri simüle ederek hareketi gözlemleyeceklerdir. Bu süreçte öğrencilerin hem görsel hem de kavramsal düzeyde daha bütüncül bir anlayış geliştirmeleri hedeflenmektedir. Ayrıca, bu yöntem farklı öğrenme stillerine sahip öğrenciler için de erişilebilir bir çözüm sunmaktadır. Görsel, kinestetik, sözel ve mantıksal öğrenme stillerine sahip öğrencilerin her biri, sürece farklı biçimlerde dahil edilerek desteklenebilecektir. Araştırmanın bir diğer amacı, gelişmiş astronomik ekipmanlara sahip olmayan okullarda da kolaylıkla uygulanabilecek bir öğretim yöntemi geliştirmektir. Basit dijital araçlar ve temel materyallerle soyut astronomi konuları daha somut hale getirilebilir. Bu sayede öğrencilerin yörünge eksantrikliği gibi zorlayıcı kavramları teorik, pratik ve görsel açıdan daha iyi kavraması ve astronomiye karşı olumlu tutum geliştirmesi beklenmektedir.

Yöntem

Bu araştırma, gezegen yörüngelerinin anlaşılmasında iki farklı öğretim yaklaşımının—manuel simülasyon ve dijital simülasyon—etkililiğini betimlemek ve karşılaştırmak amacıyla karşılaştırmalı betimsel bir yöntem benimsemektedir. Araştırmanın temel amacı, bu iki yöntemle öğrencilerin yörünge şekillerini ve dışmerkezlik (eksantriklik) kavramını ne ölçüde kavrayabildiklerini ortaya koymak ve bu öğretim yaklaşımlarının zorlayıcı astronomi kavramlarının öğrenilmesine katkı sağlayıp sağlamadığını incelemektir. Bu doğrultuda, uzmanlar tarafından yürütülen uygulamalı oturumlar ve bu oturumların ardından gerçekleştirilen Odak Grup Görüşmeleri (OGG) ile süreç ve öğrenme çıktıları ayrıntılı şekilde değerlendirilmektedir.

Sonuç

Bu çalışmada gerçekleştirilen manuel deney ve dijital görselleştirme sonuçları, Güneş Sistemi'ndeki gezegen yörüngelerinin eliptik olduğunu ve gezegenler arasında değişken eksantriklik değerleri bulunduğunu doğrulamaktadır. Manuel deneyde ölçülen 0,2–0,4 arası eksantriklik değerleri, yörüngelerin büyük oranda dairesel olduğunu gösterse de Kepler'in yasasına uygun olarak Güneş'in yörüngenin odak noktalarından birinde yer aldığı tespit edilmiştir (Voelkel, 2001). NASA Eyes ile yapılan dijital gözlemler ise gezegenlerin Güneş'e olan mesafelerinde değişimler gösterse de yörüngenin temel eliptik yapısının korunmakta olduğunu göstermiştir.

INTRODUCTION

An understanding of the solar system and the movement of the planets within it constitutes one of the fundamental topics in the study of astronomy (Karttunen et al., 2007). The most essential concept within this topic is the planetary orbit, which refers to the path traversed by a planet as it revolves around the Sun (Gutzwiller, 1998). A key issue is that many students face difficulties comprehending these orbits' shapes and properties (Gali, 2021). This challenge is primarily attributed to the abstract and complex nature of the concept, especially for students exposed to verbal or descriptive explanations without adequate visual support.

One of the primary difficulties students encounter is understanding that planetary orbits are not perfect circles but ellipses with varying levels of eccentricity. Eccentricity is a measure of how elongated the shape of an orbit is, which influences the distance between the planet and the Sun at various points along its orbit, specifically at the perihelion (closest point) and aphelion (farthest point) (Greiner, 2004). This issue becomes more pronounced when students calculate the eccentricity of a planet's orbit. Students struggle to perform accurate calculations without a solid understanding of the shape and concept of eccentricity itself. They tend to experience difficulty when asked to graph the orbit of a planet based on the theoretical knowledge they have acquired (Taber, 2005). It suggests that conceptual understanding does not always translate into the ability to accurately represent or depict the phenomenon visually.

Traditional approaches that rely on verbal explanations often do not address this difficulty. While static images or diagrams of planetary orbits may assist, these methods are frequently limited in conveying the dynamic nature of a planet's motion within its orbit (Bate et al., 2020). As a result, students often feel confused when trying to correlate theoretical concepts with actual phenomena (Bakas & Mikropoulos, 2003). Therefore, more interactive learning methods, such as manual simulations and digital visualizations, are needed to provide students with direct experience.

Manual simulations allow students to draw and calculate orbits more practically. This method will enable students to interact with the data and concepts they are studying directly; however, it still has limitations regarding accuracy and the speed of calculations. Manual simulations require more extensive direct involvement, which may not always be accessible to all students (Corter et al., 2011). Digital visualizations, conversely, can provide a more accurate and dynamic representation of planetary motion, but this may diminish student engagement in the calculation or hands-on experimental process (Genot et al., 2018).

The issue of students' difficulty in understanding planetary orbits, especially in visualizing the shape and calculating eccentricity, is a significant concern in astronomy education. A thorough understanding of planetary orbits is one of the foundational concepts in astronomy that students must master (Williamson & Willoughby, 2012). This concept underpins knowledge of planetary motion within the solar system and connects to many other natural phenomena, such as seasonal changes, celestial object position calculations, and fundamental principles of gravity (Bertotti et al., 2012; Woolfson, 2000). Therefore, students' challenges in grasping planetary orbits significantly impact their comprehension of broader natural science concepts.

Planetary orbits are not perfectly circular but elliptical, with varying levels of eccentricity (Criss & Hofmeister, 2023). Eccentricity measures how elongated the orbit is, influencing the distance between the planet and the Sun at various points along its orbit (Wu & Lithwick, 2013). This concept is inherently abstract, and without effective learning media, students often struggle to visualize or depict the shape of these orbits. The verbal explanations commonly used in education are insufficient to help students visualize this shape. Kepler's laws have described planetary motion, but without explicit visual representations, students struggle to connect theory with reality (Galano et al., 2018).

This difficulty becomes even more pronounced when students are confronted with tasks involving the calculation of eccentricity. Calculating eccentricity requires a deeper understanding of the orbit's shape, and without a precise sense, students face challenges in performing accurate calculations. As a result, students fail to arrive at the correct answer and grasp the underlying physical concepts that govern these calculations. One primary reason students struggle with astronomy concepts is the lack of direct experience with the phenomena, which are often taught theoretically or through representations that lack dynamism (Galano et al., 2018).

The importance of a solid understanding of planetary orbits cannot be overstated, as this serves as the foundation for learning many more advanced scientific topics. For example, understanding planetary orbits is fundamental for studying Newton's law of gravitation, Einstein's theory of relativity, and other more complex scientific concepts. If students lack a clear understanding of how celestial bodies move in their orbits, they will struggle when progressing to more advanced topics in physics or astronomy.

Science education in the 21st century is increasingly oriented toward using technology to enhance students' comprehension (Firdaus, 2023). Digital visualizations and interactive simulations have proven to be immensely beneficial in conveying abstract concepts (Alifiyah et al., 2023), such as planetary orbits, in a more dynamic and accessible manner (Eidikis & Svensson, 2022). Technology allows students to observe the motion of planets within their orbits directly and to visualize the changes in orbital shape caused by variations in eccentricity. These manual and digital simulations allow students to grasp the theoretical aspects of these concepts and experience them practically (Galano et al., 2018). The use of more interactive learning media significantly aids students in bridging theory with reality, thereby facilitating a deeper and more meaningful understanding (Adam et al., 1990).

A solid understanding of planetary orbits and orbital eccentricity is also crucial in daily life. For instance, knowledge of satellite orbits is directly related to modern communication technologies, global positioning systems (GPS), and numerous other applications. Learning about planetary orbits is relevant in academic contexts and vital for advancing the rapidly evolving technological landscape. By preparing students to grasp these foundational concepts, we are nurturing a workforce better equipped to face the challenges of a world increasingly dependent on science and technology. The challenges students face in understanding these concepts need to be addressed urgently. More effective and technology-based teaching methods are required to help students master these complex concepts more interactively and engagingly.

Recognizing these challenges, much research has focused on leveraging technology, such as computer-based simulations and visualizations, to assist students in understanding abstract astronomical concepts. Computer simulations in astronomy education have been shown to improve students' comprehension of planetary motion and the shape of orbits (Barnett, 2005). Digital simulations enable students to observe how planets move in their orbits directly and witness the eccentricity variations that occur within these orbits (Yu et al., 2010). This research indicates that integrating simulations into learning makes it easier for students to understand abstract concepts in a more practical and real-world connected manner.

Students using software to simulate planetary orbits demonstrate a better understanding of the differences in orbital shapes and the influence of eccentricity on planetary motion (Yu et al., 2010). These simulations allow students to observe orbital shape changes directly, a phenomenon that is difficult to convey through verbal explanations alone. The findings suggest that using simulations enhances theoretical understanding and helps students develop better observation and analytical skills. Other studies by Chen et al. (2015) and Sagardia et al. (2015) compared the effectiveness of manual (hand-drawing orbits) and digital (computer simulations) learning methods. Their results showed that while manual methods provide a basic understanding of orbital shapes, digital simulations offer a more profound and realistic learning experience. Simulations allow students to interact directly with concepts such as eccentricity and orbital variation, manipulating parameters and observing the effects in real-time. These studies underscore the critical role of technology, mainly computer-based simulations, in helping students grasp more complex astronomical concepts.

Most previous studies have focused on using digital simulations to enhance students' understanding of astronomical concepts, especially planetary orbits. However, this research explores the benefits of combining manual and digital simulations in learning. This approach will allow students to draw orbits manually, which is expected to reinforce the foundational understanding of orbital shapes and properties. Subsequently, students can use digital simulations to observe planetary orbits' more dynamic and interactive movement. This study determines whether a combined approach is more effective than a single method.

The study proposes an experimental approach, allowing students to experiment by altering specific parameters within simulations and observing how these changes affect the shape of planetary orbits. This method seeks to increase student engagement in the learning process through hands-on experimentation. Consequently, students will gain a more intuitive understanding of orbital eccentricity through simulations, which may be challenging to explain through theoretical approaches alone. This concept has not been widely explored in prior research, which has typically focused more on theoretical explanations or pre-existing simulations without providing space for student experimentation.

In addition to integrating manual and digital simulations, this research aims to introduce a more holistic approach by combining visual learning (through manual drawings and digital simulations) with conceptual learning (through theoretical explanations and classroom discussions). The objective is to develop educational tools that enable students to visualize orbital shapes and connect them with the underlying physical laws governing planetary motion (such as Kepler's Laws). This approach seeks to foster a more comprehensive and coherent understanding of astronomical education's visual and conceptual aspects.

Moreover, this study aims to provide new insights into how simulation-based learning influences students' understanding of orbital eccentricity, a concept often difficult to grasp in astronomy. Although eccentricity has been taught in many contexts, this study intends to evaluate whether the combination of manual and digital simulation methods can make this concept more intuitive. By enabling students to draw and subsequently simulate orbits with varying levels of eccentricity, this research hopes to contribute to teaching abstract concepts more effectively. Another novel aspect of this study is its application across diverse learning styles. The research will focus on students who lean towards visual or kinesthetic learning and those who may rely more on verbal or logical methods. By offering multiple ways to comprehend planetary orbit concepts—through manual drawings, hands-on experiments, and digital visualizations—this study has the potential to accommodate different learning styles, thereby maximizing overall student understanding.

A primary goal of this research is to introduce simulation-based methods as an accessible learning tool that can be implemented in schools with limited access to advanced astronomical equipment. By utilizing more straightforward tools, such as simulation software that can run on standard computers coupled with easily obtainable manual materials, this study aims to demonstrate that astronomical concepts can be taught interactively and engagingly without costly equipment. The research seeks to compare the effectiveness of manual simulations and digital visualizations in teaching planetary orbit concepts, particularly concerning orbital eccentricity. This combined approach presents a solution that offers students a more comprehensive understanding—theoretically, practically, and visually. Students are expected to improve their ability to accurately depict and calculate orbital eccentricity and reinforce their grasp of astronomical concepts, particularly those related to planetary motion within the solar system.

METHODOLOGY

This study employs a comparative descriptive method to depict and compare the effectiveness of two pedagogical approaches in understanding planetary orbits: manual simulation and digital simulation. The technique aims to explore the extent to which both approaches can assist students in comprehending the shape of orbits and the concept of eccentricity and assess whether these approaches can enhance students' understanding of challenging astronomical concepts. Based on these objectives, the research design incorporates practical sessions conducted by experts and expert evaluations through Focus Group Discussions (FGD) to provide in-depth assessments of the learning outcomes and processes.

The research utilizes an expert-based practical design aimed at exploring students' understanding through two distinct methods: manual simulation and digital simulation. This practical session will involve four experts or instructors, each possessing expertise in explaining and practicing planetary orbit concepts. These four experts will evaluate the functional outcomes using Focus Group Discussions (FGD) to gather comprehensive feedback on the effectiveness of both instructional methods.

The effectiveness of each learning method in enhancing students' understanding of planetary orbits and eccentricity will be measured using two primary instruments: a practical guide and focus group discussions. The Practical Guide is specifically designed utilizing a remote-guided learning platform, with instructions tailored to the method employed. The manual simulation will require students to draw orbits and calculate the eccentricity manually, while the digital simulation will utilize software to visualize the planetary orbital movements. Following the practical sessions, an FGD will be held with experts comprising instructors or practitioners in astronomy. The FGD aims to evaluate and provide feedback on the learning process, the challenges students face, and the success rate of each method in explaining astronomical concepts. The FGD will also explore expert perceptions of the strengths and weaknesses of both instructional methods.

Ethics Information: Research and publication ethics were followed.

RESULTS

Results of the Manual Experiment

The primary objective of the manual experiment was to calculate the eccentricity of an orbit using data obtained from the distance between pins and the length of the central axis. Eccentricity measures the degree to which a planet's orbit deviates from a perfect circular shape. Generally, if an orbit's eccentricity (e) is equal to 0, the orbit is an ideal circle. The orbit forms an ellipse if the eccentricity is greater than 0 but less than 1 ($0 < e < 1$). If the eccentricity equals 1, the orbit is parabolic; if the eccentricity exceeds 1 ($e > 1$), the orbit is hyperbolic.

Table 1. Manual experiement data

No	Distance Between Pins (cm)	Length of the Major Axis (cm)	Eccentricity	Orbital Shape Description
1	2	10	0,2	Elips
2	4	11,6	0.34	Elips
3	6	16,6	0.36	Elips
4	8	19,8	0.40	Elips

Note. Keterangan
$e = 0$ (Circle)
$0 < e < 1$ (Elips)
$e = 1$ (Parabola)
$e > 1$ (Hiperbola)

Based on the data obtained from the manual experiment, a relationship can be observed between the length of the central axis, the distance between the pins, and the calculated eccentricity of the orbit. The eccentricity values ranged from 0.2 to 0.4, all within the $0 < e < 1$ range, indicating that the resulting orbital shapes are elliptical.

In the first trial, with a distance between the pins of 2 cm and a central axis length of 10 cm, the calculated eccentricity was 0.2. This value is close to 0, suggesting that the orbit is nearly circular, though still categorized as elliptical. In the second trial, with a 4 cm distance between the pins and a central axis length of 11.6 cm, the eccentricity increased to 0.34. This value indicates that the orbit shape became slightly more elongated, though it still qualifies as elliptical. In the third trial, the distance between the pins was extended to 6 cm, with a central axis length of 16.6 cm. The calculated eccentricity was 0.36, higher than in the previous trial, showing that the orbit increasingly deviated from a circular shape, becoming more distinctly elliptical. The fourth trial, using an 8 cm pin distance and a central axis length of 19.8 cm, yielded an eccentricity of 0.40. This higher eccentricity indicates a more pronounced elliptical shape with more excellent elongation than the previous trials.

As the length of the central axis increases in the experiments, the eccentricity of the resulting orbit also increases. It suggests that the orbital shape increasingly deviates from a perfect circle, taking on a more elongated elliptical form as the central axis lengthens. These results confirm the theory that orbital eccentricity can vary depending on the ratio between the length of the central axis and the distance between the foci (pins). Thus, this data clearly illustrates how these parameters influence the shape of planetary orbits, particularly in the context of the experiments conducted. The results of the experiment can be visualized in Figure 1.

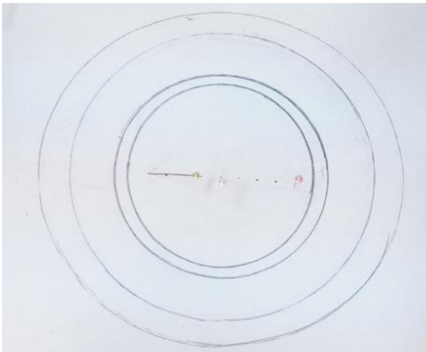

Figure 1. *Experimental results*

Figure 1 visually represents the orbital shapes produced based on the data recorded in Table 1 concerning the manual experiment. The recorded data demonstrates variations in the eccentricity of planetary orbits across four trials, each with different pin distances and primary axis lengths. Each trial resulted in a distinct eccentricity value, which influenced the observed orbital shapes depicted in the figure.

In the first trial, with a pin distance of 2 cm and a central axis length of 10 cm, the obtained eccentricity was 0.2, indicating an orbit nearly circular. It aligns with the visual observation in the figure, where the resulting orbit appears more symmetrical, closely resembling a perfect circle. However, since the eccentricity is slightly greater than zero ($0 < e < 1$), the orbit can still be categorized as elliptical, albeit with minimal distortion.

In the second trial, with a pin distance of 4 cm and a central axis length of 11.6 cm, the eccentricity increased to 0.34. This change is reflected in the figure, where the resulting orbit shows a noticeable elongation, becoming somewhat more stretched compared to the first trial. The eccentricity value, still greater than 0 but less than 1, indicates that the orbit is elliptical but with a more evident distinction between the major and minor axes.

In the third trial, with a pin distance of 6 cm and a central axis length of 16.6 cm, the calculated eccentricity was 0.36. The figure illustrates that the orbit has become even more elongated, with a more significant disparity between the major and minor axes, thus accentuating its elliptical shape. As the eccentricity value increases, the orbit increasingly deviates from a perfect circle, exhibiting more pronounced distortion.

In the fourth trial, with a pin distance of 8 cm and a central axis length of 19.8 cm, the eccentricity further increased to 0.40. The resulting image shows the most elongated orbit among all the trials, with a significant difference between the major and minor axes. This orbit exhibits a more pronounced elliptical form, reflecting the higher eccentricity value, which causes the orbit to move further away from a circular shape and towards a more distorted elliptical form.

Figure 1 visually confirms the eccentricity calculations recorded in Table 1. The visualization clearly shows how the orbital shape changes in response to central axis length and pin distance variations. As the primary axis length and pin distance increase, the eccentricity value also rises, which is visually represented by the transformation of the orbit from circular to increasingly distorted elliptical shapes. This analysis reinforces the understanding that orbital eccentricity is directly related to the orbital shape, which is observable through this visualization.

Nasa Eyes Digital Visualization Results

Observations of planetary orbits within the solar system can be conducted through various methods, both manually and with the aid of advanced technologies. One approach to digitally visualize planetary orbits is through applications such as NASA Eyes, which enables high-accuracy imaging and tracking of planetary trajectories. In this study, observations using NASA Eyes focused on the positions of the planets around the Sun, both at perihelion (the closest point to the Sun) and aphelion (the farthest point from the Sun), to better understand the shape of their orbits. The visualization from NASA Eyes is depicted in Figure 2.

Table 2. Observation data using NASA eyes

No	Planet	Planetary Positions	Orbit Shape
1	Mercury	Perihelion	Elips
2	Venus	Perihelion	Elips
3	Earth	Perihelion	Elips
4	Mars	Perihelion	Elips
5	Jupiter	Aphelion	Elips
6	Saturn	Aphelion	Elips
7	Uranus	Aphelion	Elips
8	Neptune	Aphelion	Elips

The NASA Eyes observations demonstrate that all the planets observed, whether at perihelion or aphelion, possess elliptical orbits. It aligns with the theory proposed by Johannes Kepler in the early 17th century, which asserts that planetary orbits around the Sun are elliptical, with the Sun located at one of the ellipse foci. The recorded orbital shape is elliptical for Mercury, Venus, Earth, and Mars, which are situated at perihelion. The same applies to Jupiter, Saturn, Uranus, and Neptune, which are at aphelion and show elliptical orbital shapes. The positions of these planets at either perihelion or aphelion do not affect the fundamental shape of their orbits, which remain elliptical.

The data obtained indicates that the orbital shape remains consistently elliptical despite the varying distances between the planets and the Sun at different points in their orbits. The perihelion and aphelion positions only influence the distance between the planet and the Sun, but they do not alter the fundamental elliptical shape of the orbit. The results derived from the use of NASA Eyes provide confirmation of Kepler's law, which reveals that the orbits of planets within the solar system are indeed elliptical. This observation also offers a more straightforward and accurate depiction of a planet's position at specific points in its orbit and how digital technology can be employed to visualize and comprehend complex astronomical concepts.

DISCUSSION

The manual experiment and the digital visualization results from NASA Eyes reveal consistent findings regarding the shape of planetary orbits, all of which are elliptical, by the theory proposed by Johannes Kepler in the 17th century. However, despite the similar outcomes from the experimental and digital observations, several aspects warrant further investigation to deepen our understanding of orbital eccentricity and its implications in astronomy and physics.

Findings on Eccentricity and Orbital Shape

The manual experiment results show orbital eccentricity values ranging from 0.2 to 0.4, all falling within $0 < e < 1$, indicating that the resulting orbits are elliptical. The influence of changes in the length of the central axis on orbital eccentricity is also evident. As the significant axis length increases, the eccentricity value rises, resulting in a more pronounced orbit distortion from a perfect circle. These findings are consistent with the foundational understanding in astronomy that planetary orbits in the solar system are elliptical with varying degrees of eccentricity.

According to Kepler's theory, each planet moves in an elliptical orbit with the Sun located at one of the foci. Orbital eccentricity measures how much an orbit deviates from a perfect circular shape. As the eccentricity approaches zero, the orbit becomes more circular, whereas as the eccentricity approaches one, the orbit elongates. For example, Earth's approximately 0.0167 eccentricity represents an almost circular orbit, while Mercury's higher eccentricity (around 0.2056) indicates a more elongated orbit.

Comparison with Digital Observation Data

The observations using NASA Eyes confirm the manual experiment findings, where the orbits of the planets in the solar system are indeed elliptical, despite variations in the planets' distances from the Sun at perihelion and aphelion. The positions of perihelion (the closest point to the Sun) and aphelion (the farthest point from the Sun) do not affect the basic elliptical shape of the orbits. It reaffirms Kepler's law, which states that the Sun is located at one of the foci of a planet's orbit, and although the distance between the planet and the Sun varies along the orbit, the orbit's shape remains unchanged (Voelkel, 2001).

Analysis and Implications

One notable point is that although the manual experiment provides results consistent with theory, the eccentricities calculated in this experiment are relatively low (ranging from 0.2 to 0.4), which more closely resemble orbits that are elliptical but nearly circular. It is in line with the characteristics of the planets in our solar system, which tend to have low eccentricities. However, some planets, like Pluto, have higher eccentricities, indicating more elongated orbits.

According to astronomical literature, planets with higher eccentricities, such as Mercury, have more distorted orbits and are more sensitive to gravitational perturbations from other planets. It is particularly relevant for understanding the dynamics of planets with high orbital eccentricities, including the role of planetary perturbations in influencing the orbit and its long-term stability (Murray & Dermott, 1999). Furthermore, digital visualization techniques, such as NASA Eyes, represent a significant advancement in accurately visualizing planetary orbits. Technologies like these allow scientists and educators to observe planetary orbits more dynamically and interactively, offering new perspectives in understanding planetary orbits and applying Kepler's laws. This technology also enables simulations of planetary motion over extended time scales, enriching our understanding of the evolution of planetary orbits within the solar system (Voelkel, 2001).

CONCLUSION AND RECOMMENDATIONS

The manual experiment and digital visualization conducted in this study confirm that the orbits of the planets in the solar system are elliptical, with varying eccentricities among the planets. The results from the manual experiment show eccentricities ranging from 0.2 to 0.4, indicating nearly circular orbits, yet still conform to Kepler's law, which states that planetary orbits are elliptical with the Sun located at one of the foci (Voelkel, 2001). These findings are also consistent with the digital observations using NASA Eyes technology, which depict variations in the planets' distances from the Sun but do not affect the fundamental shape of the orbit itself. These manual and digital results illustrate the crucial role of technology in the visualization and understanding of astronomy and how digital technologies, such as planetary orbit simulations, can enhance our knowledge of planetary motion within the solar system. In conclusion, although most planets exhibit low eccentricity orbits, there is an apparent variation, especially for planets with higher eccentricity, such as Mercury and Pluto.

Recommendations

1. Based on these findings, it is recommended that further development and utilization of computer-based simulations be utilized to model planetary orbits under various conditions, such as the effects of gravitational perturbations from other planets. It will help provide a more realistic depiction of how planetary orbits may change over the long term.

2. Further research should focus on planets with higher eccentricities, such as Pluto and Mercury, to gain deeper insights into the dynamics of more distorted orbits. It includes investigating the influence of other planets in the solar system on the stability of these orbits.

3. Increased use of visualization technologies, such as NASA Eyes, in educational processes is recommended to introduce complex astronomical concepts to students and the general public. These technologies can enrich the learning experience by making it more interactive and immersive.

4. Future research could explore the relationship between planetary orbital eccentricity and its potential impact on climate change on those planets, particularly Earth and planets with similar characteristics. This research is also critical for understanding the potential for life on other planets with different orbital conditions.

5. Integrating manual and digital practical exercises should be more designed explicitly in its application, ensuring a more cohesive approach to teaching and understanding astronomical phenomena.

Researcher Contribution Rate

Thoriqi Firdaus: Conceptualization, Investigation, Methodology, Data Curation, Writing Original Draft. Listiawan: Resources, Review, Editing. Riski Dewanto: Validation, Review, Editing. Ihza Rizky Winedar: Formal Analysis, Review.

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Research and publication ethics were followed.

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Conflict of Interest

The authors declare that there is no conflict of interest in this study.

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