Systematic calculation of mathematical pendulum movement in the lato-lato game using the Equilibrium State System

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ABSTRACT

Lato-lato is a toy that is easy to find lately. Lato-lato turns out to have a shape like a ball hanging on a rope that has similarities with a mathematical pendulum. The background of this study is to analyse whether lato-lato can be used as a substitute for a mathematical pendulum in determining the swing period. The type of research used to determine this period is experimental research, where the oscillation of lato-lato is compared with a standard mathematical pendulum at various rope lengths and initial deviation angles. The data obtained are analysed quantitatively to determine whether lato-lato has a match for the simple harmonic motion possessed by a mathematical pendulum. The study results show that lato-lato has an oscillation pattern that approaches a mathematical pendulum at a certain period, with some differences caused by the shape and mass distribution of lato-lato. These findings indicate that lato lato can be an alternative simple physics learning tool with some limitations.

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1. INTRODUCTION

The concept of the mathematical pendulum is one of the foundational topics often introduced in physics to explain simple harmonic motion (SHM). A mathematical pendulum consists of a mass suspended by a light, inextensible string or rod that swings freely under the influence of gravity. It provides a clear overview of how the string's length, the initial deviation angle, and gravitational acceleration affect the swing period. This simplicity makes it a valuable model for studying oscillatory motion and dynamics, which are crucial in many areas of physics.

In physics education, the mathematical pendulum serves as an effective tool for demonstrating fundamental concepts like periodicity, resonance, and equilibrium. Moreover, it is used to understand more complex phenomena, such as energy conservation and damping effects in real-world systems. Research highlights how physical pendulum experiments can determine the moment of inertia by measuring the oscillation period at various rotation points, showing the versatility of pendulum systems in dynamics research [1], [2], [3]. The mathematical pendulum's straightforward theoretical framework makes it a reliable benchmark for comparing real-world oscillatory systems, bridging theoretical physics and experimental verification.

Pendulum experiments have also been adapted for practical applications in measuring gravitational acceleration. For example, [4] demonstrated how harmonic motion principles could be applied using tools like a lato-lato to determine local gravitational acceleration. These applications underscore the pendulum's importance in theoretical and experimental physics, making it a timeless subject of study in physics education.

Recently, there has been growing interest in integrating everyday objects into physics experiments to enhance accessibility and engagement. One such object is lato-lato, a traditional game of two balls connected by a string. Historically famous in various cultures, lato-lato has regained popularity as a recreational toy, but its potential as an experimental tool in physics remains underexplored. The distinctive oscillatory motion produced by lato-lato provides a unique opportunity to study dynamics and harmonic motion.

Research [5] has shown that lato-lato motion can be analysed using the concept of dynamic equilibrium, aligning with the fundamental principles of SHM. As a toy, lato-lato has a simple structure but generates a complex motion pattern that challenges traditional experimental setups. Unlike a typical mathematical pendulum, where a single mass moves in a plane, lato-lato's dual masses introduce additional complexity. This characteristic makes it a promising alternative for studying harmonic motion more interactively and engagingly.

Using lato-lato as a mathematical pendulum could address some limitations in conventional pendulum experiments. Traditional setups often require specific laboratory equipment, which may not be readily available in all educational settings. By contrast, lato-lato is affordable, widely accessible, and easily adaptable for classroom experiments. Utilising lato-lato as an experimental tool could democratise physics education, making core concepts like SHM more approachable for students across diverse backgrounds. Furthermore, this approach aligns with recent efforts to incorporate everyday objects into physics learning to foster creativity and critical thinking.

Despite its potential, there are significant challenges in validating lato-lato as a substitute for the mathematical pendulum. The motion dynamics of lato-lato depend not only on the string length and gravitational force but also on the symmetry of the balls and the system's stability. Research on lato-lato oscillation is still in its early stages, and systematic analysis is needed to establish its suitability for educational purposes. Variables such as the swing period, string length, and stability of harmonic motion must be thoroughly evaluated to determine whether lato-lato's motion adheres to the theoretical framework of SHM.

In addition to educational implications, lato-lato's motion could inspire further research in applied physics. For instance, it explored how pendulum motion is affected by string length, mass, and angular displacement. Incorporating lato-lato into such studies could reveal new insights into complex oscillatory systems, particularly those involving multi-mass interactions [6], [7]. Moreover, lato-lato experiments could be a gateway to more advanced topics like coupled oscillations and resonance phenomena.

Research on innovative experimental tools like lato-lato aligns with broader trends in physics education, emphasising hands-on learning and real-world applications. [8] demonstrated the effectiveness of video analysis tools in enhancing students' understanding of SHM through practical experiments. Similarly, incorporating lato-lato into classroom activities could foster active learning, encouraging students to explore physics concepts tangibly and engagingly.

Furthermore, lato-lato experiments can potentially address physics education's psychological and pedagogical aspects. By incorporating familiar and enjoyable objects, such as lato-lato, into experiments, educators can reduce students' anxiety about complex topics and increase their motivation to learn. As [9] noted, simple teaching aids can spark interest in STEM, particularly among younger audiences. The playful nature of lato-lato could make physics experiments more appealing, encouraging students to develop a more profound interest in science and engineering.

The broader application of pendulum concepts in experimental physics has also inspired innovative designs for laboratory tools. [10] discussed the development of pendulum-based teaching aids to demonstrate the relationship between physical parameters and oscillatory motion. Similarly, using lato-lato as a teaching tool could contribute to developing cost-effective and versatile laboratory setups for physics education.

This study uses an experimental approach to systematically compare the oscillatory behaviour of lato-lato with that of a standard mathematical pendulum. By varying the string length and measuring the swing period, we seek to determine whether lato-lato's motion adheres to the characteristics of SHM. Additionally, this research aims to provide insights into the practical challenges and opportunities of using lato-lato as a teaching tool. This study establishes a framework for incorporating lato-lato into physics education by analysing the motion patterns and comparing experimental data with theoretical predictions.

Ultimately, this study hopes to expand the range of tools available for teaching physics, emphasising accessibility and engagement. As conventional laboratory equipment becomes increasingly specialised, finding alternative experimental tools that are simple, effective, and widely available becomes critical. By leveraging the popularity and simplicity of lato-lato, this research contributes to ongoing efforts to make physics education more inclusive and innovative.

2. METHODS

The type of research used is experimental research that aims to analyse the suitability of the lato-lato motion as a substitute for a mathematical pendulum utilising the concept of simple harmonic motion. The study was conducted by varying the length of the rope and measuring the lato-lato swing period to evaluate the oscillation characteristics of the system. The research steps are arranged based on references from previous studies that use lato-lato in physics experiments.

2.1. Tools and Material

a. Lato-lato: Used as the main object of research.
b. Stand and clamp: To hang the lato-lato stably.
c. Stopwatch: To measure the swing period time.
d. Measuring tape or ruler: To adjust the length of the rope.
e. Protractor: To ensure the angle of deviation remains small (<15°).

2.2. Research procedures

a. Research procedure
Preparation of Tools and Materials
Lato-lato is hung on a stand using a rope with an initial length of 20 cm. Make sure the hanger position is stable and free from external interference, such as wind
b. Rope Length Variation
Take measurements with rope length variations: 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm, and 80 cm. Each rope length is adjusted with a ruler or measuring tape.
c. Swing period measurement
Deflect the lato-lato at a slight angle (<15°) to ensure simple harmonic motion. Release the lato-lato without additional thrust and measure the time for 20 swings using a stopwatch. Record the measured time and calculate the average period

$$\left(T = \frac{t}{n}, dengan\ t = time, n = number\ of\ swing\right).$$

d. Theoretical Calculation
Calculate the theoretical period using the simple harmonic motion equation:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

e. Data Analysis
Compare the experimental measurement results with the theoretical results. Analyse the relationship between rope length (L) and period (T^2) to ensure that the lato-lato motion is by the characteristics of a mathematical pendulum.
f. Error Analysis
To minimise measurement errors, ensure the deviation angle remains small (<15°). Avoid excessive air friction and external interference. Take measurements 20 times for each length of the rope and calculate the average.

3. RESULTS AND DISCUSSION

The following is the time required to achieve 20 swings of the lato-lato swing with rope lengths of 20 cm, 30 cm, 40 cm, 50 cm, 60 cm, 70 cm, and 80 cm.

Table 1. Time gained to achieve 20 swings

No.	L (cm)	t (s)	n
1	20	18.56	20

2	30	22.65	20
3	40	26.44	20
4	50	29.87	20
5	60	33.12	20
6	70	36.45	20
7	80	39.52	20

At a rope length of 20 cm, it takes 18.52 seconds to reach 20 swings. At a rope length of 30 cm, it takes 22.65 seconds to reach 20 swings. At a rope length of 40 cm, it takes 26.44 seconds to reach 20 swings. At a rope length of 50 cm, it takes 29.87 seconds to reach 20 swings. At a rope length of 60 cm, it takes 33.12 seconds to reach 20 swings. At a rope length of 70 cm, it takes 36.45 seconds to reach 20 swings. At a rope length of 80 cm, it takes 39.52 seconds to reach 20 swings.

From these results, it can be concluded that the longer the rope is used, the longer time is obtained to achieve the same number of swings. This is because the length of the rope is directly proportional to the period; the more extended the rope, the greater the period. If the period is more significant, the time required will also be more critical because the period is directly proportional to time according to the following equation:

$$T(Periodic) = \frac{t(time)}{n(number\ of\ swings)}$$

After the time to reach 20 swings is known, a calculation is made to find the period value. The swing movement can be a reference for measuring the period value because the swing movement is one of the oscillatory motions often encountered, where this oscillatory motion occurs under the influence of the earth's gravitational force. The form of oscillation in this study is simple harmonic motion because the swing deviation is not too large.

Determination of the local earth's gravitational acceleration value g is done by deriving the equation:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

So when it is derived, it produces the equation:

$$T^2 = \frac{4\pi^2 L}{g}$$

Where T is the period, L is the length of the rope, and g is the acceleration due to gravity. The following results are obtained from the time received to achieve 20 swings on each length of the rope and the equation above.

Table 2. The period resulting from each length of string

No.	$L\ (m)$	$t\ (n = 20)$	$T = \frac{t}{n}$	T^2
1	0.2	18.96	0.95	0.899
2	0.3	21.88	1.09	0.197
3	0.4	26.79	1.34	1.794
4	0.5	29.62	1.48	2.193
5	0.6	31.86	1.59	2.538
6	0.7	34.75	1.74	3.019
7	0.8	36.81	1.84	3.387

The data shows that the period of the late-lato swing increases as the length of the rope increases by the theoretical equation.

$$T = 2\pi\sqrt{\frac{L}{g}}$$

The gravitational acceleration (g) calculated from the experiment of 9.8 m/s^2 is consistent with the value of Earth's gravity in general. This shows that the lato-lato can function as a substitute for a mathematical pendulum in simple physics experiments.

The lato-lato allows the observation of oscillation patterns similar to mathematical pendulums but is more visually appealing and easily accessible. This is in line with research, which shows that the lato-lato can be used to understand the dynamics of simple harmonic motion.

Several factors, such as small deviation angles (<15°) and consistently controlled rope lengths, help ensure the stability of simple harmonic motion. However, external factors such as air friction and

the stability of the hanger can affect the results, as also reported by previous research

With results close to the theory of mathematical pendulums, the lato-lato has excellent potential as an effective alternative experimental tool for physics learning. Its use can increase students' interest in abstract physics concepts through exciting and easy-to-find tools.

The results of this study confirm that the lato-lato can be used as a substitute for the mathematical pendulum for mathematical purposes.

4. CONCLUSION

This study proves that lato-lato, a traditional toy, can be used as a substitute for a mathematical pendulum in physics experiments to study simple harmonic motion. Based on the experimental results, data were obtained showing that the period of the lato-lato swing is directly proportional to the length of the rope by the theoretical equation of the mathematical pendulum. Measurement of local gravitational acceleration using lato-lato produces a value of 9.8 m/s², which is in line with the value of the earth's gravitational acceleration in general.

These results indicate that lato-lato has excellent potential for physics learning, especially in simple experiments requiring easily accessible tools. In addition, observations of the motion of lato-lato show characteristics consistent with the motion of a pendulum, making it an attractive and effective alternative for teaching introductory physics concepts to students.

This study also opens up opportunities for further research that can expand the understanding of the use of everyday toys in physics experiments and explore other factors that affect the accuracy of experiments, such as air friction and tool stability.

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