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Development of a Web-Based Virtual Laboratory for the Study of Simple Pendulum Using HTML

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Abstract: Virtual laboratories have emerged as an effective pedagogical tool for enhancing conceptual understanding and experimental skills in physics education. In this work, a web-based virtual laboratory on the Simple Pendulum has been developed using HTML and deployed through Google Sites. The virtual lab allows users to vary key physical parameters such as length of the pendulum and initial angular displacement, and to input experimental data through a structured data table. Based on the user inputs, the system computes the time period of oscillation or the acceleration due to gravity (g) using standard theoretical relations. This virtual experiment replicates essential features of a real pendulum experiment and provides an interactive, accessible, and cost-effective alternative to traditional laboratories, particularly useful in blended and remote learning environments.

Keywords: *Virtual Laboratory, Simple Pendulum, Physics Education, HTML Simulation, Time Period, Acceleration Due to Gravity.*

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I. INTRODUCTION

Experimental learning constitutes a fundamental pillar of physics education, as it enables students to bridge the gap between theoretical concepts and real-world physical phenomena [1]. Through laboratory-based experimentation, learners develop critical skills such as observation, measurement, data analysis, and scientific reasoning. However, in many academic institutions, effective implementation of hands-on laboratory instruction is often hindered by practical challenges, including limited availability of laboratory infrastructure, large student enrollments, safety concerns, equipment maintenance issues, and constraints on instructional time. These limitations can reduce students' opportunities to engage meaningfully with experimental physics.

In this context, virtual laboratories have emerged as a powerful and complementary pedagogical tool [2, 3]. By leveraging advances in web technologies and computer simulations, virtual labs allow students to conduct experiments in a controlled, interactive, and repeatable simulated environment [4, 5]. Such platforms facilitate self-paced learning, immediate visualization of physical processes, and repeated trials without additional cost or risk, while preserving the conceptual and mathematical rigor of traditional laboratory experiments. Virtual laboratories are particularly valuable for reinforcing theoretical understanding and for pre-laboratory preparation or post-laboratory analysis.

The simple pendulum experiment is a cornerstone of pre undergraduate physics curricula and is widely used to introduce students to the concepts of periodic motion, simple harmonic motion, and experimental determination of physical constants. Conventionally, the experiment investigates the dependence of the time period of oscillation on parameters such as the length of the pendulum and the angular amplitude of oscillation, and enables the estimation of the local acceleration due to gravity. Despite its pedagogical importance, conducting the experiment in a physical laboratory may be affected by measurement uncertainties, environmental disturbances, and time limitations.

The present work addresses these challenges by focusing on the design and implementation of a simple pendulum virtual laboratory. The developed virtual environment allows users to independently vary key experimental parameters, including pendulum length and initial angular displacement, and to observe their effects on the time period of oscillation. An interactive data input and output framework enables students to record observations, compute the time period or gravitational acceleration, and analyze the results quantitatively. The virtual laboratory is implemented using HTML-based web technologies, making

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it accessible through standard web browsers without the need for specialized software.

Overall, the proposed virtual simple pendulum laboratory aims to enhance experimental learning by providing an accessible, flexible, and pedagogically effective platform that supports conceptual understanding, mathematical analysis, and inquiry-based learning in pre undergraduate physics education.

II. THEORETICAL BACKGROUND

A simple pendulum consists of a point mass (bob) suspended from a rigid support by a light, inextensible string. For small angular displacements, the motion of the pendulum is simple harmonic.

SCAN ME

The time period T of a simple pendulum is given by:

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

Where,

L = length of the pendulum

g = acceleration due to gravity

Rearranging the equation, the value of gravitational acceleration can be calculated as:

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

The time period is independent of the mass of the bob and, for small angles, independent of the initial angular displacement.

III. DESIGN AND METHODOLOGY OF THE VIRTUAL LAB

The developed virtual laboratory simulates the motion of a simple pendulum by numerically solving its nonlinear equation of motion and visualizing the result in real time using HTML5 Canvas and JavaScript. The code integrates classical mechanics with numerical methods and computer graphics to accurately represent continuous pendulum motion. Because the equation of motion of Simple pendulum is nonlinear, an analytical solution is not feasible for large angular displacements. Therefore, the simulation employs the fourth-order Runge–Kutta (RK4) method, which is implemented in the coding function. The physical length of the pendulum (in meters) is mapped to pixel units using a scaling factor: 1 m = 220 pixels. The code includes real-time user controls for: Initial angular displacement, Gravitational acceleration, and Pendulum length. Slider and input elements dynamically update the simulation parameters without restarting the animation. This feature enables users to observe how changes in L and g affect the time period and motion characteristics.

The laboratory is hosted on Google Sites, ensuring wide accessibility, ease of deployment, and seamless integration with web-based educational platforms. This design choice guarantees platform independence, allowing students and instructors to access the virtual experiment through any standard web browser without the need for specialized software or additional installations.

The virtual pendulum module incorporates essential adjustable parameters that closely replicate the real experimental setup. Users are able to vary the length of the pendulum and the initial angular displacement, enabling them to systematically investigate the dependence of the time period on these physical variables. By modifying these parameters, students can observe trends, compare theoretical expectations with simulated results, and develop a deeper understanding of periodic motion.

To support quantitative analysis, the virtual laboratory includes a structured data input and calculation module. Users can enter the length of the pendulum and the measured time taken for a fixed number of oscillations in a dedicated data table. Based on these inputs, the system dynamically computes the time period of oscillation and the corresponding value of the acceleration due to gravity. All calculations are carried out in real time using HTML-based scripting, providing immediate feedback, minimizing computational errors, and enhancing the overall learning experience.

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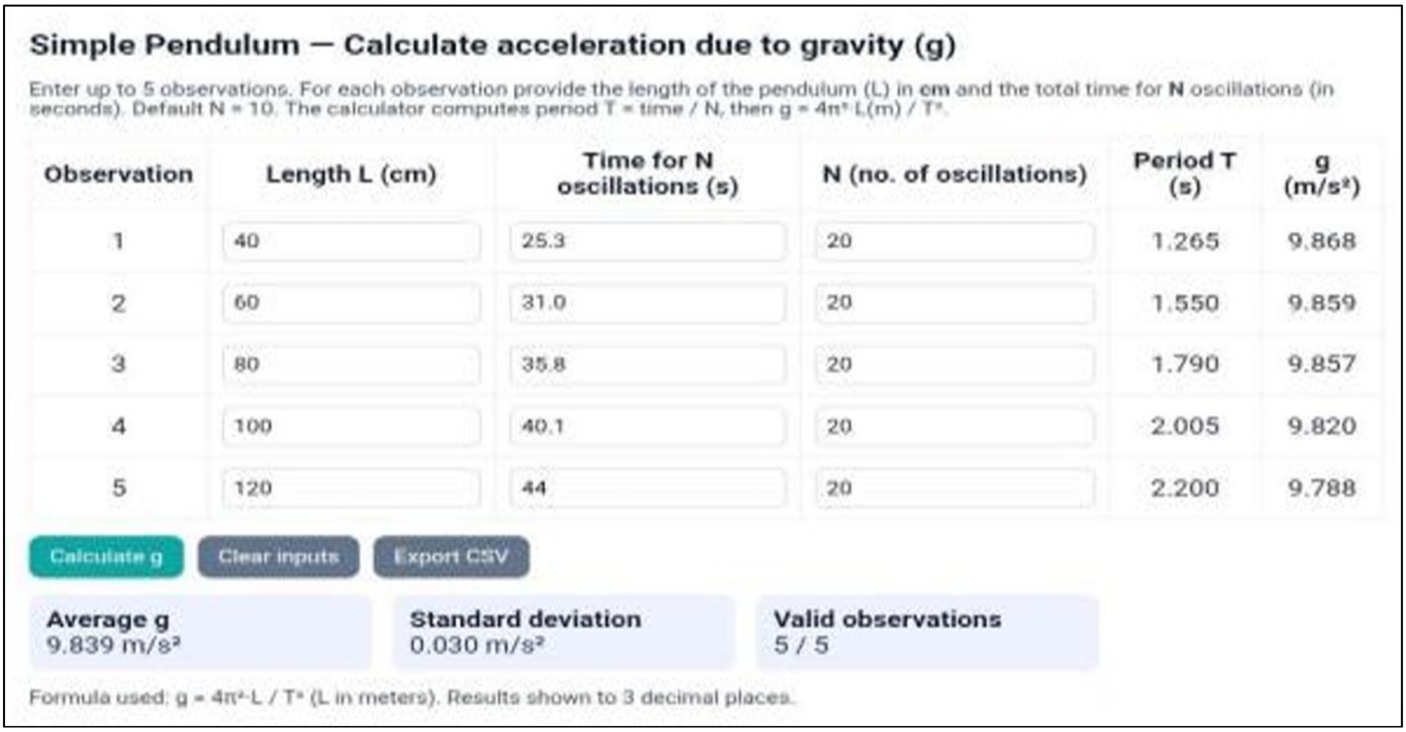

Simple Pendulum — Calculate acceleration due to gravity (g)

Enter up to 5 observations. For each observation provide the length of the pendulum (L) in **cm** and the total time for **N** oscillations (in seconds). Default N = 10. The calculator computes period T = time / N, then g = 4π² L(m) / T².

Observation	Length L (cm)	Time for N oscillations (s)	N (no. of oscillations)	Period T (s)	g (m/s²)
1	40	25.3	20	1.265	9.868
2	60	31.0	20	1.550	9.859
3	80	35.8	20	1.790	9.857
4	100	40.1	20	2.005	9.820
5	120	44	20	2.200	9.788

Calculate g | Clear inputs | Export CSV

Average g 9.839 m/s² | Standard deviation 0.030 m/s² | Valid observations 5 / 5

Formula used: g = 4π²·L / T² (L in meters). Results shown to 3 decimal places.

Fig 1 Data Input and Calculation Module

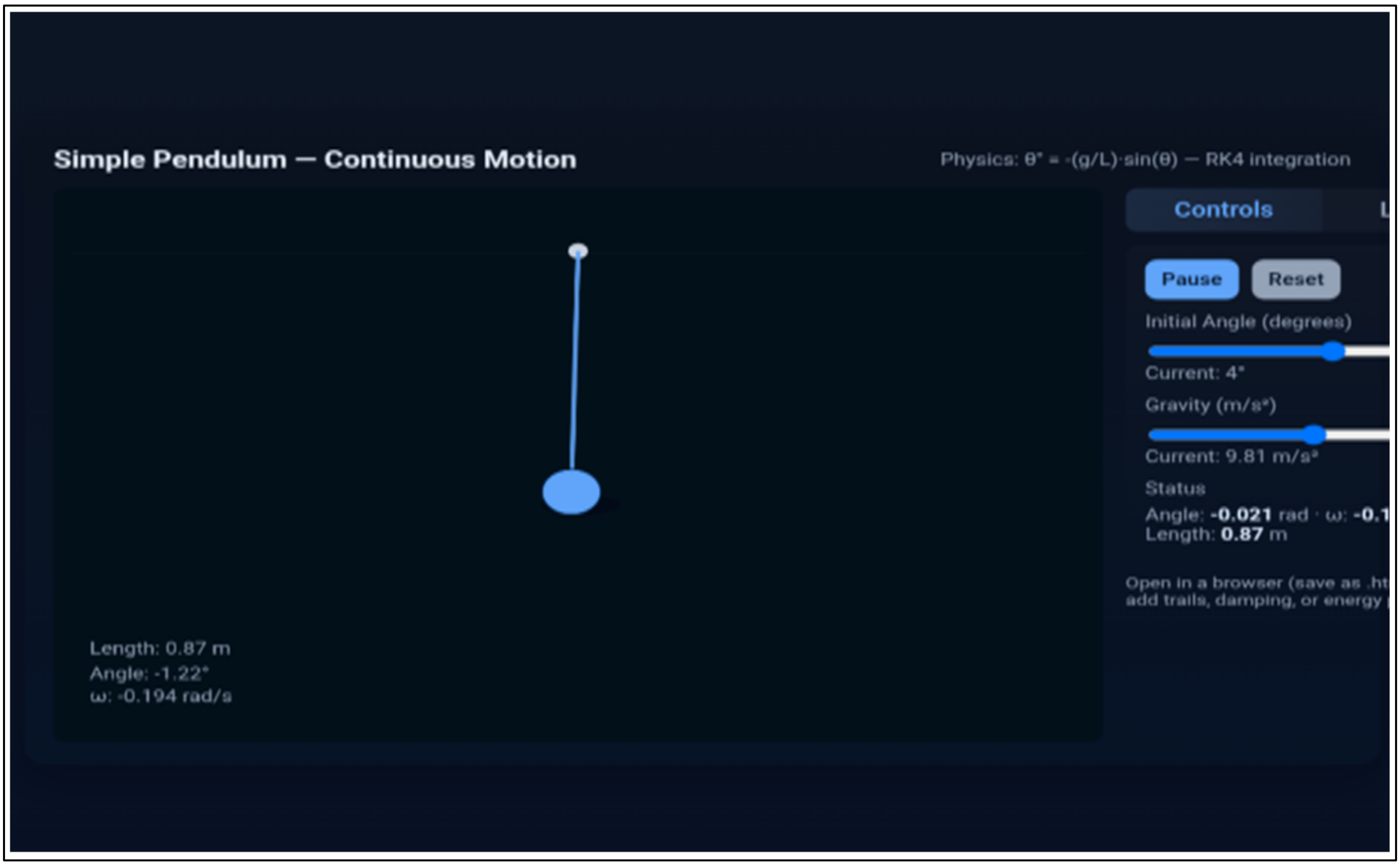

Fig 2 Virtual Pendulum

IV. WORKING PRINCIPLE

The user begins the experiment by selecting the desired length of the pendulum and the initial angular displacement. The experimentally observed time values for a fixed number of oscillations are then entered into the provided data table. The virtual laboratory processes these inputs and computes the time period by averaging the oscillation times. Using the standard mathematical relation for a simple pendulum, the value of the acceleration due to gravity is subsequently

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calculated and displayed. Students can repeat the experiment for different pendulum lengths, enabling them to verify theoretical relationships and analyze the dependence of the time period on the system parameters. A digital stopwatch was implemented using HTML, CSS, and JavaScript with millisecond resolution to measure the time period of a simple pendulum. The lap function enables the recording of time for multiple oscillations, thereby improving experimental accuracy. However, students may also use a conventional manual stopwatch to observe and record the time period, allowing comparison between digital and manual measurement techniques.

V. EDUCATIONAL SIGNIFICANCE

The developed virtual laboratory offers several important pedagogical advantages that enhance the teaching–learning process in physics. It reinforces theoretical concepts by allowing students to engage in interactive experimentation, thereby strengthening the connection between mathematical formulations and physical behavior. The virtual environment enables repeated trials without the constraints of limited equipment, time, or laboratory availability, promoting deeper exploration and conceptual clarity. By automating measurements and calculations, the system significantly reduces human and instrumental errors, leading to more reliable and consistent results. Furthermore, the virtual lab is particularly effective for remote learning and self-paced study, making it accessible beyond traditional classroom settings. In alignment with the objectives of the Indian National Education Policy (NEP), the platform supports digital, flexible, and technology-driven education, fostering experiential learning and improving student engagement in undergraduate physics courses.

VI. RESULTS AND DISCUSSION

Using the virtual laboratory, students observe that the time period of the pendulum increases with an increase in the length of the pendulum, while remaining nearly independent of the initial angular displacement for small angles of oscillation. The calculated value of gravitational acceleration g is found to be in close agreement with the standard accepted value, demonstrating the reliability of the simulation. These observations are fully consistent with the theoretical predictions of simple harmonic motion, thereby validating the accuracy and pedagogical effectiveness of the virtual experiment.

Despite its advantages, the virtual laboratory has certain limitations. Effects due to air resistance and damping are not incorporated into the simulation, which may lead to idealized results. The overall accuracy of the outcomes depends on the correctness of the user-entered experimental data. Additionally, for large angular displacements, deviations may arise that are not accounted for within the small-angle approximation inherent in the simple harmonic motion model.

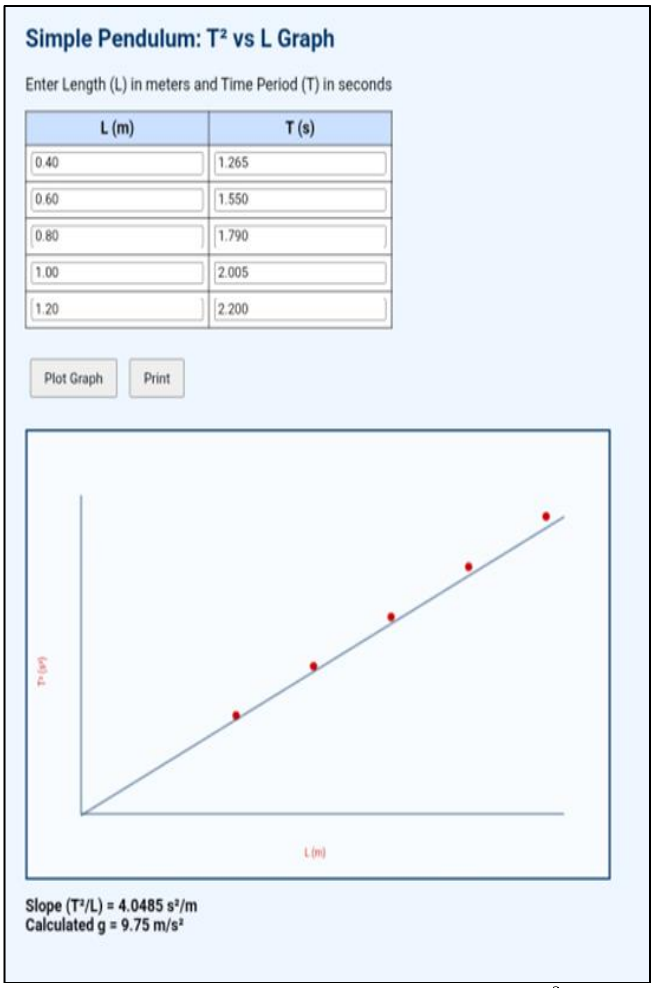

Fig 3 Structured Plotting Table for L and T^2

VII. CONCLUSION

A simple and effective web-based virtual laboratory for the simple pendulum has been successfully developed using HTML. The laboratory provides interactive control over key physical parameters and enables automated calculation of essential experimental quantities such as the time period and acceleration due to gravity. The virtual experiment closely reproduces the behavior of a real laboratory setup and serves as a valuable supplementary learning tool for pre undergraduate physics education. In addition, a structured plotting table for the graph between the square of the time period and the length of the pendulum has been incorporated within the virtual lab. In the present virtual laboratory, the least squares method is employed to obtain the best-fit straight line between the square of the time period and the length of the pendulum from experimentally entered data. This statistical technique minimizes the effect of random errors in observations and provides an optimal estimate of the linear relationship predicted by theory. However, in accordance with pedagogical guidance, students are encouraged to plot the corresponding graph manually on graph paper. This approach ensures the development of essential experimental skills, including scale selection, accurate plotting, and interpretation of linear relationships, thereby complementing

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the advantages of digital experimentation with traditional laboratory practices.

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