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Finding the Acceleration Due to Gravity Using the Hydrostatic Pressure Simulation of PhET

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ABSTRACT

This study explored the concept of hydrostatic pressure and its relationship with various heights of water using the PhET simulation platform. This research aims to determine the value acceleration due to gravity using the hydrostatic pressure simulation of PhET. The experiment's independent variable is the water column at various heights and the dependent variable is the pressure. The method used in this study is pure experimental wherein controlled variables like atmospheric pressure were kept constant. By systematically varying the water height above the ground, the experiment examined how pressure changes respond to these variations. A straight line of best fit was formed when pressure and height were plotted, which is consistent with the theory. This result indicated that as the height of the water column increases, the pressure increases proportionally, demonstrating the direct influence of gravity and water density on hydrostatic pressure. Also, the acceleration due to gravity was measured to be 9.82 ms-2. Therefore, the following were afforded by PhET simulation in this experiment: reliable data, convenient usage, eliminating the need for sophisticated equipment, and an intuitive interface for exploring physical phenomena. This study recommends PhET for teaching and learning processes. It engages the students and provides experiential learning to teachers and students.

INTRODUCTION

Matter, regardless of its state, exerts pressure. Liquids and gases exert equal pressure on all sides of a container. The force exerted by a fluid per unit area on a surface in contact with it is known as hydrostatic pressure (Shi et al., 2015; Tadmor et al., 2017; Thiessen & Man, 2023). This article explores hydrostatic pressure in the context of determining the acceleration due to gravity using a PhET simulation. Dy et al. (2024) and Pacala (2023) state that PhET simulations are an effective and interactive educational tool. They enable students to visualize phenomena in a simulated environment, helping them better understand the intricate physical processes involved (Lindgren, 2016; Fallon, 2019; Oliveira, 2019).

Hydrostatic pressure is the pressure exerted by a fluid at equilibrium at any point due to the force of gravity (Nihous, 2016; Newman, 2018; Jarvis, 2020). This pressure is directly proportional to the fluid's depth, as the fluid's weight increases with depth. The fluid pressure can result from a closed container's gravitational forces, acceleration, or external forces. For example, consider a column of water in a bottle: the pressure at a given point is influenced by the weight of the water above it. Moving deeper into the bottle, the accumulated weight of the water layers above increases pressure. Cui et al. (2015) and Bair (2019) described this phenomenon as explaining why the pressure at the bottom of a container is better than at the top.

Using the simulation, the researchers determined the relationship between the pressure and the water column. This relationship allowed the researchers to compute the acceleration due to gravity.

Pressure that varies in vertical position is caused by elevation or height (Carr et al., 2018). The presence of the Earth's gravitational pull can also vary the vertical pressure on the fluid. Raju (2011) said that a reduction in height corresponds to a taller column of fluid weighing down on that point for the same given fluid.

Graver (2016) and Patrice Williams (2023) clearly show how depth affects fluid pressure. When ears pop during a flight or ache while diving deep into a swimming pool, this phenomenon is being experienced. At sea level, the air pressure exerted on the body is due to the weight of the air above. As altitude increases, this pressure decreases because there is less air above. Conversely, underwater pressure increases with depth, as it is caused by the combined weight of the water above and the atmosphere above the water. According to Learning (2021), while you might sense a change in air pressure during an elevator ride spanning several floors, it only takes diving about a meter beneath the surface of a pool to experience a noticeable increase in pressure. Water is about 775 times denser (LibreText, 2024).

Hydrostatic pressure in a liquid can be calculated as:

$$P = \rho g h \quad (1)$$

Where p is the pressure exerted by the liquid in Nm^{-2} or Pa, ρ is the density of the liquid in kgm^{-3}, g is the acceleration due to gravity taken as $9.81ms^{-2}$, and h is the height of the fluid column in meters (OpenstaxCollege, 2023).

Consider the container shown in Figure 1.1. The bottom supports the weight of the fluid it contains. Dincer (2020) explained that the pressure exerted on the bottom is calculated as the weight of the fluid, mg, divided by the area of the container's bottom, A: P=mg/A. The mass of the fluid is found using its density and volume: $m = \rho V$. The fluid's volume, V, is expressed as V=Ah, where A is the cross-sectional area and h is the depth. Substituting $V = Ah$ into $m = \rho V$ gives $m = \rho Ah$. Replacing m in the pressure equation, P=mg/A results in $P = (\rho Ah)g/A$. Simplifying further, the area A cancels, yielding $P = \rho gh$, which shows that pressure depends on the fluid's density, gravitational acceleration, and depth.

When density and gravity are approximately constant (for relatively small changes in height), simply multiplying height difference, gravity, and density will yield a good approximation of pressure difference. If the pressure at one point in a liquid with uniform density ρ is known to be P_0, then the pressure at another point is P_1:

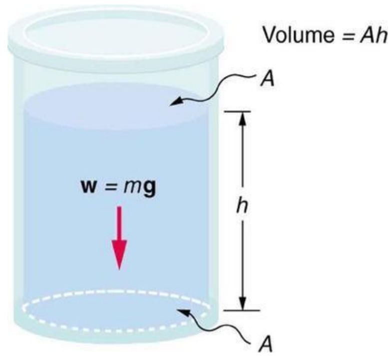

Figure 1. The liquid's weight = mg creates pressure due to gravity, which acts over the cross-sectional area (A) at a depth (h). The container's volume is represented as Ah, emphasizing the relationship between depth and pressure in a fluid. Picture borrowed from OpenstaxCollege (2023).

$$P = P_0 = \rho g (h_1 - h_o) \quad (2)$$

The term h_1-h_0 represents the vertical distance between two points. When different fluids are layered, the total pressure difference can be calculated by summing the pressure differences across each layer. This involves calculating the pressure difference from point 1 to the boundary and from the boundary to point 2, substituting the appropriate values for density (ρ) and height difference (Δh) for each fluid. If the fluid's density changes with height, mathematical integration becomes necessary. Whether gravity and density can be approximated as constant depends on the required accuracy and the height scale, as gravity and density decrease with increasing elevation. For density, the type of fluid is also a key factor. Schmidt (2018) set an example: seawater is considered an incompressible fluid, meaning its density changes with height far less than air. As a result, water's density can be more reliably assumed constant compared to air (Cavusoglu et al., 2017). For the same height difference, pressure differences in water are nearly uniform regardless of elevation, whereas, in air, the variations are more pronounced.

Therefore, this research aims to determine the value acceleration due to gravity using the hydrostatic pressure simulation of PhET. The objectives are to collect the hydrostatic pressure from various heights, plot a graph of pressure against heights, calculate the value acceleration due to gravity, and measure the uncertainty value of this computed acceleration due to gravity.

METHODS

The materials utilized in the experiment within the PhET simulation include a water pressure gauge, a ruler, water, two tubes for controlling water flow, and two gardening taps. Accurate measurements were obtained directly from the simulation, as sourcing physical materials and handling the required water volume posed significant challenges. This paper includes one experiment. The independent variable is height, and the dependent variable is pressure. Figure 2 shows how the magnitudes were measured.

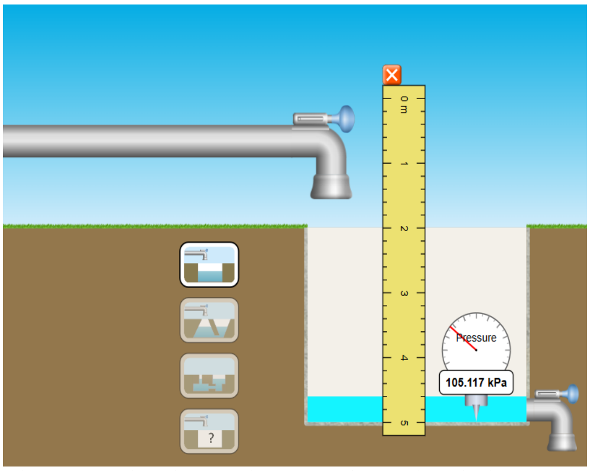

Figure 2. The figure shows a PhET simulation setup for hydrostatic pressure, featuring a container with water, a pressure gauge at the bottom displaying 105.117 kPa, and a ruler measuring water depth. Two pipes, controlled by taps, manage water inflow and outflow.

According to equation 2, we can find different pressures with different heights. Hence, after measuring pressures at six different heights, we will put them into a graph to determine how we made errors in our research. This should create an increasing graph. The heights were from 0.4 meters to 1.6 meters. We created a table and plotted measurements using Microsoft Excel into a graph. On the x-axis, the independent value, height, is plotted, and on the y-axis, the dependent value, pressure, is plotted to create a particular graph.

Hydrostatic pressure in a liquid can be calculated using Equation 1. To determine g through graphing, the researcher measures the pressure (P) at various depths (h) in a liquid of known density (ρ). These measurements are then plotted on a graph with pressure (P) on the y-axis and depth (h) on the x-axis. The researcher expects the graph to be straight, as pressure is proportional to depth. The slope of this line represents the product of the liquid's density and gravitational acceleration (ρg). By dividing the line's slope by the fluid's known density, the researcher can accurately determine the value of g. This method provides a reliable and practical approach to calculating gravitational acceleration by analyzing the relationship between pressure and depth.

RESULTS AND DISCUSSION

We used six height measurements to sketch the graph in the diagram: 0.4, 0.6, 0.8, 1.0, 1.4, and 1.6 meters. Table 1 presents data generated using the PhET simulation, showing the relationship between the height of a liquid column (h) in meters and the corresponding pressure (P) in kilopascals. The data demonstrates that pressure increases with the depth of the liquid, consistent with Equation 1.

For instance, at a depth of 0.400 m, the pressure is 105 kPa, and as the height increases to 1.60 m, the pressure rises to 117 kPa. The incremental increase in pressure with height indicates the steady accumulation of the liquid's weight, exerting force on the surface below. However, slight variations in pressure differences between intervals, such as a 2 kPa increase from 0.400 m to 0.600 m and a 3 kPa increase from 0.800 m to 1.00 m, may be due to simulation rounding or density assumptions within the PhET environment.

Table 1. Pressure vs. Height Data Generated from PhET Simulation

Height/m	Pressure/kPa
0.400	105
0.600	107
0.800	108
1.00	111
1.40	115
1.60	117

This data highlights the principles of hydrostatic pressure and serves as a foundation for analyzing the relationship between pressure and depth. By graphing the pressure values against the corresponding heights, the researcher can calculate the slope of the line, representing the product of the liquid's density and g. Dividing the hill by the known density allows for determining gg, illustrating the practical application of PhET simulations in exploring hydrostatic pressure concepts.

Afterward, the researcher plotted height on the x-axis and pressure on the y-axis, as shown in Figure 2. The resulting graph displayed a nearly perfect linear fit, indicating a consistent relationship between the two variables. Microsoft Excel determined that the line equation with the gradient was calculated as 9816.2 Pa/m.

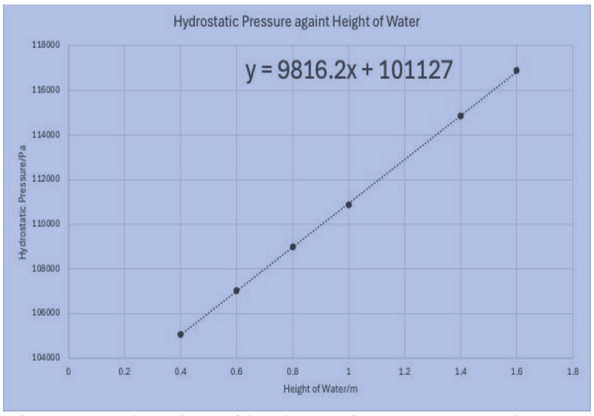

Figure 2. The plot of hydrostatic pressure and water height formed a straight line of best fit, indicating the correct relationship between the two variables.

Based on equation 1, the gradient of the graph (P/h) is equal to ρg, where ρ is the density of water, and g is the acceleration due to gravity. Given that the density of water is $1000\ kg/m^3$, dividing the gradient (P/h=9816.2) by the water's density yields g. The calculation was performed at $9816.2/1000 \approx 9.816\ ms^{-2}$, close to the accepted value of gravitational acceleration, $9.81\ ms^{-2}$. This result validates the accuracy of the research and confirms that the experiment was conducted correctly.

Hydrostatic pressure can be determined using various methods, but the most commonly used approach is applying the essential hydrostatic pressure in Equation 1. In our research, using a water pressure gauge provided an advantage by allowing us to obtain accurate pressure readings. The gauge measured the total pressure, including atmospheric and water pressure. To isolate the water pressure, we subtracted the atmospheric pressure from the total pressure, a method used by McEnaney et al. (2017).

Initially, obtaining pressure values exceeding 100,000 Pascals seemed unrealistic for water. However, upon theoretical calculation, the pressure exerted by 1 meter of water should be approximately 9810 Pascals. After subtracting the atmospheric pressure, it became clear that the gauge accurately provided the total pressure rather than being faulty. Despite this, we encountered random errors during the experiment. Specifically, the measured height of the water column had an uncertainty of ±0.03 meters, leading to minor discrepancies. For instance, due to this uncertainty, the atmospheric pressure derived from the graph's equation was 101,127 Pascals instead of the standard 101,325 Pascals.

In real-life experiments, determining pressure using physical instruments would be far more challenging than using PhET simulations (Samsudin et al., 2020; Ng & Chua, 2023; Syuzita, 2024). Both random and systematic errors would contribute to deviations, and the resulting graph would likely not form a perfectly straight line as observed in the simulation (Bratley et al., 2011; Morris et al., 2019; Azmandian et al., 2022). Conducting such experiments, in reality, would require substantial resources, including a large pool and specialized tools. In contrast, the simulation allowed us to replicate the conditions conveniently on a computer. As a result, our calculated value for the acceleration due to gravity closely approximated the accepted value, demonstrating the effectiveness of the simulation. Also, Ryan et al. (2023) and Kılınç (2023) argued that AI could be integrated into PhET simulations to provide personalized learning experiences by adapting the difficulty level and content based on individual student performance. Hooda et al. (2022), Pacala (2023), and Rane (2023) supported this. They claimed that AI could analyze student interactions with simulations to provide real-time feedback, suggest areas for improvement, and offer tailored practice problems to enhance understanding of complex scientific concepts.

Conclusion

The experiment demonstrated the principles of hydrostatic pressure and emphasized the importance of connecting theoretical concepts with practical applications. By using the PhET simulation, we explored how pressure is influenced by gravity, the density of the liquid, and the height of the liquid column. This hands-on, virtual approach bridged the gap between theory and practice, making the concepts more accessible and engaging for learners. The ability to manipulate variables in the simulation allowed for a deeper understanding of the underlying physics, fostering curiosity and critical thinking skills among students and researchers alike.

PhET simulations have proven to be a reliable and user-friendly platform for conducting virtual experiments, eliminating the challenges of setting up physical equipment. Asad et al. (2021) and Reyes et al. (2024) noted that this accessibility benefits students by offering a safe and efficient learning method and provides researchers with a cost-effective alternative to traditional experiments. However, while simulations are invaluable tools, they have limitations. Real-life experiments often involve complexities such as random and systematic errors, which may not be fully replicated in a virtual environment. Thus, future improvements could focus on integrating more advanced features into simulations, including error margins or environmental factors, to make the virtual experience closer to reality (Konrad, 2016; Li, 2017; Delgado et al., 2020).

The PhET platform could be enhanced by incorporating additional interactive elements in future enhancements. Features like real-time feedback on user inputs or the ability to simulate different environmental conditions, such as varying atmospheric pressures or fluid densities, would provide a more comprehensive understanding of hydrostatic pressure (Trelles, 2018; Hughes et al., 2021; Yin et al., 2024). Developing companion resources, such as guided tutorials or assessments, could help students and researchers apply their Learning more effectively, as added by Allan (2016), San Jose (2019), and Alam (2022). These improvements would enhance the platform's usability and support more advanced research and educational endeavors.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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