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Teaching Hydrostatics Using A 3D-Printed Didactic Kit

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Summary
This work aims to apply a didactic kit for hydrostatics, made using the 3D printer. The construction of this material meets the teacher's practical needs in the classroom, where he can make the pieces according to the experiments that he will work on with the class. For the application of the kit, experimental activities are developed, where the presentation of didactic proposals is discussed, focusing on the development of problem situations based on the Theory of Meaningful Learning (TAS) that seeks to relate the learning object with the knowledge that is present in the cognitive structure of the student. The presentation of some suggestions for experimental scripts is intended to help the teacher guide the class throughout the activity and achieve the objectives proposed in the experiment.
Keywords: *Physics teaching. Didactic kit. Hydrostatic.*

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I. Introduction

Teaching physics at the high school level, particularly in the case of hydrostatics, faces challenges due to the abstract nature of the concepts and the lack of experimentation in many schools. The use of didactic kits produced with 3D printers presents itself as an innovative alternative to minimize these difficulties, providing students with the opportunity to interact practically with theoretical concepts.

This work proposes the use of a didactic kit developed through 3D printers, allowing students to explore concepts such as density, buoyancy, and pressure through practical, easy-to-perform experiments that are accessible to the school environment.

II. Methodology

The didactic kit was designed using SolidWorks software for the modeling of parts, which were printed with a 3D printer. The kit includes cubes, cylinders, and blocks of varying densities, which enable the study of the relationship between mass, volume, and density, as well as experiments related to buoyancy and Archimedes' principle.

The proposed experiments use simple materials, such as scales, dynamometers, and beakers, with the objective of creating an active learning environment where students are encouraged to explore, test hypotheses, and discuss the observed results.

Basic Hydrostatics Concepts

Density (ρ) is a physical quantity that relates the mass (m) of a substance to its volume (V), as defined by the equation:

$$\rho = \frac{m}{V}$$

The pressure (p) exerted by a fluid at rest on a surface is given by the ratio between the applied force (F) and the area (A) over which the force is distributed:

$$p = p_0 + \rho g h$$

In fluids, pressure increases with depth according to the hydrostatic equation:

$$p = \frac{F}{A}$$

Where p0p_0p0 is atmospheric pressure, ggg is the gravitational acceleration, and hhh is the depth in the fluid.

Archimedes' Principle

Archimedes' principle is fundamental for understanding the behavior of objects immersed in fluids. It states that a body submerged in a fluid experiences a buoyant force (E) equal to the weight of the displaced fluid. The equation describing this principle is:

$$E = \rho_{fluid} V_{sub} g$$

Where ρ f_{luid} is the density of the fluid, V_{sub} is the submerged volume of the object, and ggg is the gravitational acceleration. The practical application of this principle was explored in experiments with different materials and objects printed in 3D, allowing the direct observation of floating and sinking phenomena.

Experimental Application

The experiments conducted with the didactic kit included measuring the density of 3D-printed materials and observing the effects of buoyancy on submerged objects. A practical classroom example was the calculation of the density of cubes made from different materials, using the formula:

$$\rho = \frac{m}{V}$$

Additionally, experiments were conducted to study equilibrium in fluids, where students observed that objects of varying densities exhibit different behaviors when submerged in water.

These activities not only facilitated the understanding of hydrostatic concepts but also stimulated scientific curiosity and the development of problem-solving skills.

Conclusion

The use of a 3D-printed didactic kit for teaching hydrostatics proved to be an effective tool for fostering meaningful learning. By providing practical and experimental interaction, students were able to both understand and apply the concepts of density, pressure, and buoyancy in a concrete way. The flexibility of the kit also allowed the material to be adapted to meet the needs of different experiments, making the teaching experience more dynamic and engaging.

III. Description Of Experimental Practices For Teaching Hydrostatics

Experiment 1

Measurement of the density of geometric objects

Objective

The objective of this practice is to determine the density of geometric objects and verify the quantities that are related to the density of these objects.

Related concepts

- Density of materials;
- Volume of solids;
- Errors, Measurements;
- Unit transformation.

Materials used

- Scale (item 10)
- Test blocks - 3 cubes with different masses and the same volume – (item 04)

 Ruler (item 05)

Experimental Procedures

Students will measure the edges of the cubes with a ruler and determine their volume, in cm3 . The values should be written down in the table to facilitate calculations later;

Turn on the scale and make sure it is calibrated. Measure the mass in grams of each cube directly. Write down the mass value in the table, taking care to write down the mass value correctly for each cube, as there is a difference in the mass value for each cube;

Using the equation for calculating densities: $d = \frac{m}{V}$determine the density value of each cube.

	Cube 15%	Cube 50%	Cube 100%
Volume (cm^3)			
Mass (g)			
Density (g/cm^3)			

Table 1: Determination of the density of objects built on the 3D printer depending on the filling.

Note to the teacher: *Although the experiment is quite simple, some observations are important: the teacher should guide the students to perform the measurement correctly with the ruler, noting that the measurement in centimeters will provide two digits after the decimal point. The teacher should draw attention to these measurements, so that they are as accurate as possible. If the length measurement was performed with two decimal places, the measurement of the mass of the blocks should be done with two decimal places as well, and this value of decimal places will be considered in the calculations.*

During the activity, the teacher must explore the concepts by asking the class questions, for example:
a) If we use an object of the same volume and greater mass, will its density be greater, lesser or equal to what was measured previously?
b) Why do objects have different densities?
(discuss the differences in the values found).
c) Why do objects have different densities if they have the same volume and are made of the same material?
(this is a question that the teacher needs to clarify carefully for the class to avoid any misunderstandings).
After these discussions the teacher will be able to explain the difference between density and specific mass ;
The experiment can be repeated for cylinders of different masses.
Proposed questions (for assessment or discussion in class)
1. According to the concepts developed and studied so far, the density of an object depends on which factors?
2. If a beaker is graduated in ml (milliliters), what will be the conversion ratio of this unit to cm^3?

Experiment 2
Buoyancy and Apparent Weight
Objective

The objective of this practice is to experimentally verify Archimedes' Principle, which has the following statement:

"Any-body immersed totally or partially in a fluid (liquid or gas) receives from this fluid a vertical force, from bottom to top (known as Buoyancy Force), of intensity equal to the weight of the volume of fluid displaced by the body."

Related concepts
 Archimedes' principle;
 Volume of solids;
 Thrust.

Materials used
 Irregular block of PLA filament (item 02);
 2N dynamometer (item 01);
 Beaker with minimum calibration of 250ml (item 12);
 Dynamometer support (item 07 and 08).

Experimental Procedures
Place the dynamometer on the stand, adjust the "zero" to calibrate and measure the weight of the test cylinder;
Dip the block into the beaker with water and note the value read on the dynamometer as apparent weight;

Determine the magnitude of the force that caused the apparent decrease in the weight of the body: **Thrust** .

Note to the teacher: *Although it is natural for students to always choose water to carry out the experimental procedure, the teacher should always consider the possibility of trying other liquids. This allows general laws to be established for this activity, always arriving at Archimedes' observation.*

Proposed questions (for assessment or discussion in class)
1. Justify the **apparent** decrease in the weight of the cylinder when submerging it in water (known as apparent weight).
2. What is the module, direction and sense of the Buoyancy?

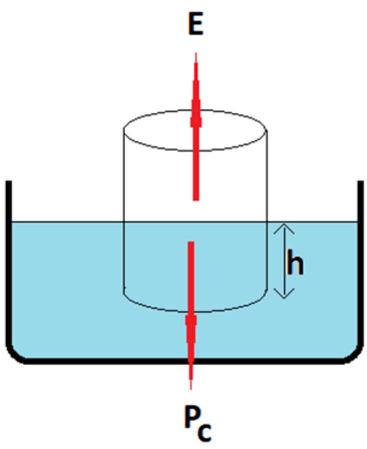
Experiment 3
Buoyancy Measurement – Partially Submerged Body
General Objective of the Experimental Practice
Determine the buoyant force received by an object partially submerged in water;
Verify that the buoyant force varies when the density of the liquid changes.

Related concepts
- Density of the liquid;
- Weight strength;
- Thrust.

Materials used
- Test cylinder (50% filled) (item 03);
- Wire of approximately negligible mass (item 09).
- Beaker with minimum calibration of 250ml (item 12);
- Balance;
- Ruler (item 05).

Experimental Procedures
Remember that:
If the object is in equilibrium the Buoyancy is equal to the weight of the cylinder:
$E = P_c = mg$ *(equation 1)*

According to Archimedes' Law, Buoyancy is defined as the weight of the displaced liquid, therefore:
$E = P_{net} = d_{net} V_{liquid}\, g$ *(equation 2)*



For this experimental activity we will consider g=9.8 m/s ^{2} ;
Measure the mass (m) of the cylinder with the scale;
Measure the diameter (d) of the cylinder with the ruler;
Place the cylinder in the beaker with water, and check that part of the object is out of the water;
Since the cylinder is in equilibrium, calculate E (thrust) with equation 1;
Using the beaker's graduation, determine the height (h) of the cylinder that is submerged;

Using the measured values of diameter and height, determine the volume (V), submerged;

$$V = \frac{\pi\, d^2\, h}{4}$$

This submerged volume is equal to the volume of displaced liquid;
Considering the density of water $1 g/cm^3$, use equation 2 to determine the Buoyancy.

Add salt to the water until you see that a larger part of the cylinder is now out of the water;
Measure the new height h, which is submerged;
Again determine the volume of displaced liquid (which is the same volume as the submerged cylinder);
Equating equations (1) and (2), we will have:
m = $d_{liquid}\, V_{liquid}$

Since the mass of the cylinder has not changed, it is now possible to determine the density of the liquid (after adding salt to the water).

Note to the teacher: *Considering that an aqueous solution was formed with the table salt, ask the student if the buoyancy will be greater, lesser or the same. Discuss with the class whether the displaced liquid will be greater, lesser or the same, and why this happens. What is the relationship with the "new" density of the liquid?*

Proposed questions (for assessment or discussion in class)

1. Why does the cylinder "rise" in the water after adding salt?
2. What is the value of buoyancy after putting salt in water?
3. The value of buoyancy increased or decreased when the density increased (when salt was added to water), why did this happen?

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