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Design of a Microcontroller-based Hydrostatic Pressure Experiment Tool in Science Education

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ABSTRACT

This study aims to create a microcontroller-based hydrostatic pressure experiment tool in science education. The digital system makes the tools used more effective and time-efficient. The digital system used in this tool consists of a microcontroller, digital display (LCD), and the MS5637 Barometer sensor. This series of tools processes digital data into hydrostatic pressure, displayed on the LCD. The method used in this study is following Archimedes' principle. The independent variable in this study is the depth of the funnel thrust into the measuring cup, while the dependent variable is the hydrostatic pressure displayed on the LCD. The results showed that the hydrostatic pressure values obtained were close to theoretical calculations. Then, the r-squared result between Δh of water and hydrostatic pressure through experiments with a microcontroller (Arduino) is 0.9981. This value is good enough to show the proportion or percentage of hydrostatic pressure affected by Δh of water. Thus, experiments using this tool are quite effective in science learning.

INTRODUCTION

The progress of the 21st century has forced us to be literate in technology. The progress is marked by incorporating technology into the educational world, designed to make manual things completely digital. This advance affects the skills students need in education in the 21st century, such as being actively involved in learning, thinking at a higher level, collaborating, and being responsive to technology (Almerich et al., 2020). STEM education aims to create students who have 21st-century skills (Büyükdede & Tanel, 2019; Gök & Sürmeli, 2022; Hiğde & Aktamış, 2022; Kutlu et al., 2022; Tsai et al., 2021; Uğur et al., 2020). The implementation of STEM activities in learning prioritizes practice so that students are involved throughout the process (Eroğlu & Bektaş, 2022; Hiğde & Aktamış, 2022). STEM integration can develop problem-solving abilities (Eroğlu & Bektaş, 2022; Simeon et al., 2022), creative thinking, analytical and collaboration skills (Gülen & Yaman, 2019; Hiğde & Aktamış, 2022). Therefore, improving the learning process is essential so students achieve better competence. As the curriculum in Indonesia changes, many demands must be achieved in the science learning process. An important aspect of learning science is not only conceptual skills; students must also have the skills to experiment. Experimental activities can improve students' creative thinking (Fauziah et al., 2018). Experiments can also increase student interest in learning (Adam et al., 2022). In addition, experimental activities

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make students directly involved in learning and can build higher-order thinking skills, process skills, learning attitudes, and communication skills in discussions (Awansyah, 2022 ; Wang et al., 2015).

Experiments in science learning are very important because they have many significant benefits. Through experimental activities, students can see and experience firsthand the science concepts taught (Aprilia, 2018). Experiments in science learning also encourage students' critical and creative thinking skills (Hajjah et al., 2022), develop scientific skills (Shofiyah & Wulandari, 2018), and improve collaboration skills (Masruroh & Arif, 2021). So, experiment with a good science learning method to help students understand science concepts.

There are still concepts of science learning that are difficult for students, and appropriate learning media is needed to understand certain science concepts. Previous studies about hydrostatic KIT can improve student learning outcomes (Permatasari & Rosdiana, 2018). Practical tools are useful in experimental activities (Marianus & Rende, 2020). Based on the previous studies that have been described, hydrostatic pressure experiments are still carried out using non-modern equipment. The experiment is still being carried out manually and has not used digital tools that are automatic. Experiments using manual tools have weaknesses, such as less accurate experimental data (Anshory et al., 2015; Diatri et al., 2014; Solehan et al., 2022). Therefore, it takes experimental activities using digital system equipment. The tool developed with a digital system minimizes data errors obtained during the experimental process manually. So, the novelty of this research is to create a digital-based experimental tool.

This study aims to design a hydrostatic pressure digital experiment tool that can show hydrostatic pressure results directly. This tool is designed to minimize errors when using manual tools, such as parallax errors. The tool was developed with a microcontroller (Arduino), LCD, and MS5637 barometer sensor.

METHODS

Principle of Hydrostatic Pressure

The hydrostatic pressure experimental system was developed according to Archimedes' principle. If an object is immersed in a fluid, the fluid will exert a force perpendicular to the object's surface in contact with the fluid (Tipler, 1998), as in all cases experienced by divers. The pressure continues to build as the diver is further and further from the surface of the ocean. If a fluid is on a free surface, then the pressure is measured from the difference in the distance from the free surface to a certain point or object below it (depth). With total pressure P, environmental pressure (earth's atmosphere) P_0, gravity g, and depth h, then the pressure equation is:

$$P_h = P_0 + \rho g h$$

Description

P_h = Hydrostatic pressure (pa)
P_0 = Pressure at the free surface (atm)
ρ = Density of fluid(kg/m^3)
g = Acceleration due to gravity (m/s^2)
h = Fluid depth (m)

From the above equation, we know that pressure is directly proportional to density, Acceleration due to gravity, and depth. So, the greater the density value, the Acceleration due to gravity, and the depth of the object immersed in the fluid, the greater the pressure exerted by the fluid on the objects below it (Serway & Jewett, 2008)

Experimental tool design using Arduino in the form of hardware and software. The Arduino board has 14 digital pins and 6 analog pins. This tool connects Arduino, MS5637 Barometer sensor, and LCD 16 X 2 with I2C Module on the board. Figure 1. shows the installation of the Barometer MS5637 sensor and LCD to Arduino. First, the MS5637 Barometer sensor is filled with the configuration SDA to A4, SCL to A5, GND to GND, and VIN to 5V. Second, the LCD is connected with SCL configuration to

A5, SDA to A4, VCC to 5V, and GND to GND. The male-to-female hookup cable is used to connect Arduino to the Barometer MS5637 sensor and LCD. Installation of the MS5637 Barometer sensor and LCD to Arduino can be seen in Figure 1.

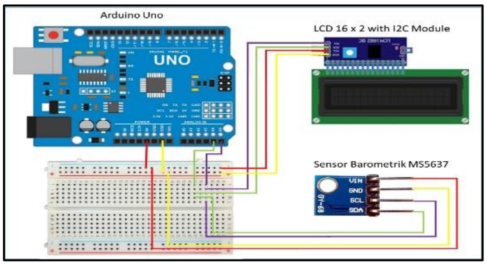

Figure 1. Installation of the Barometer MS5637 Sensor and LCD to Arduino

The Arduino circuit is connected to a plastic pipe and a glass funnel, ensuring no outside air is affecting it. Then, attach it to the processing center of the Arduino program on the computer. Then upload the encoding that has been set to the program. The design of the experimental tool with Arduino is shown in Figure 2.

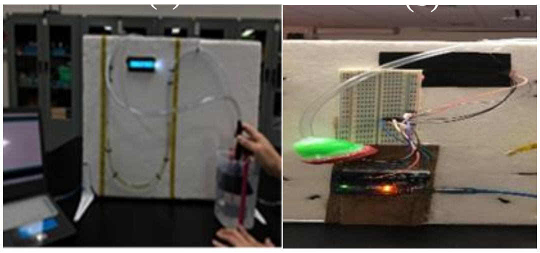

Figure 2. Experimental Tool Design with Arduino (a) Front View (b) Back View

Arduino coding for measuring Hydrostatic Pressure is shown in Table 1.

Table 1. Arduino Coding

Include dan Void Setup	Void Loop

#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C LCD(0x27,20,4);
#include "SparkFun_MS5637_Arduino_Library.h"
MS5637 barometricSensor;
float a;
float inPascal;
void setup(void) {
Serial.begin(9600);
if (barometricSensor.begin() == false)
{
Serial.println("MS5637 sensor did not respond. Please check wiring.");
while(1);
}
// setResolution barometricSensor
barometricSensor.setResolution(ms5637_resolution_osr_8192);
// initialize the LCD
lcd.init();
lcd.backlight();
lcd.setCursor(7,0);
lcd.print("ALAT");
lcd.setCursor(4,1);
lcd.print("PRAKTIKUM");
delay (2000);
lcd.clear();
lcd.init();
lcd.setCursor(5,0);
lcd.print("TEKANAN");
lcd.setCursor(3,1);
lcd.print("HIDROSTATIS");
delay (2000);
lcd.clear();}
	void loop (void) {
	float pressure = barometricSensor.getPressure();
	float P = pressure - 909.615 ;
	inPascal = P * 100;
	if (inPascal >= 1){
	a =inPascal;
	Serial.print(" Pressure = ");
	Serial.print(a, 3);
	Serial.print("Pa");
	}
	else if (inPascal <= 1){
	a = 0;
	Serial.print(" Pressure = ");
	Serial.print(a, 3);
	Serial.print("Pa");
	}
	// initialize the LCD
	lcd.init();
	lcd.backlight();
	lcd.setCursor(1,0);
	lcd.print("Nilai Tekanan");
	lcd.setCursor(2,1);
	lcd.print(a, 2);
	lcd.setCursor(12,1);
	lcd.print("Pa");
	Serial.println();
	delay(1000);
	}

Variables

This study has three variables: independent variables, dependent variables, and control variables. The variables are shown in Table 2.

Table 2. Arduino Coding

Variable	Description
Independent	Depth based on the thrust on the funnel
Dependent	Hydrostatic pressure
Control	Funnel cross-sectional area

Procedure

This experimental procedure was carried out to explain the principle of liquid pressure. The experiment was carried out in the laboratory. Before the hydrostatic pressure experiment was carried out with a microcontroller, a hydrostatic pressure experiment was carried out with a manual tool. The manual tool design can be seen in Figure 3.

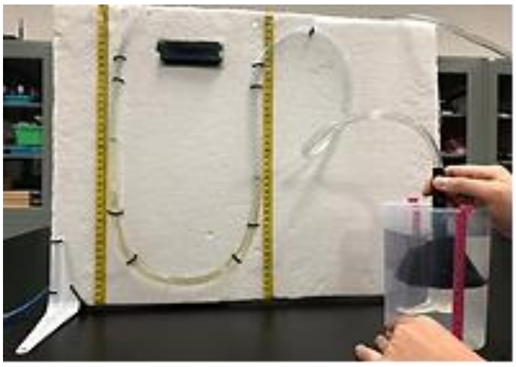

Figure 3. Hydrostatic Pressure Manual Tool Design

Before experimenting, ensure the condition of the U pipe is perpendicular to get better data. Some of the steps to experiment manually are as follows. First, fill the measuring cup with the material provided at a specified depth point. Second, apply a thrust connected to the U-pipe containing oil into the water in the measuring cup. This experimental tool will work by utilizing the air pressure between the room in the funnel and the oil in the U pipe. When a thrust is given to the water in the measuring cup, the air pressure in the pipe increases, which is marked by a change in position. The height of the oil material in the U pipe. This experiment was repeated by varying the thrust force at a specified depth. The process of repeating the experiment was carried out to get better results. After getting the experimental data with a manual tool, an experiment was carried out with a microcontroller designed to measure hydrostatic pressure.

Experiments with Arduino tools utilize the air pressure in the pipe, which the MS5637 barometer sensor can read. The LCD will show the result of reading the air pressure in the pipe. Checking the data from the reading of the serial monitor on the Arduino program. Then enter the coding set to average the data from previous pressure readings in Pascal units. After uploading the encoding, wait a few minutes until the LCD shows 0 Pa. The experimental settings can be seen in Figure 4.

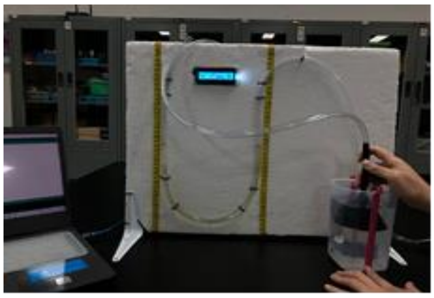

Figure 4. Microcontroller-based Experiment Tool

The steps for the hydrostatic pressure experiment with the microcontroller are the same as those carried out with the previous manual tool, but there is no need to put oil in the U pipe. Fill the measuring cup with water provided at a certain set depth point. Next, apply a thrust into the water in the measuring cup and see the readings on the LCD. The measurement results on the LCD can be seen in Figure 5.

Figure 5. Hydrostatic Pressure Measurement with Δh of Water 8.4 cm

Then, this experiment was repeated by varying the thrust at the same certain depth when using the previous manual experiment tool.

RESULTS AND DISCUSSION

Table 3 shows the results of hydrostatic pressure measurements using manual tools. The thrust given according to Figure 2 is varied by giving a deviation of 1 cm for each data. As a result of this pushing force, there is a change in the water level (Δh of water) and the oil level (Δh of water) in the U pipe from before.

Table 3. Data on changes in water level in the measuring cup and oil in the U pipe

Δh of water (cm)	Δh of oil (cm)
3.4	3.0
4.4	4.0
5.4	5.0
6.4	6.0
7.4	7.0
8.4	8.0
9.4	9.0
10.4	10.0
11.4	11.0

After getting the data from the first experiment, the Δh of oil theoretically can be determined using the hydrostatic pressure principle. Then the r-squared or R^2 between Δh of oil and Δh of water (experiments and theory) with Excel can be seen. The result of r-squared or R^2 between Δh of oil and Δh of water experimentally is one and theoretically is 0.9999. The r-squared or R^2 value is 0-1; the closer to 1, the better (Minium & King, 1993). The r-squared or R^2 value between Δh of oil and Δh of water is experimentally very good. It means that the proportion or percentage Δh of oil affected by Δh of water is suitable. The graph shows that the higher the Δh of water, the higher the Δh of oil, and vice versa. The graph can be seen in Figure 6.

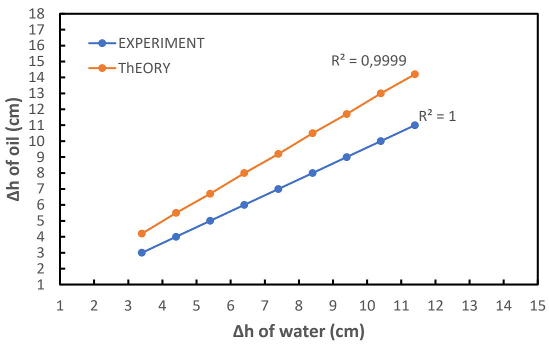

Figure 6. Microcontroller-based Experiment Tool

The graph in Figure 7 represents the relationship between Δh (change in height) of oil experimentally and Δh of oil theoretically. The r-squared or R^2 value is a statistical measure that indicates how well the data points fit a regression line. In this case, the R^2 values of 0.9999 and 1 indicate a strong correlation between the experimental and theoretical values of Δh of oil.

A high R^2 value suggests a good fit between the data points and the regression line, meaning that the model used to calculate the values is accurate. In this context, the high R^2 value indicates that the hydrostatic pressure theory is a reliable model for predicting the change in the height of oil in a container.

However, the statement that the R^2 value between Δh of oil and Δh of water is good because it is close to 1 is inaccurate. The R^2 value between Δh of oil and Δh of water would only be meaningful if there was a relationship between the two variables. Since the height of the water is not affected by the presence of oil, there is no correlation between the two variables, and therefore, no meaningful R^2 value can be calculated.

The high R^2 value between Δh of oil experimentally and theoretically in Figure 7 provides strong evidence that the hydrostatic pressure theory is a reliable model for predicting the behavior of fluids in containers (Minium & King, 1993).

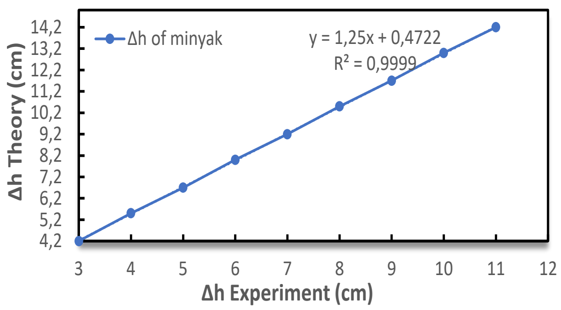

Figure 7. Graph of Oil Δh Relationship (Experiments and Theory)

Table 4 shows the results of hydrostatic pressure measurements using a microcontroller. The thrust given follows Figure 8, varied by giving a deviation of 1 cm for each data. As a result of this pushing force, there is a change in the water level (Δh of water) and a change in the pressure value shown on the LCD installed on the device.

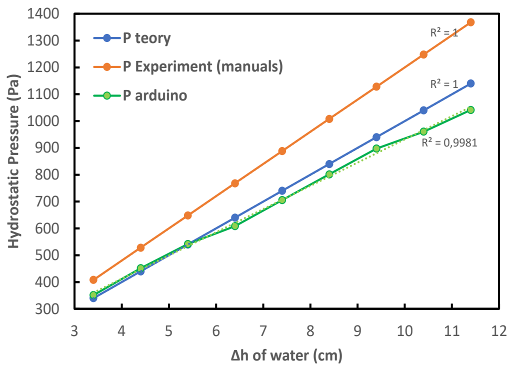

Figure 8. The Relationship between Δh of Water and Hydrostatic Pressure (Experiments, Theory, and Arduino)

Table 4. Data Δh of water and pressure with Arduino tool

Δh of Water (cm)	Hydrostatic Pressure with the Arduino Tool (Pa)
3.4	351.5
4.4	451.5
5.4	541.5
6.4	608.5
7.4	705.5
8.4	801.5
9.4	897.5
10.4	960.5
11.4	1041.5

Figure 8. shows a graph of the relationship between Δh of water and hydrostatic pressure using manual and microcontroller-based tools. The hydrostatic pressure formula calculates the hydrostatic pressure value from experimental data with manual tools. However, the LCD display can read the pressure value from the experimental data with a microcontroller-based tool. It means we no longer need to calculate theoretically using the hydrostatic pressure formula. The graph also shows that the greater the Δh value of water, the greater the hydrostatic pressure. On the other hand, the smaller the Δh value of water, the smaller the hydrostatic pressure. Hydrostatic pressure depends on the object's size in the liquid (Ferlianti et al., 2022; Firdausi et al., 2019; Munawaroh et al., 2022). In addition, it can be seen in the graph the value of r-squared or R^2 between Δh of water and hydrostatic pressure. The r-squared or R^2 value is 0-1; the closer to 1, the better (Muslimin & Kartiko, 2020). The result of r-squared or R^2 between Δh of water and hydrostatic pressure through experiments with manual tools equals 1. In theory, the result of r-squared or R^2 between Δh of water and hydrostatic pressure is 1. This means that the proportion or percentage of hydrostatic pressure affected by Δh of water is suitable. The result of r-squared or R^2 between Δh of water and hydrostatic pressure through experiments with a microcontroller (Arduino) is 0.9981. The r-squared or R^2 value has not yet reached a value of 1, but 0.9981 is good enough. This is because the microcontroller-based hydrostatic pressure tool is still not very accurate. However, it is close to the pressure value calculated by theory, and this tool is still in the initial design stage. However, a microcontroller-based hydrostatic pressure tool can read hydrostatic pressure automatically if an object is in a fluid at a certain depth.

This microcontroller-based measuring instrument has several advantages and disadvantages. The advantages of this tool are as follows; Using a microcontroller-based measuring instrument, we do not need to manually calculate the pressure value, which has a long process. but the results can be seen on the LCD (Siswoko et al., 2019), the use of microcontroller-based tools is very easy (Qomariyah et al., 2020); this measuring tool also reduces errors when experimenting with manual measuring tools such as parallax errors (Prastia et al., 2022), with this microcontroller application the resulting data can be digital, more accurate, thorough, flexible and more interesting in learning (Arifin et al., 2018). The disadvantages of this tool are as follows; the reading of the pressure value is still unstable, the trial tool is still on a small scale, dan the reading data of this tool is still not very accurate because it requires repeated testing of the tool on a large scale.

CONCLUSION

Measurement of hydrostatic pressure using a measuring instrument based on a microcontroller was successfully carried out. Compared to manual measurements, these measurements are easier to do, and the hydrostatic pressure results come out automatically on the measuring instrument. Retrieval of experimental data does not take a long time but is more effective and time efficient. Hydrostatic pressure data is obtained by varying the thrust on the funnel, which changes the water level (Δh of water). The pushing force is distinguished by providing a deviation of 1 cm for each data. There are nine experimental data. The experimental results show that the greater the Δh value of water, which indicates the object's depth in the fluid, the greater the hydrostatic pressure value. In the design activities of this tool, there are several limitations. There is coding in the Arduino program that must be adjusted again to get more accurate data. Then, the thrust force on the funnel during the experiment must be perpendicular to the surface of the fluid.

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