A new manometer with Arduino

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Abstract. Manometer, the U-shaped tube contains liquid, is the apparatus for measuring pressure. By reading the risen liquid level, the pressure can be obtained. Arduino is the microcontroller that plays a crucial role for physics instruction because the device is simple, inexpensive and accurate. Arduino can be connected with many types of probe, for example, lux meter, sound meter, pressure meter, etc. Due to its application, teaching physics with Arduino can draw students' attention excellently. The purpose of the study was 1) to invent the new manometer with Arduino for measuring pressure at different level of dept and figuring out the buoyance force on the object 2) to improve students' understanding in pressure and buoyance force. The participants were 40 students. The method for the study was a one-group pretest-posttest design including 10 three-tier questions. The finding indicated that 1) the new manometer was handy and accurate 2) students' concept about pressure and buoyance force had been improved at the significant level of .05.

1. Introduction

The apparatus for measuring pressure in general laboratory usually comes with a U-shaped glass tube or a U-shaped hose which contain colored liquid. The scale on the side of the tube determines the level of the liquid. At the beginning, the level of the liquid is the same on both sides. When one side of the tube is connected to the container, filled with another type of liquid, the level of the liquid in the tube changes due to the difference of pressure. The observer can measure and interpret the value of pressure from the tube by recording the different height from both sides of the tube. Then, the height will be used to calculate the pressure as in figure 1. The U-shaped glass tube for measuring pressure was invented by Christian Huygens, a Dutch physicist and astronomer, in 1661 which was adapted from Barometer that first created by Torricelli. Originally, the purpose of the tube was to find the difference of gas pressure. The instrument was first called “U-shape manometer” [1]. A U-shaped manometer could be reproduced and used without difficulty by reading the additional height of the liquid. Vice versa, some types of manometer do not have a scale to indicate pressure value which increase the probability of human error.
in a laboratory. Furthermore, the analog value is not as convenient as the digital value when the observer needs a quick response or real-time display.

In the present, teaching physics is widely utilized Arduino (figure 2), the microcontroller, to collect the data in experiments. According to Arduino has ability to connect many probes which can measure physical quantity. There are many examples from using the probe such as, an ultrasonic distance sensor is adapted to measure the strength and direction of magnetic field [3], and a sound meter and thermal probe are integrated to find the speed of sound in a term of temperature [4] and the voltage probe is connected to investigate the charging or discharging of capacitors in the RC circuit [5]. In addition, the microcontroller can be used with variety of probes, including light, sound, pressure meter, etc. Arduino is convenient, inexpensive, and accurate to use. The real-time display from Arduino is preferable to physics laboratories integrated with inquiries physics. The learning process helps students to overcome advanced scientific concepts and minimize their misconceptions by inquiry. Moreover, the process excels at building students’ motivation and attention in physics class [2,6]. Based on the result of the pilot study, we found students’ misconception on the topic of pressure. For example, some students tough at the same depth of two sizes of tube (large and small) which contained liquid had different pressure by arguing that the large one had more weigh of liquid than the small one. In fact, the pressure value at the same depth has to be the same value [7]. Furthermore, the experience of the author found that students had misconception about the buoyance force. For example, when the object submerged. Some students argued that the buoyance force increased when the object went deeper in liquid. However, the buoyance force does not depend on the depth. Another misconception of buoyance force happened when students considered the force on the two equal-mass objects that had different volume. The students gave the reason that the large volume object had more buoyance force than the small object when both of them had the same mass. In reality, the buoyance force has the same magnitude on the two objects. These misconceptions might perhaps take place before students came to a physics class. Otherwise, students might form these misconceptions during a physics class. One of the best ways to tackle misconceptions was to encourage students learning by inquiry from the situation. By doing an experiment as a small discussion group led students to the right concept. Besides the alternative concepts, the problem, usually found in class, was students unable to link the concepts between topics such as pressure and buoyance force. Therefore, teachers should design an instrument that can help students to overcome this difficulty.

The study investigated applications of Arduino and limitations of a U-shaped manometer to design the new manometer. The new manometer used Arduino board, air pressure and load cell to measure pressure and weight. The real-time digital display of the new manometer was purposely designed to read easily, accurately. Finally, the physics activity by inquiry in the topic of pressure and buoyance force was developed to use with the new manometer.
2. Methodology
The study aimed to 1) develop the new manometer which integrated with Arduino 2) use the manometer in the physics class with 40 students to evolve their conceptual understanding in the topic of pressure and buoyance force. The new manometer was used during the activity to find pressure in a liquid at different height and buoyance force on the object by teaching physics by inquiry. The teaching method consisted of 5 steps: 1) the questions were asked including what factors related to pressure? and does the pressure depend on the volume of containers? how to determine the buoyance force? 2) students formed a group of four by the suggestion of the instructor 3) students did the experiment to answer the questions 4) students linked their explanations to the information from the internet or the book 5) students presented their result from the experiment. The research method was a one group pretest-posttest design. The conceptual survey test was 10 three-tiers questions and the attitudes towards physics survey was used at the end of the activities.

The new manometer was redesigned with the combination of four parts including Arduino Nano 3.0 Mini USB, two air pressure sensors, LCD display (model IIC I2C 2004 204 20 x 4 letters) and load cells. The two sensors were attached to the saline cord with load cells in figure 3.

2.1. Experimental setup
The teaching method was physics by inquiry and had two activities. The first activity was finding the density four types of liquid including honey, glycerol, water and palm oil. The equipment was organized in figure 4 by attaching. Students gradually dipped the saline cord with the ruler in the liquid to collect the data. Then, the observer recorded the depth and gauge pressure. To find the gauge pressure, students used the value of pressure in the liquid minus the value of pressure in the air. After that, the depth-pressure graph was plotted to figure out the density of the liquid. The efficiency of the new manometer was calculated by comparing the density values from the experiment with the standard values in term of error percentage. The second activity was to find the relationship between pressure and buoyance force by setting up the experimental instrument in figure 5. The cylinder plastic bottle fully filled with clay was attached with a cord to make it movable. At the top and bottom of the bottle were attached with a tip of a saline cord that linked to the sensor pressure $P_1$ and $P_2$ respectively. The load cell was placed under a water-filled beaker. The bottle was gradually placed under water until it was all submerged, then recording $P_1$, $P_2$ and the additional weight of the load cell ($\Delta F$), was the buoyance force acted on the bottle according to Newton’s third law.
3. Results and discussion
The new manometer displayed the pressure value in two digits which came from two pressure sensors at the top and bottom of the bottle. In addition, the new manometer had a function that could measure the weight at the same time that was shown on the LCD display with two digits. The implication of the new manometer which integrated with physics by inquiry that allowed students to explore four types of liquid, honey, glycerol, water, and palm oil. Students plotted graph between the depth and gauge pressure in figure 6. After that students calculate the density value of liquids from the slopes of the graphs as table 1. Finally, the density values from the experiment were compared with the reference values of density were from the measurement between mass and volume of different types of liquid which validated at that time. The result shown the new manometer had 2.21% of error; therefore, the efficiency of the new manometer was 97.79%.
Table 1. The density value of liquids.

| Liquid   | Experimental Density (kg/m³) | Referenced Density (kg/m³) | Error (%) |
|----------|------------------------------|----------------------------|-----------|
| Palm Oil | 878.15                       | 899.12                     | 2.33      |
| Water    | 983.43                       | 998.76                     | 1.53      |
| Glycerol | 1,227.31                     | 1,262.55                   | 2.79      |
| Honey    | 1,331.88                     | 1,361.63                   | 2.18      |
| Average  |                             |                            | 2.21      |

The equation from the relationship between pressure and buoyance force by considering figure 7

\[
\Delta F = F_2 - F_1
\]
\[
\Delta F = P_2 A - P_1 A
\]
\[
\Delta F = (P_0 + \rho gd)A - (P_0 + \rho gx)A
\]
\[
\Delta F = \rho g h A \quad \text{where } h = d - x
\]
\[
\Delta F = \rho g V \quad \text{where } V = Ah
\]

where \(\Delta F\) is buoyance force, \(F_1\) is the force on the top of the bottle (N) downward, \(F_2\) is the force on the top of the bottle (N) upward, \(P_1\) is the summation of atmospheric pressure \((P_0)\) and gauge pressure at the depth of \(x\) \((\rho gx)\), \(P_2\) is summation atmospheric pressure \((P_0)\) and gauge pressure at the depth of \(d\) \((\rho gd)\), \(g\) is gravitational acceleration, \(A\) is the cross-sectional area of the cylinder plastic bottle (square meter), \(\rho\) is density of the liquid (kilogram per cubic meter), \(d\) is the depth from the surface of liquid to the bottom of the bottle (meter), \(x\) is the depth from the surface of liquid to the top of the bottle (meter), \(h\) is the height of the bottle (meter) \(V\) was the volume of the bottle (cubic meter).

The equation illustrates the buoyance force can be computed by the difference of pressure. The force depends on the submerged part of the object which corresponds to the principle of Archimedes. The new manometer can measure pressure and buoyance force, and operates with a real-time LCD display. The finding indicated students’ conceptual understanding score from the pretest-posttest survey significantly increased at the level of .05. Because, students involved with the experiment with the
inquiry activities. Finally, students had positive attitudes towards physics, and pleased in learning physics. The satisfaction survey, 5-rating scale (very satisfied, satisfied, normal, unsatisfied, very unsatisfied), was used to collect data after the activities. The survey shown that 87.5% of students were very satisfied when learning physics.

4. Conclusion
A new manometer with Arduino was able to measure pressure at different depth and illustrated the relationship between pressure and buoyance force. The instrument was able to gather the data which led to compute the approximate density of liquids by the accuracy of 97.79%. When the instrument was used in physics by inquiry, students conceptual understanding in the topic of pressure and buoyance force improved at the significant level of .05. The conceptual change happened after doing these activities, for example, gauge pressure and buoyance force. The gauge pressure depends on depth and density of the liquid but does not depend on the volume of the container. When the object submerged, the buoyance force was determined by the difference between the upper pressure and the lower pressure of the object. However, the buoyance force depends on the submerged volume of the object which does not relate with the depth. After the activity, 87.5% of students were satisfy when learning physics. The advantages of Arduino as a physical measurement tool in physics laboratory was effectively, simply and inexpensive. Furthermore, the instrument also motivated and attracted students in learning physics.

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