Development of a microcontroller-based instrument for measuring liquid density

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Abstract. The purpose of this research was to develop a practical tool to measure the density of liquids. This research was a research and development research that referred to the development model of Borg and Gall. The research instrument used was a questionnaire with a 4-Likert scale. Evaluation phase included the assessment of media validator, students’ responses, and laboratory test. The product quality data obtained were analyzed using descriptive analysis. The quality of the product based on the analysis of the media expert's assessment obtained a value of 3.30 which was in very good category. Meanwhile, the results of student responses in the limited-testing obtained a value of 3.30 which showed that they strongly agree with the product’s usability. The test results and questionnaire analysis indicated that the microcontroller-based density determination practicum tool developed was feasible to use. From the experimental results, the density value of water was 0.95 gr/cm$^3$ with a standard deviation of ±0.044 and a relative uncertainty value of 0.22%. The density value for salt water was 1.04 gr/cm$^3$ with a standard deviation of ±0.011, compared with the literature which is 1.10 gr/cm$^3$. Moreover, the density of coconut oil measured was 0.76 gr/cm$^3$ with a standard deviation of ±0.045, while the literature is 0.84.

1. Introduction
Practicum is required to help students understand the real application of the concepts of physics. It provides opportunities for students to find theories and prove theories. Through practicum, students can see the demonstration of the physics concepts and principles. In addition, hands-on activities can increase students’ creativity and skills and subsequently improve their learning performance [1], motivation [2], engagement [3], and curiosity [4,5]. These are the attribute to intrigue self-studying.

The involvement of hands-on activities also increases students’ motivation to study technology and engineering related areas for their higher education [6].

Topic about density has been learned by students since junior high school. This quantity is used in many physics’ concepts. However, in most cases, the value of density has been provided during problem solving because the focus of problem is the other quantities.

According to its definition and formula, determining the density of a substance can be done by measuring the mass per unit volume. For liquid, there are some methods that can be used to determine the density without calculating the mass and volume of the liquid. It uses the principles of Archimedes with a simple mathematical ratio [7,8]. It was based on a study of Hughes [9] that explored a more accurate and faster method to measure small object volume. In addition, Putranta et al [10] designed a simple measuring tool for density based on Hook’s Law using simple materials, such as pipe, rulers, springs, and wooden table. However, the experiments related to density are commonly conducted...
manually, especially for science learning in schools by measuring the mass and calculating the volume of an object. Although this activity can improve their scientific skills, it takes more time.

Since the advancement of technology and science, they get strongly intercorrelated. Most of the activities in education sector, including laboratory activities have widely involved the utilization of technology. In higher education, most of measuring instruments are digital. However, there has not been a digital measurer of density in the researchers’ department. Some researchers have been conducted to develop a laboratory tool using the technology-based. For example, Warsito [11] conducted research to measure density using a sample of a liquid with the help of an LDR sensor. For the measurement process, a Visual Basic 6.0 program was used which was displayed on a monitor. The results obtained were close to the literature. Moreover, Pande [12] conducted a study on the realization of a liquid density measuring instrument based on the hydrostatic pressure method using a photodiode sensor based on an Atmega 8535 microcontroller. The result indicated that the accuracy value was 97%. Megantoro et al [13] designed a digital liquid density meter based on Arduino, while Roy et al [14] used piezoelectric Micromachined Ultrasound Transducers (PMUTs). All the results of the previous research showed that the density measurement were accurate.

Therefore, we intended to develop a practical tool for determining the density of liquids based on a microcontroller. The components required for measuring instruments based on microcontroller are relatively low cost and low power system [15]. Moreover, our intention was that this product can provide more accurate results within a short time. By saving their time would give the students more time for discussion and brainstorming of their gained results.

2. Methods

This research was a Research and Development (R&D). The research model adapted the model of Borg and Gall [16]. The steps of the research model are presented in Figure 1.

![Figure 1. Stages of research and development (R&D) methods according to Borg and Gall](image)

However, this study only conducted six stages, including the Potential and Problems, Data Collection, Product Design, Product Validation, product revision and product trial (limited test). The subjects of this study were students of the Sub-Department of Physics Education, Faculty of Teacher Training and Education, Tadulako University. The data were collected through questionnaire distribution to a media expert, and 10 of undergraduate students as prospective users for the limited-test. The questionnaire consists of questions that can be used to assess the quality and feasibility of the resulting learning media. Students were given the questionnaires after using the developed product in the basic physics lesson. Before testing to students, the product has been undergone field-test in laboratory to see the density value of the measured substance. The data were analyzed using descriptive analysis with the maximum average value of 4.0. It was based on the 4-Likert scale of the questionnaire [17].
3. Results and Discussion

3.1. Initial Stage
The initial stages of this research involved designing the product, gathering the components, and arranging the practical tools according to the initial design. Manufacturing stage was started with designing the mechanical parts of the tool to make all sensors function properly. For example, the researchers had to consider on how the shape of the plywood to make the load cell and the layout the sensors and other components to make them function properly. It was a critical stage since the mechanical shape of the components greatly affects the accuracy of the measuring instrument. The next stage was managing the electrical components. At this stage, it was also significant to carefully scrutinize the load cell and ultrasonic sensor, especially on how the sensor were connected with the battery with the driver and with the microcontroller used (Arduino). They will serve as a volume meter. Moreover, after the practicum tool has been arranged properly, the next stage was programming. The programming language used was the C++ language in the Arduino application. The developed product was displayed as Figure 2.

![Figure 2. Display of practical tools](image)

3.2. Lab Manual
In this study, we also provided a lab manual to help students operating the practical tool and to allow self-study between them. Figure 3 is an example of the descriptions of materials used during the experiment. Figure 3 provides tools and materials used including a heavy sensor, Arduino uno, rainbow cable, battery, LCD, i2c, and plastic jars.

3.3. Laboratory Test Result
Laboratory test was done after the product was considered ready to be used. Laboratory tests were conducted to three kinds of liquid. They were water, coconut oil, and salt water. The detailed comparison between the density value based on the product measurement and the literature were displayed in Table 1. From the experimental results, the density value of water is 0.95 gr/cm$^3$ with a standard deviation of ±0.044 and a relative uncertainty value of 0.22%. The density value for brine obtained is 1.04 gr/cm$^3$ with a standard deviation of ±0.011 while the density of coconut oil in the literature is 1.10 gr/cm$^3$. For coconut oil, the density obtained is 0.76 gr/cm$^3$ with a standard deviation of ±0.045 and the density according to the literature is 0.84. Based on the laboratory test, there were some revisions made. First, the quantities displayed on the LCD previously were mass, volume, height and radius. It was changed to mass, volume, height and density.

| Liquid    | Density (ρ) gr/cm$^3$ (literature) | Density (ρ) gr/cm$^3$ (measurement) | Standard deviation (σ) |
|-----------|-----------------------------------|------------------------------------|------------------------|
| Water     | 1.00                              | 0.95                               | 0.044                  |
| Coconut oil | 0.84                              | 0.76                               | 0.045                  |
| Salt water | 110                               | 1.04                               | 0.011                  |
3.4. Expert Evaluation

The media assessment was used to evaluate the feasibility of the practicum tools and the feasibility of the lab manual. Some suggestions that were given by the expert included the improvement in product quality by stabilizing the numbers that appear on the LCD. The expert reckoned that the numbers kept
changing. It was an imperative comment since the numbers indicated the measurement results. Further, the expert suggested to apply the product to other kinds of liquid to ensure the measurement accuracy of the product. In addition, the lab manual was required to cover conclusions and suggestions columns.

The results of expert assessment showed that the average score of product feasibility was 3.50 which was in very good category. In the ergonomic aspect, the average value was 3.00 with good category. In terms of the suitability of the device with the concept of physics, the average value was 3.20 in good category. Meanwhile, it got a perfect score of 4.0 for the aspect of time efficiency. Meanwhile, the results of the manual lab assessment in the aspects of the content presentation and language obtained 2.50 and 3.50 respectively. These results denote that the tool was feasible to be tested in the field with revisions.

3.5. Limited-test (Field-test)

The limited test was conducted to measure the aspects of the physical appearance of the device, ergonomic, learning motivation, and operational and performance. The physical appearance gained an average score of 3.00 and was categorized as agree. Meanwhile, the rest of the aspects, the ergonomic, learning motivation, and operational and performance aspects were in strongly agree category with the average of 3.55, 3.37 and 3.45, respectively. Overall, students strongly agree with the feasibility and usability of the developed product, with the average score of 3.31. these results were in accordance with the assessment result of the manual lab. The lab manual was assessed based on the content presented and language and both aspects obtained the average score above 3.0.

4. Conclusion

A practical tool for determining the density of liquids based on a microcontroller has been made. The results of the assessment from the media expert and undergraduate students indicated that the tool was feasible to use. Besides the positive feedback and respondents from the respondents, the feasibility of the product also was shown from the laboratory test. Although the density values of the measurement were not exactly the same as the literature, the small value of standard deviation should be considered as the feasibility of its application.

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