Asian Journal of Education and Social Studies

21(2): 1-8, 2021; Article no.AJESS.72898
ISSN: 2581-6268

Development of Portable Force Measurement Kit Using Arduino and Android Phone App for Pascal's Law

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Authors' contributions

This work was carried out in collaboration between both authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJESS/2021/v21i230501
Editor(s):
(1) Dr. Der-Jang Chi, Chinese Culture University, Taiwan.
(2) Dr. Roxana Plesa, University of Petrosani, Romania.
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Complete Peer review History: https://www.sdiarticle4.com/review-history/72898

Original Research Article

Received 27 June 2021
Accepted 07 September 2021
Published 10 September 2021

ABSTRACT

Learning through experimentation is a teaching method that allows students to conduct investigations through planning, implementation and discussion. However, the implementation of experiments is less emphasized due to limited teaching time and insufficient laboratory equipment, thus reducing students' interest in Physics subject. Therefore, this study aims to develop an Arduino-based portable kit for force measurement and to test the reliability of the developed measurement kit. The development of this measurement kit was determined for Pascal's law to diversify the practice in this topic. This kit consists of pressure sensor, Arduino microcontroller, android device and Bluetooth module. This study used a questionnaire instrument to measure the reliability of this kit. The validity of the kit was obtained from two (2) experts, and its reliability was evaluated from 15 Form 4 students through questionnaires. The result of the study showed a satisfactory reliability level with Cronbach alpha of 0.88. Therefore, it is expected that the development of this measurement kit can facilitate teachers in the teaching process and enhance students' interest in Physics subject in Malaysia.

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Keywords: Measurement kit; teaching aid; Pascal's law

1. INTRODUCTION

The concept of Physics that is too abstract can be made real so that it is easy to understand, one of which is by conducting experiments [1]. Practical or experimental activities can develop scientific skills, understanding of concepts, scientific attitudes, creative thinking and cognitive abilities. This is essential in the learning process as it can provide new experiences and a clear picture of science concept especially for Physics subject [2,3]. Therefore, the experimental activities are a contextually appropriate learning method for Physics subject with a relatively large number of theories. However, teachers do not implement experiments in Teaching and Learning (TnL) as they ought to pursue the syllabus content due to limitation of time. In addition, inadequate laboratory equipment also contributes to the lack of hands-on in schools [4]. In fact, some measurement kits cannot produce accurate and reliable measurement as they are rarely used. Students are also less interested in Physics subject if they are not given adequate opportunities to engage in concepts taught by teachers.

Arduino microcontroller is ideally used by teachers and students to prove the law of physics, build low-cost scientific instruments, or start programming and robotics. It provides advantages, such as low cost, flexibility, user-friendliness, and its user community is significant [5]. Arduino is widely used in education of Physics to perform a number of different measurements, such as measuring Newton's law of cooling constant [6] and electrical current [7]. In this research, an Arduino-based portable measurement kit for force measurement was explicitly developed in Pascal's law to diversify the experiments involved. Students can easily conduct experiments in school in a short period of time using this measurement kit. The advantages of this portable measurement kit are lightweight, flexible and user-friendly tool. Due to lack of measurement kit that could be used by students to measure the force pressure applied of Pascal's law, the researchers took the opportunity to develop a portable Arduino-based kit to serve the purpose.

2. MATERIALS AND METHODS

2.1 Research Design

In this study, the measurement kit was developed and subjected to validity and reliability tests. A quantitative study was employed. Researchers used ADDIE model as a guide or framework during the kit development. The ADDIE model consists of analysis, design, development, implementation and evaluation phases. In the analysis phase, the researchers conducted a literature review to identify educational problems, especially in Physics education. Based on the problem statement, the experimental activities have been given less emphasis due to limited teaching time and insufficient laboratory equipment. Therefore, during the design phase, the researchers proposed the force measurement kit using Arduino.

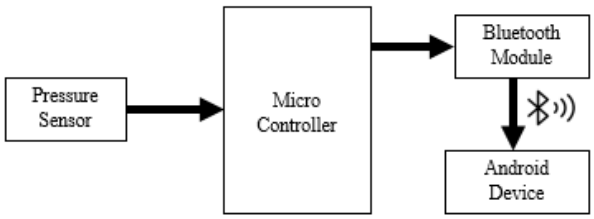
The Arduino microcontroller was used in this study which aimed to build a portable and easy-to-use kit. Fig. 1(a) shows the block diagram of the kit consisting of pressure sensor, and the output was sent to an android smartphone via Bluetooth module. Arduino and Bluetooth module are essential for developing a force measurement system. Fig. 1(b) shows the circuit diagram; the pressure sensor was connected to PIN 1 (analog pin). Two Bluetooth module pins were connected to the receiver and transmitter, and the other pins were connected to V_{cc} and Gnd, respectively. Then, a flow chart of the measurement system was sketched first as depicted in Fig. 2. It started by initializing the force sensing resistor (FSR) sensor and Bluetooth module, and then the data from the FSR sensor were read by the microcontroller, the data were processed and the outputs were sent to smartphone to display the final force value. In the implementation phase, the questionnaire used as instrument in this research was validated by two experts, while the reliability of the questionnaire was obtained from the respondents among upper secondary students for Physics subject.

The theoretical background involved in this study was Pascal's law. According to the law, any force applied to a confined fluid is transmitted uniformly in all directions throughout the fluid regardless of the shape of the container [8]. Mathematically, the general equation for Pascal's law is

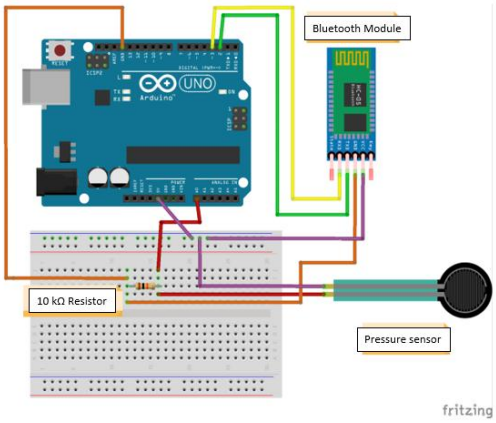
$$F_1 A_1 = F_2 A_2$$

where, F_1 and A_1 are force and area of the first container, respectively, and F_2 and A_2 are force and area of the second container, respectively.

Assuming the container has a syringe shape as shown in Fig. 3, a pressure exerted on the first syringe produces an equal increase in pressure on the second syringe in the system as defined by the Pascal's law. If the syringe piston has an area 10 times that of the first, the force on the second syringe is 10 times greater, even though the pressure is the same as that on the first syringe. The FSR sensor was used in this measurement kit, which its resistance changes as more force is applied. When the force is absent, the sensor will act as an open circuit. The higher the force applied, the lower the resistance value.



(a)



(b)

Fig. 1. Force measurement kit (a) Block diagram (b) circuit diagram

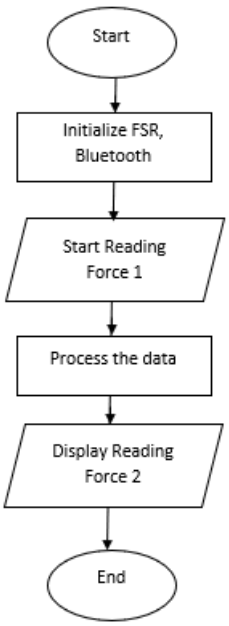


Fig. 2. Flow chart of the measurement system

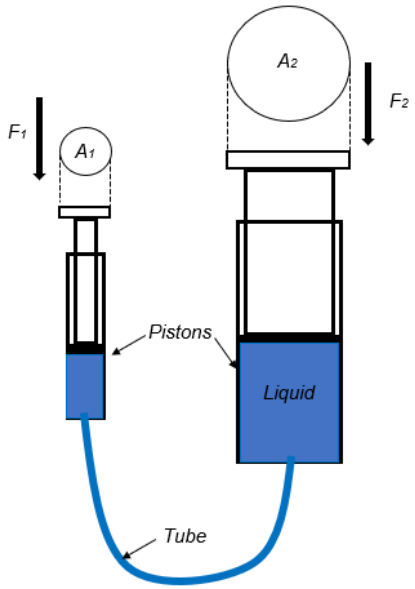


Fig. 3. Illustration of pascal law kit

2.2 Research Population and Sample

The sampling method used in this study was non-random sampling with simple sampling technique. Based on Table 1, the study sample was divided into two groups depending on the sampling purposes. The experts involved for validity was a secondary school teacher who taught Physics subject and a Physics lecturer from the university. Then, the reliability of the instrument was carried out through a pilot test, which involved 15 respondents among upper secondary Physics students.

2.3 Research Instrument

In this study, the instrument used for data collection was in the form of questionnaire. The questionnaire was developed by adapting it from other researchers and modified according to the researcher's practical suitability and user manual [9]. Each item of the questionnaire was in the form of a five -point Likert scale to determine the validity and reliability of the measurement kit. The instrument consisted of two parts, namely Part A (respondents' personal information) and Part B (students' evaluation of the measurement kit developed). Meanwhile, Part B comprised several categories including the design and suitability of the contents of the user manual and measurement kit. The questionnaire modified by the researchers was validated first by the experts before being distributed to the respondents.

2.4 Data Analysis

Data obtained from the face and content validity of the questionnaires were analyzed according to the formula by Noah and Ahmad [10]. A module has high validity if obtained 70% and is considered to have achieved an excellent level of mastery. To determine the level of validity of the experiment and user manual kit, the total scores filled in by the expert (x) were divided by the total maximum scores (y) and multiplied by 100. The total maximum score (y) was calculated based on the number of items with the maximum score of the Likert scale.

3. RESULTS AND DISCUSSION

3.1 User Manual and Measurement Kit

The front page of the user manual is shown in Fig. 4, where it contains the objectives of the module, tools and materials used. The manual indicated the measurement kit and the guideline to conduct the force measurement. The load was varied and the force measurement was recorded to study the relationship between force and area in accordance with the Pascal's law.

Fig. 5(a) shows the force measuring system using Pascal kit and smartphone to display the measurement result. The Pascal kit was used in conjunction with a force measuring system to determine the force required on a small syringe to lift a load on a large syringe. It was built using

two syringes with different surface areas inside the syringe, namely 1.2 x 10^{-4} m^2 for the small syringe and 6.61 x 10^{-4} m^2 for the large syringe. A tube was connected between two syringes. The load was placed on the top of the large syringe for force measurement, and then the force applied to push a small syringe was measured using the measurement kit. The pressure sensor was placed on the plunger of the small syringe.

The graphical interface used in the smartphones was Remote XY application, which can be easily used to control the Arduino microcontroller device via a mobile application. It was developed as an element of control, display or decoration on the smartphone. The text elements found on the indicator and the label found on the decoration were selected for use in the graphical interface display as shown in Fig. 5(b). Before the pilot test was carried out, the measurement kit was first tested and the experimental data were collected and repeated for three times, then, the experimental data were compared with the analytical data. The measurement data are depicted in Fig. 6. From the experiments, it was found that the force on the small syringe, F1, was smaller than the force on the large syringe, F2 which is force applied by load. This could be influenced by the surface area of the small syringe, $A1$, which was smaller than the surface area of the large syringe, $A2$. Based on the graph, the experimental data were in line with the analytical data. The experimental gradient value experiment was 0.21, while the analytical gradient value was 0.18. The percent error is 17% where it is acceptable for the measurement kit. Both linear regression value for analytical and experimental are 0.9986 and 0.9961, respectively. is 0.58.

3.2 The Validity of Instruments

Two experts evaluated the validity of this measurement kit. This validity was divided into two parts, namely face validity and content validity. Face validity is evaluated through eight aspects, while content validity has ten aspects to be evaluated. Aspects for face validity were the user manual display and the measurement kit design. In contrast, aspects for content validity were the suitability of the user manual content and the measurement kit design. Table 2 and Fig. 6 show the percentage of consent received for each face validity and content validity. Both experts agreed by 96% for the measurement kits and user manual developed by the researchers. The percentage of consent received exceeded 70%, indicating that the measurement kit and user manual have reached a good mastery level [11]. Thus, a validity value of 90% was considered to have reached a high level of achievement.

Table 1. Demographic information of respondents according to purpose and phase of involvement

No	Purpose of Sampling	Phase Involved	No. of Respondent
1	Expert validity	Implementation	2
2	Instrument reliability	Implementation	15

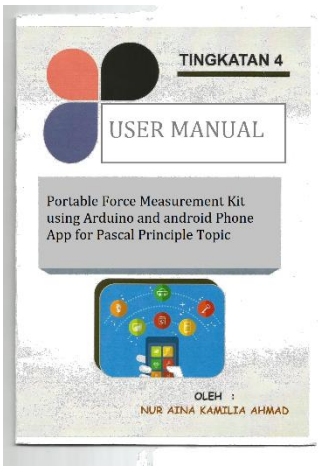
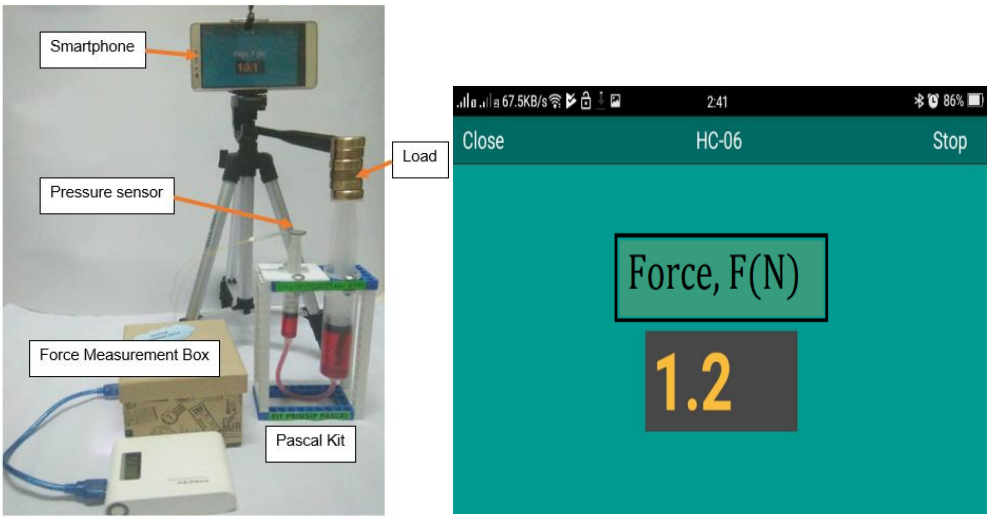


Fig. 4. Frontpage of the user manual



(a) (b)

Fig. 5(a). Measurement kit for force (b) RemoteXY application on android

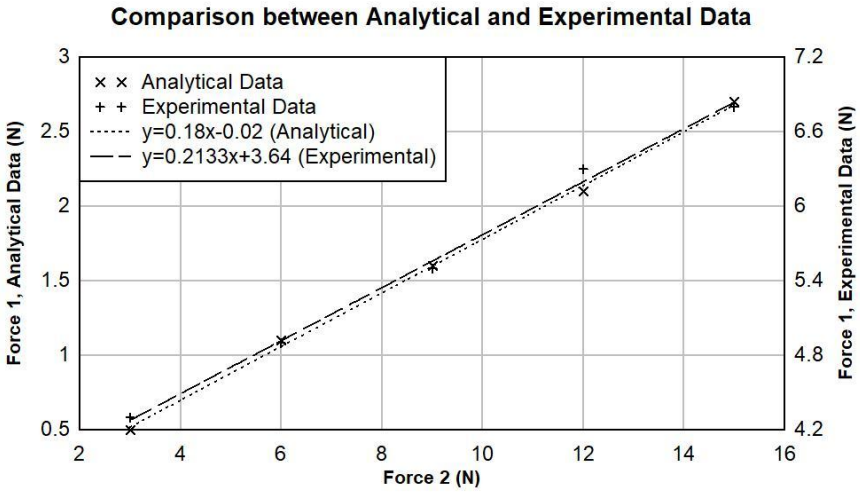


Fig. 6. Comparison between experimental and analytical data

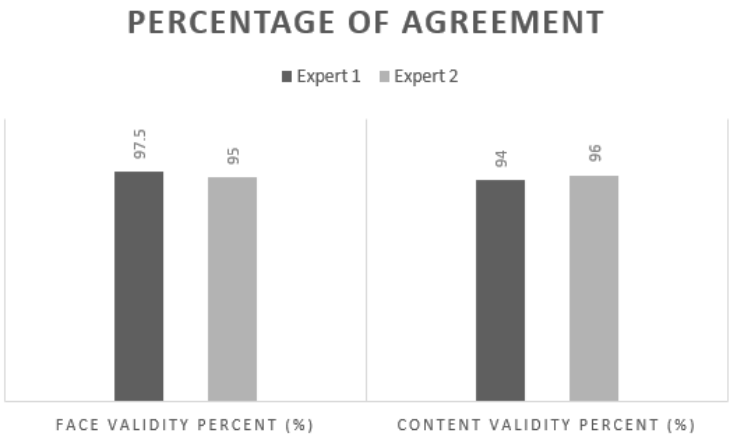


Fig. 6. percentage of agreement

Table 2. Average percentage of agreement for kit validity

	Face validity percentage (%)	Content Validity percentage (%)
Expert 1	97.5	94.0
Expert 2	95.0	96.0
Average	96.3	95.0

3.3 The Reliability of Instruments

A pilot test was carried out to collect data for reliability. The pilot test can be a small test to assess feasibility, time, cost, reversal effects or adverse effects and size of its effect to improve the study design before conducting actual research [12]. In this study, the pilot test assisted the researchers to conduct the actual data analysis process to achieve the objectives of the study. In the pilot test, the reliability and feasibility of the designed questionnaire were reviewed and improved based on the respondents' feedback. Questions that did not achieve the objectives were discarded. Cronbach's Alpha is a statistic commonly used by researchers to measure reliability to ensure that the constructed questionnaire instrument is approved for in the actual study [13]. Reliability data were analyzed using questionnaires from 15 respondents among the upper secondary Physics students.

From the result, the Cronbach's alpha obtained from SPSS was 0.882. The reliability values between 0.60 to 0.70 are considered to have moderate acceptance limits [14]. Therefore, this measurement kit has good reliability, which exceeded 0.70. Through the analyzed reliability data, the developed portable measurement kit obtained a Cronbach's alpha reliability coefficient of 0.882. This is in line with the study by Mohd Majib (2000) and stated that if the reliability coefficient value is high (minimum of 0.60), the module indicates a good consistency level. Thus, it can be concluded that this measurement kit can be used in schools aiding the teaching and learning processes.

4. CONCLUSION

This study has successfully developed a force measurement kit using Arduino microcontroller and then the results were displayed on the smartphone. This portable measurement kit is also easy to carry anywhere as it is lightweight and flexible. Practical activities are not necessarily carried out in the laboratory only but also anywhere. The validity evaluation from two experts demonstrated high total percentage of validity agreement of 96.3% for face validity and 95.0% for content validity. The Cronbach's Alpha value obtained for the pilot study was 0.88, indicating high-reliability level. Thus, the measurement kit can be used by teachers as an alternative tool for experimental activities kit and hands-on related to Pascal's law topic.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the authors.

ACKNOWLEDGEMENTS

The authors also would like to thank all fellow research in the Faculty of Science and Mathematics, UPSI for their support and assistance throughout the work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
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