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Development of Digital Calorimeter Experiment Kit to Train the Designing Experiments Ability of Pre-Service Science Teacher

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ABSTRACT
This study aims to develop a digital calorimeter experimental kit that is valid, accurate, precise, and as well and to analyze the profile of the ability to design experiments in pre-service science teachers after taking lectures using the digital calorimeter experiment kit. This research used the ADDIE model. The digital calorimeter that has been developed has digital innovation by using a digital temperature controller W1209 and an integrated heater. Expert validation results show valid criteria. The experimental results show a precision level of 98.9% and an accuracy rate of 95.6%. After the digital calorimeter was applied to lectures, a profile of the ability to design experimental science teacher candidates was obtained in the high category with an average score of 83.16. So it can be concluded that the digital calorimeter experimental kit developed is valid, accurate, precise, and able to train the ability to design experimental pre-service science teacher. The development of a digital calorimeter experiment kit can be an alternative to providing technology-based experiment tools and can also train the abilities of pre-service science teachers related to science experiments.

INTRODUCTION

Education is one of the key factors in a country's development. Qualified pre-service teachers are essential to ensure effective and quality education. One of the most important things for pre-service science teachers is having the ability to design science experiments [1]. This is because science learning is not only oriented towards understanding the concepts of scientific theory but also must be able to strengthen science process skills in scientific investigations carried out by students [2]. Students' science process skills can be well acquired through experimental activities; therefore, it is very important for pre-service science teachers to be able to design effective and efficient science experiments [3]. It is important to train the ability to design experiments of pre-service science teacher because science learning is not only oriented to scientific theory but is also related to science process skills which are trained through experimental activities.

The ability of pre-service science teacher to design experiments is certainly influenced by the availability of practical tools or experimental kits. The experimental kit is one aspect of the success of the experimental activity process in science learning. The use of experimental kits during the practicum process can simplify the material being taught so that learning will be far more efficient and effective [4]. The problem that is often experienced by teachers in using experimental kits in the practicum process is that the experimental kits used are not attached to one place so that it slows down the learning process [5]. Research by Juniarta et al [6] mentions the inadequate number of experimental kits as a medium to support the science learning process, if there are very few of them. Noviyanti's research [7] states that generally the experimental kits used to support the practicum process have not been integrated with technology so that it has an impact on the inaccuracies and inaccuracies of the results obtained. These problems make it difficult for science teachers to design science experimental activities that should be in accordance with learning objectives (effective), obtain correct and appropriate results (accurate), and require a short time (efficient).

The use of conventional experimental kits in the current era is not able to optimize the learning process because in the 21st century learning, technology must be integrated in the field of education so that it can present learning that is more innovative and in accordance with the demands of the times [8]. The emergence of digital technology is a solution to replace conventional experimental kit equipment so as to minimize the risk of errors in the data obtained and increase the accuracy of the data obtained [4]. Research by Henderson et al [9] states that the use of digital technology has advantages including learning to be more interesting and interactive, learning quality is more optimal, saving time, and having high accessibility. Integration of digital technology in the experimental kit will make it easier for science teachers to design experiments. One of the science experiment kits that can be developed is a digital calorimeter

Digital calorimeter is a modified analogue calorimeter with the addition of digital technology such as thermocouple sensors and load cells. Digitizing the calorimeter teaching aids aims to minimize errors in the observation data obtained and save experiment time [7]. The development of a digital calorimeter can make it easier for pre-service science teacher to practice designing experiments practically. The advantage of a digital calorimeter is that it takes a shorter time to measure temperature and minimizes errors in measuring temperature. The developed of digital calorimeter can be an experimental kit that can be used to design various experiments related to temperature and heat at the junior high school level.

Several studies related to digital calorimeters have been carried out, such as Noviyanti et al [7] who conducted a digital calorimeter design set experiment with thermocouple sensors and load cells based on Arduino Uno which showed that the digital calorimeter developed had precise and accurate temperature readings. The next research is to develop a coffee cup calorimeter practical tool to measure specific heat with the help of Arduino Uno [10]. The findings in this study are the result of measuring the specific heat of a material using a tool design that shows conformity with previous theoretical studies. In addition, Ulfah et al [11] also designed a specific heat aid with the aid of a load cell and ds18b20 sensor using multi-representation-based android. The developed teaching aids obtain valid values according to experts. In addition to research related to the development of digital calorimeters, previous research has also been carried out regarding the ability to design experiments for prospective science teachers. The research was conducted by Fiteriani [12] who examined the relationship between concept mastery, science process skills, and the ability to design experiments in science teacher candidates. Based on previous research, no one has researched the development of digital calorimeter experimental devices to train the ability to design experiments for pre-service science teacher. Therefore, in this research a digital calorimeter was developed in the form of an experimental kit so that it can be used to design various experiments related to temperature and heat in a practical, effective, and efficient manner. The digital calorimeter experimental kit that was developed was then applied to train the designing experiments ability for pre-service science teacher. The objectives to be achieved through this research were to develop digital calorimeter experimental devices that were valid, accurate, precise, and practical, as well as to analyze the profile of the design

experiments ability on pre-service science teachers after attending lectures using digital calorimeter experimental devices.

METHOD

This study uses the ADDIE development model which consists of the analysis, design, development, implementation, and evaluation stages [13]. The product that has been developed is a digital calorimeter experimental kit. Based on the ADDIE development model, the research procedures for developing the digital calorimeter experiment kit are in Table 1.

Table 1. ADDIE model

ADDIE model	Description
Analysis	Conduct literature studies related to digital calorimeters, experimental kits, and the ability to design experiments based on research results in reputable journals. As well as an analysis of the need for a digital calorimeter experimental kit and the ability to design experiments for pre-service science teacher at the trial location, namely the Science Education Study Program, Universitas Negeri Semarang. Interviews were conducted with laboratory managers and lecturers.
Design	Designing a digital calorimeter experiment kit begins with designing drawings for the design of a digital calorimeter experiment kit tool, choosing component materials, equipment and materials to become an experimental kit, and compiling research instruments including digital calorimeter experiment kit validation sheets and Experiment design ability assessment sheet. The digital calorimeter design is shown in Figure 1.

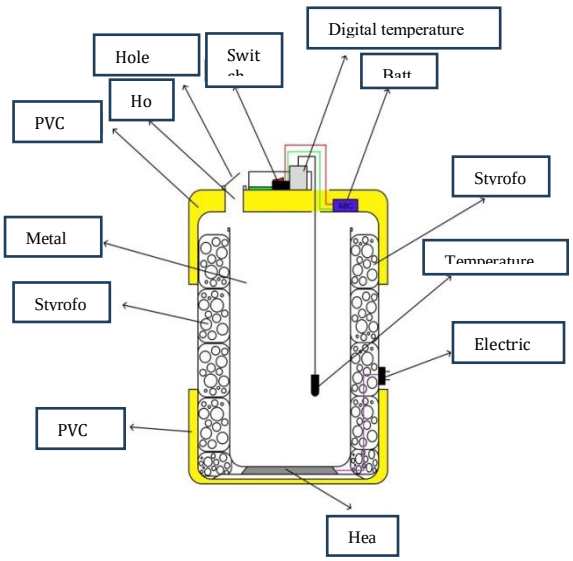

Fig 1. *Design of Digital Calorimeter*

The experimental design ability assessment sheet was adapted from Komives, et al [14] consisting of (1) determining the objective of the experiment, (2) researching and explaining relevant theories or principles used in the experiment, (3) choosing the right and safe tools and materials used in experimental activities, (4) selecting the variables used in the experiment, (5) determining the appropriate experimental procedures or steps, and (6) determining the amount of data measured and the appropriate method of data analysis.

Development	The digital calorimeter experiment kit that had been compiled was then validated by 5 experts, then a revision process was carried out according to expert input. The experts give a rating of 1 to 4 on each item quality indicator of the product. Product quality is determined by score according to Aiken's V formula (equation 1) [15]. The product was valid if the V score more than or equal 0.87 $V = \frac{\sum s}{[n(c-1)]}$ (1) Where V = validation score, s = $r-lo$, r = score form expert, lo = minimum score, n = amount of expert, and c = maximum score The revised digital calorimeter experiment kit product was then tested with experiments to see its accuracy and precision. The revised digital calorimeter experiment kit product was then tested with experiments to see its accuracy and precision. Precision is determined through experiments using a digital calorimeter to determine the heat capacity and calculate the standard deviation. While the accuracy is carried out through experiments to determine the specific heat of water then compared with the standard water specific heat of 1000 J/kg^{0}C.
Implementation	The implementation stage of the digital calorimeter experiment kit was carried out in the Undergraduate Science Education Study Program, Universitas Negeri Semarang. The research subject used was 1 class of pre-service science teacher (30 students) who had taken 6th semester. At this stage, profiles of the ability to design experiments was also analyzed for pre-service science teacher students after taking lectures using the digital calorimeter experiment kit.
Evaluation	Evaluation is carried out at each stage of development. Suggestions and input from validators, lecturers, and pre-service science teacher students were obtained for product improvements that have been developed.

RESULTS AND DISCUSSIONS

Product Description and Specifications

The product that has been developed in this study is a digital calorimeter experimental kit which has cylindrical dimensions with a diameter of 10 cm and a height of 20 cm. Digital calorimeter of PVC pipe with a diameter of 10 cm as the outside, metal mug with a diameter of 8 cm as the inside, Styrofoam with a thickness of 1.5 cm as the wall layer, PVC pipe lid as the cover. The digitization of the experiment kit can be seen from the addition of a temperature controller w1209 which functions as a tool to measure temperature and control the desired calorific temperature, as well as the use of a heater at the bottom of the mug which functions as a water heater.

The temperature controller w1209 is supplied with a 12-volt DC battery voltage source and the heater is supplied with a 220-volt AC voltage source. The choice of PVC material on the outside and the Styrofoam layer is to minimize heat coming out of the calorimeter [16]. The metal mug on the inside functions to speed up the heating of the water in the calorimeter when heater activated. The w1029z temperature controller was equipped with a temperature sensor that can measure temperatures from -50 ^{0}C to 100 ^{0}C. Digital temperature measurement allowed for fast, accurate readings, and minimizes parallax errors when reading temperature scales [17]. The heater integrated in the calorimeter speeds up the experimental process because if we need hot water, we don't need to boil the water outside the calorimeter first. The physical details of the digital calorimeter are shown in Figure 2.

(a) (b) (c)

Fig 2. *Digital calorimeter experiment kit products (a) side view, (b) top view, (c) inside view*

Product Validation

The results of the validation of digital calorimeter are shown in Figure 3. All aspects of product have a V score or Aiken index more than 0.87 so that it can be said to be valid according to experts. Aiken index can be used as a basis for measuring the content validity of a product [14].

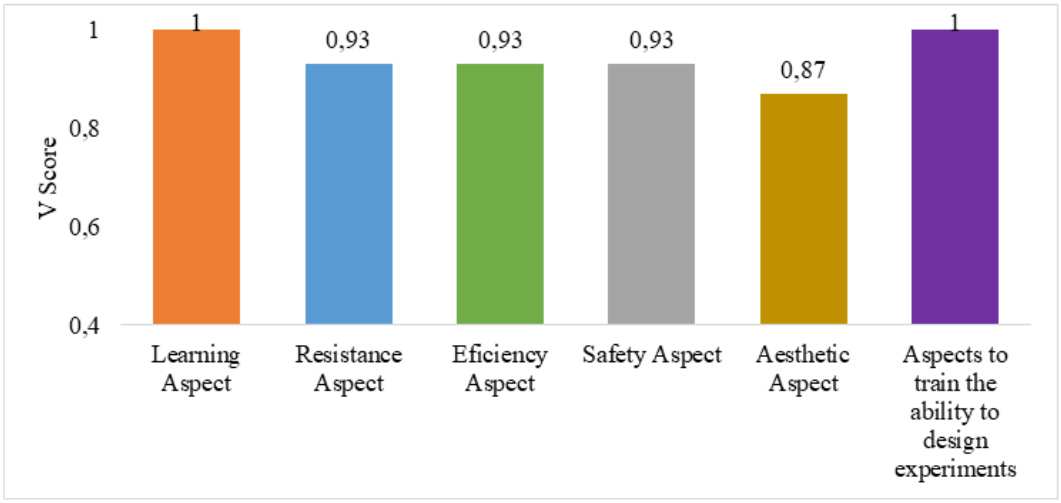

Fig 3. *Product Validation Score*

In the learning aspect, the digital calorimeter was assessed by experts as appropriate to the subject matter and can be used to achieve learning outcomes in the subject matter of heat, temperature and expansion at the junior high school level. Experimental activities must support the achievement of learning outcomes [18]. This calorimeter experimental kit supports learning outcomes in the aspect of process skills, namely students are able to take measurements of the physical aspects encountered in everyday life which are closely related to temperature and heat.

The calorimeter also obtained a valid score on the endurance aspect. This is because the outer material used is sturdy, namely PVC. In addition, all components in the digital calorimeter are arranged in a compact manner so that they are not easily separated. Digital calorimeters are also easy to maintain because the metal mug material is easy to clean when finished using for experiments.

In terms of efficiency, the digital calorimeter experimental kit is considered very efficient for use in experiments. This is because the digital calorimeter uses a w1209 temperature controller with a temperature sensor that is fast in measurement. The digital display also makes it easier to read so that experiments take place more quickly [19]. The use of a heater that is integrated in a digital calorimeter allows experiments to take place more practically because the practitioner does not need to prepare hot water outside the calorimeter.

The digital calorimeter also obtains valid values for safety aspects because it uses non-sharp materials, does not use flammable materials, and does not use toxic materials. In addition, the shape of the calorimeter which is cylindrical or does not have an acute angle makes its use more comfortable. Styrofoam-coated PVC outer material is an insulator so it doesn't get hot when held [20] [21]. The developed digital calorimeter product also has good aesthetic value. The choice of contrasting black and yellow makes it attractive. The design of the digital calorimeter also looks simple so it's comfortable to look at and the size is not too big.

The last aspect assessed is the aspect of practicing experimental design skills. Digital calorimeter experiment kit can assist science teacher candidates in determining experiment objectives, researching and explaining relevant theories or principles used in experiments, choosing variables to use in experiments, choosing tools and materials that are appropriate and safe to use in experimental activities, determining procedures or steps appropriate experiment, and determine the amount of data to be measured and the appropriate method of data analysis [14].

Precision of Digital Calorimeter

Precision results of digital calorimeter experiment kit were obtained by conducting experiments to determine the heat capacity of the calorimeter. The experiment was carried out by mixing hot water and cold water. Experimental data results are presented in table 2.

Table 2. Experiment result for measuring capacity of the calorimeter

m_1 (kg)	T_1 (^{0}C)	m_2 (kg)	T_2 (^{0}C)	Tc (^{0}C)	C_{cal} (J/^{0}C)
0.10	78.0	0.10	27.2	54.8	79.7
0.10	78.0	0.08	27.2	57.5	76.6
0.10	78.0	0.06	27.2	61.0	81.0
0.10	78.0	0.04	27.2	65.2	78.8
0.10	78.0	0.02	27.2	70.7	80.5
				$\overline{C_{cal}}$	79.3
				ΔC_{cal}	0.87

*Notes: m_1 = mass of hot water, m_2 = mass of cold water, T_1 = mass of hot water, T_2 = temperature of cold water, T_C = mix temperature, C_{cal} = heat capacity of the digital calorimeter, $\overline{C_{cal}}$ = average of heat capacity ΔC_{cal} = error (standard deviation) of heat capacity

Based on the experimental results, the heat capacity of the digital calorimeter is (79.3 ± 0.87) J/^{0}C. If these results are calculated, a relative error of 1.09% or a precision level of 98.9% is obtained. This result is higher than the standard relative error value for educational tools, which is 5% [22]. The precision level of the digital calorimeter obtains high results because experiments can be carried out practically and quickly using a digital sensor thereby minimizing heat transfer out of the calorimeter [19]. If the experiment is not carried out quickly, the heat will gradually come out because the calorimeter system is not perfectly isolated.

Accuracy of Digital Calorimeter

Precision results of digital calorimeter experiment kit were obtained by conducting experiments to determine the heat capacity of the calorimeter. The experiment was carried out by mixing hot water and cold water. Experimental data results are presented in table 3.

Based on the experimental results, the specific heat of water is (4383.2 ± 226.8) J/kg^{0}C. If these results are compared with the standard specific heat of water (4200 J/kg^{0}C), an accuracy of 95.6% is obtained. Experimental accuracy can obtain good results because experiments using digital calorimeters procedurally meet standards. The heater that is integrated with the calorimeter so that hot water does not need to be prepared outside the system so as to minimize heat leaving the calorimeter.

Table 3. Experiment result for measuring capacity of the calorimeter

m_1 (kg)	T_1 (^{0}C)	m_2 (kg)	T_2 (^{0}C)	Tc (^{0}C)	c (J/kg^{0}C)
0.10	78.0	0.10	27.2	54.8	4640.4
0.10	78.0	0.08	27.2	57.5	4347.9
0.10	78.0	0.06	27.2	61.0	4111.2
0.10	78.0	0.04	27.2	65.2	4230.5
0.10	78.0	0.02	27.2	70.7	4585,8
				$\bar{c}$	4383.2
				Δc	226.8

*Notes: m_1 = mass of hot water, m_2 = mass of cold water, T_1 = mass of hot water, T_2 = temperature of cold water, T_C = mix temperature, c = specific heat of water, $\bar{c}$ = average of specific heat, Δc = error (standard deviation) of specific heat

Profiles of designing experiment ability

The digital calorimeter is a development of the analog calorimeter by adding a thermocouple sensor and a load cell which makes this calorimeter digital based and makes temperature measurements more accurate. Only by pouring the material whose temperature you want to measure, the digital calorimeter can directly read the temperature you want to measure, so you can save measurement time and simplify the practicum process. This will answer the problems of science teachers who experience difficulties in designing science experimental activities that should be in accordance with learning objectives (effective), obtain correct and precise results (accurate), and require a short time (efficient). In line with Dewi et. al. [4] that with the appearance of digital-based experimental kits, namely the digital calorimeter experiment kit, a solution to replace conventional experimental kit equipment, thereby minimizing the risk of errors in the data obtained and increasing the accuracy of the data obtained.

Aspects of the ability to design experiments according to Komives, et al [14] consisting of (1) determining the objective of the experiment, (2) researching and explaining relevant theories or principles used in the experiment, (3) choosing the right and safe tools and materials used in experimental activities, (4) selecting the variables used in the experiment, (5) determining the appropriate experimental procedures or steps, and (6) determining the amount of data measured and the appropriate method of data analysis.

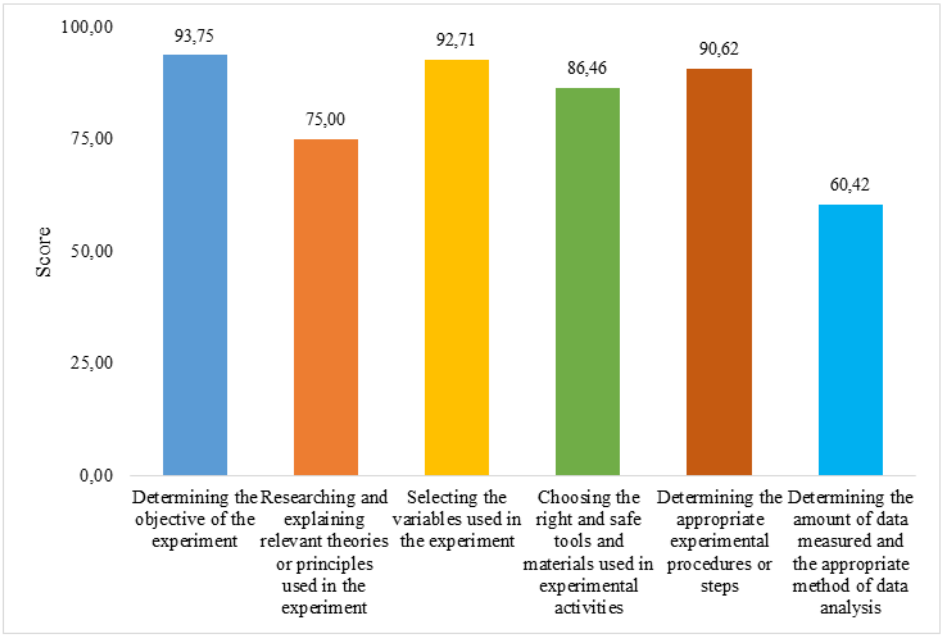

***Fig 4.** The ability to design experiments of pre-service science teacher*

Data from the research on the profile of the ability of pre-service science teacher in designing experiments using the digital calorimeter experiment kit obtained from these aspects can be seen in Figure 4.

Figure 4 shows the average score for each aspect observed regarding the ability of science teacher candidate students in designing experiments using the digital calorimeter experiment kit. Based on the results of the diagram, it is known that the highest average score on the aspect of determining the objective of the experiment is 93.75. Meanwhile, the lowest average score is 60.42 on the aspect of determining the amount of data measured and the appropriate method of data analysis. But overall, the average ability to design experiments using the digital calorimeter experiment kit for each student pre-service science teacher in the high category. This can be answered from previous research conducted by Noviyanti et al [7] namely with a digital calorimeter making temperature readings precise and thorough, so that the digital calorimeter experiment kit has an effect on aspects of the ability to design experiments on pre-service science teacher.

The average score on the aspect of determining the objective of the experiment obtained the highest score is 93.75 This illustrates that using the digital calorimeter experiment kit makes it easier for student science teacher candidate to determine the objectives of the practicum they want to do, as suggested by Khair et. [23]. Aspects of researching and explaining relevant theories or principles used in the experiment have an average score of 75.00. This is because the use of a digital calorimeter does not fully help prospective science teachers understand theory. Theories about temperature and heat that are relevant to experiments are only knowledge gained during lectures, not due to the use of digital calorimeters. The aspect of selecting the variables used in the experiment got a fairly high score from pre-service science teacher with an average of 92.71. Pre-service science teacher students understand the variables used for practicum using the digital calorimeter experiment kit such as temperature and mass.

The assessment of the next aspect, namely choosing the right and safe tools and materials to use in experimental activities, obtained an average score of 86.46. Pre-service science teacher students are still confused about the right material to use for practicum, especially using a digital calorimeter experiment kit, which is a modification of the usual conventional calorimeter. In the aspect of determining the correct experimental procedure or step get average score of 90.62. Pre-service science teacher students already know the right way or step to do a practicum using a digital calorimeter experiment kit. The last aspect in the profile of the ability to design experiments on pre-service science teacher gets the lowest average score of 60.41 on the aspect of determining the amount of data to be measured and the right data analysis method. Determining the amount of data and the process of analyzing it is a difficult thing for pre-service science teacher students. Overall, the designing experiment ability of pre-service science teacher obtains high criteria with an average score of 83.16.

CONCLUSION AND SUGGESTION

Based on the research, it can be concluded that the digital calorimeter experimental experiment kit developed was valid, had high accuracy and precision. With this kit, the average ability to design experiments for each pre-service science teacher student using a digital calorimeter experimental device has high criteria. The digital calorimeter experimental kit can train the ability to design experiments for prospective science teacher students as a whole. However, from the six aspects of assessing the ability to design experiments, digital calorimeters have not been able to train aspects of determining the amount of data measured and appropriate data analysis methods. This indicates the need for a modification of the digital calorimeter experimental kit by adding experimental data analysis guidelines.

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