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Research article

An Experimental Set for Studying the Changing State of Matter with Smart Learning Media Displayed Through the IoT System for Smart-Lab

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Abstract: The purposes of this research were to develop and find the quality of the experimental set for studying the changing state of matter with smart learning media displayed through the IoT system. The data collection tools used in this research were 1) the accuracy percentage, 2) a suitability assessment form 3) a learning achievement test in "changing state of matter" and 4) satisfaction questionnaires. The statistics for analyzing the collected data were mean ($\bar{X}$), percentage, standard deviation (S.D.), and t-test dependent. The result showed that the Digital Thermo Sensor had 98.5% accuracy in 30℃ -100℃ compared with the standard thermometer. The experimental set was used to determine the melting points of pure substances, Naphthalene, Biphenyl, and water's boiling point. The result found that the accuracy of melting point of Naphthalene and Biphenyl and the boiling point of water was 99.87, 99.75, and 99.99, respectively. The quality of the experimental set was also studied. Three experts evaluated the developed experiment set at a very good level. The experimental set successfully developed students' understanding of a change of state concept. About 80% of students scored above the prescribed criterion of 70% of the total score. After learning, the scores of the students were higher than those before learning at a confidence level of 0.01. 30 grade-10 students evaluated the satisfaction evaluation at an excellent level. Therefore, the experimental set developed suitable for student learning in the topic of change of state effectively.

Keywords: Thermal analysis; Changing state of matter; Smart lab

1. Introduction

Chemistry phenomena are explained in terms of atoms and molecules. It is critical for chemistry students to correctly understand and apply the concepts of the particulate nature of matter (PNM). Nevertheless, changing the state of matter is one of the most challenging topics due to the abstract nature of atoms and molecules, which requires students' ability to logically operate on information and symbols beyond personal experience and concrete cases in the real world [1,2]. Students have difficulty learning chemistry at the particulate level, like atoms and molecules that cannot be observed or experienced directly. In particular, many of these students have misconceptions about the structures and behaviors of submicroscopic particles due to the obstacle of building appropriate mental models [3]. To help students comprehend the change of state concepts, chemistry educators have developed various visual representations and are trying to bridge concrete phenomena and abstract concepts. An experimental set and learning media can visually represent particulate structures and processes that may help students build mental models or imaginations [4].

Science experiments often rely on sensors to collect data. Digital sensors allow people to gather a large quantity of raw data. Traditionally, these data are kept as original records to support scientific claims. In many cases, the data are used only by the experimenters themselves and may be forgotten or discarded after some time [5]. Technological advancements inspired our Internet of Things (IoT) research. The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction [6]. The Internet of Things is vital in the Fourth Industrial Revolution, or Industry 4.0 [7]. Likewise, they can also be used to transform school labs. Their applications have been demonstrated in engineering education [8] but seem underexplored in chemistry education. This study aimed to introduce a low-cost instrument developed by Arduino board with Digital Thermo Sensor illustrating smartphone results via the Blynk application through the Internet of Things. This research develops an experimental set based on Arduino and its technology to help students learn the change of state concepts and improve their chemistry comprehension.

2. Materials and Methods

2.1 NodeMCU V3 ESP8266

NodeMCU V3 ESP8266 is a microcontroller based on an ESP8266 Arduino board connected to a wifi signal. The main parts are nine digital input/output pins, one analog input pin, a USB connection, the power jack, and a reset button. The NodeMCU V3 ESP8266 can be programmed with the Arduino Software (IDE) and powered by an AC to DC adapter (or battery) to start [9]. NodeMCU V3 ESP8266 in this research is shown in Figure 1A.

2.2 DS18B20 temperature sensor

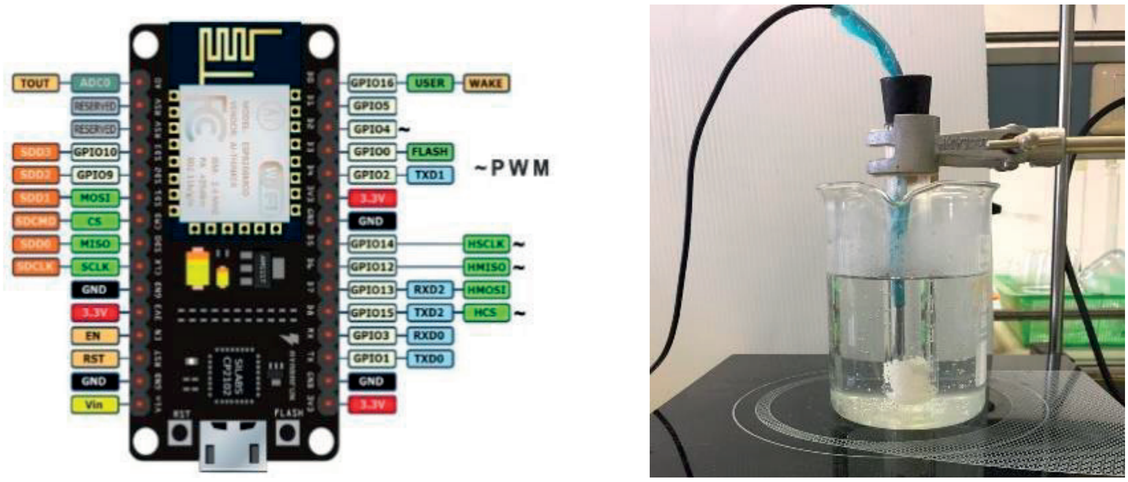
DS18B20 is a digital temperature sensor providing -55 °C to 125 °C measurable temperature ranges. It is one of the most popular temperature sensors on the market. It can be used as the temperature monitor tool in a smart farm, house, water station, etc. It is similar to DHT11/DHT22 temperature and humidity sensor. The DS18B20 temperature sensor has many formats, including IC and waterproof sensors. This study uses the NodeMCU ESP8266 board, reads data from a sensor, and displays results on a serial monitor [5]. Figure 1B shows the temperature sensor developed in this research.

2.3 Blynk application

Blynk is a free platform with iOS and Android applications to control Arduino. It is easy to program, use in real-time, and connect with Arduino, ESP8266, ESP32, NodeMCU, Rasberry pi [5].

2.4 The changing state of matter

Detecting a changing state of matter is not always straightforward as seeing a kettle boil, so special techniques have been developed. One technique is Thermal analysis, which takes advantage of the effect of the enthalpy change during a changing state of matter. This work studied the changing state of matter such as Naphthalene and Biphenyl. The change of state was examined by incubating Naphthalene and Biphenyl over its melting point. Then, a sample was allowed to cool, and its temperature was monitored. The heat evolved at a changing state of matter, and the cooling stopped until the transition was complete. The cooling curve along the isobar (1 atm). The transition temperature was obvious and was used to mark as freezing point (*liquid* → *solid*). The diagram of an experimental set and the experimental set are depicted in Figure 2 and Figure 3, respectively. The thermal analysis graph for changing state of matter with smart learning media displayed through the IoT system display with the Blynk application on a smart device is shown in Figure 4



(A) (B)

Figure 1. (A) diagram of NodeMCU V3 ESP8266, (B) temperature sensor used in this study

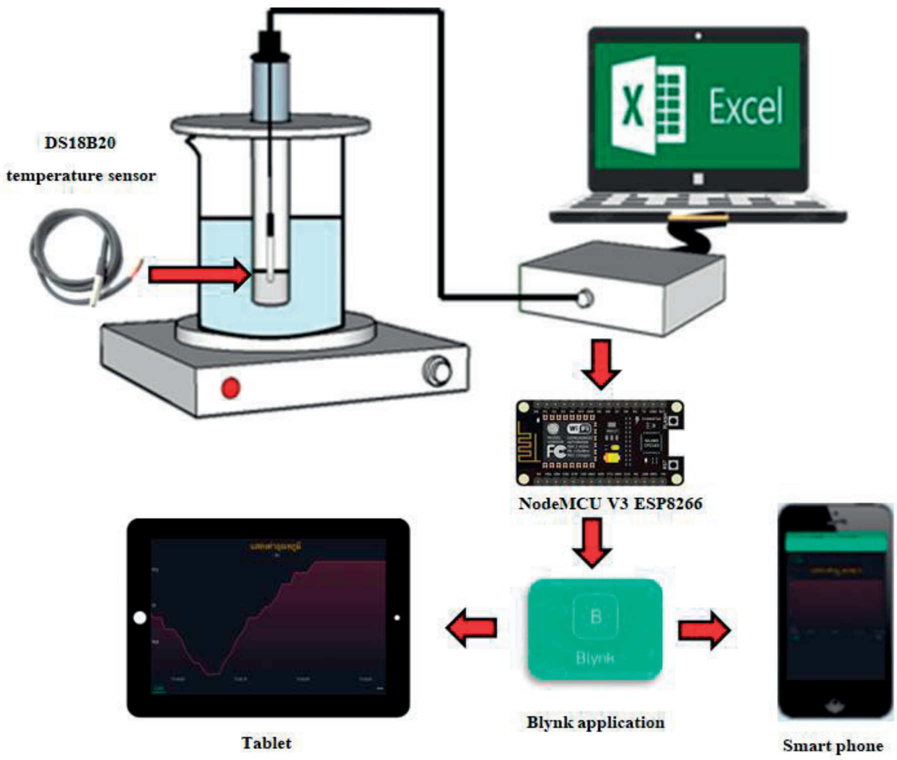


Figure 2. Diagram of an experimental set

Figure 3. An experimental set for studying the changing state of matter with smart learning media displayed through the IoT system for smart-lab

Figure 4. Thermal analysis graph for changing state of matter with smart learning media displayed through the IoT system displayed with the Blynk application on a smart device

2.5 The efficiency of an experimental set

To ensure that the experimental set is suitable, we invited the experts, who are university professors in chemistry, to measure the quality of the experimental set by using questionnaires. We modified the experimental set based on their suggestions. Finally, the experimental set was administered to students. Then, the learning achievement of students and satisfaction were also evaluated.

2.6 Research participant

The research participants included 30 science students in grade 10 in the second semester of the 2021 academic year. Three science educators checked the pre- and post-test in change of state concept and ensured content validity and understandability of questions. A T-test was used for paired comparison [10]. Statistical analysis was performed using the Statistical Package for Social Science.

3. Results and Discussion

The results of this research are presented in the following sections.

3.1 The accuracy of Digital Thermo Sensor (DTS) detection

The accuracy of DTS detection was studied. The increasing rate of water temperature was detected at room temperature (30°C) until boiling water (100°C). They measured the temperature of 200 mL water in a breaker at room temperature (30 °C) initial temperature and increased the temperature to 100 °C. The temperature was recorded every 10 seconds until it reached 100°C. The accuracy of DTS compared with a standard thermometer is shown in Figure 5. The accuracy percentage of DTS was calculated. It was defined as:

$$\% \text{ error} = \left|\frac{X_{mea}-X_i}{X_i}\right| \times 100$$

$$\% \text{ accuracy} = 100 - \% \text{ error}$$

where X_{mea} is the measured value by DTS and X_i is the true value of a standard thermometer. The result found that DTS had 98.5% accuracy in 30°C -100°C.

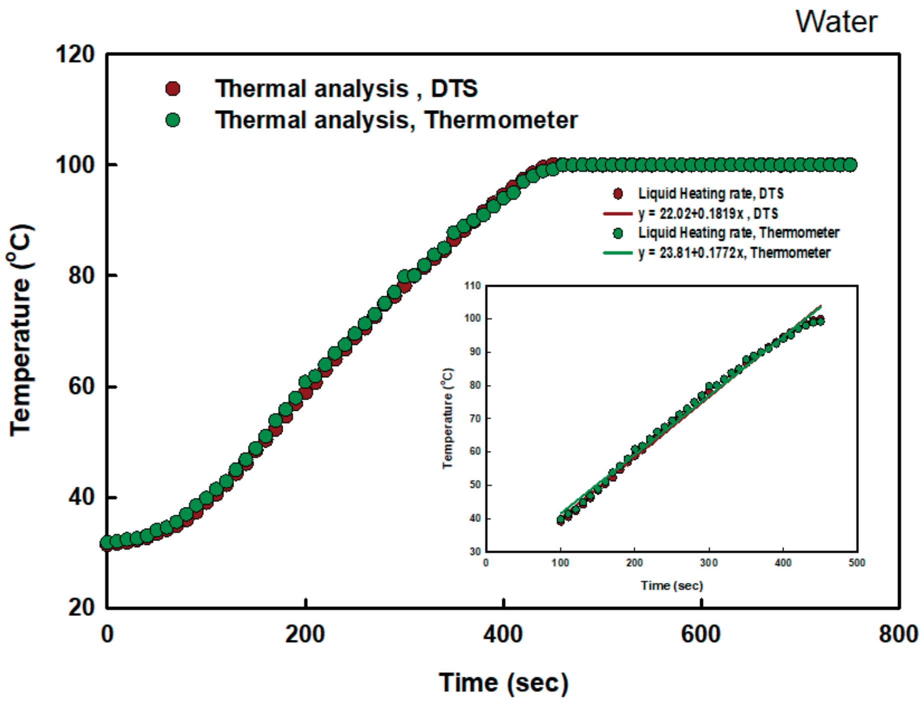


Figure 5. The accuracy of DTS compared with a standard thermometer for 200 mL water measured at 30°C initial temperature and 100°C

3.2 Determination of changing state of matter by using an experimental set

Changing states of matter such as Naphthalene, Biphenyl, and water were determined using an experimental set. The result revealed that the boiling point of water and melting point of Naphthalene and Biphenyl was 100.01, 80.05, and 69.03, respectively.

The thermal analysis behavior of pure Naphthalene is shown in Figure 6. A continuous decrease in temperature was observed when Naphthalene was cooled up to 1000 sec (liquid cooling period). In this stage, the liquid of Naphthalene releases heat into the environment. The temperature decreased as the entropy of the Naphthalene molecules decreased. Then, the temperature remained steady at 80°C. At this stage, the liquid was converted into a solid state. The freezing of Naphthalene began at 1000 sec (80°C), and the freezing was complete at 1300 sec (80 °C). Therefore, the local solidification time was 1000-1300 sec. After that, the temperature decreased due to the thermal exchange between Naphthalene in solid form and the surroundings (solid cooling period).

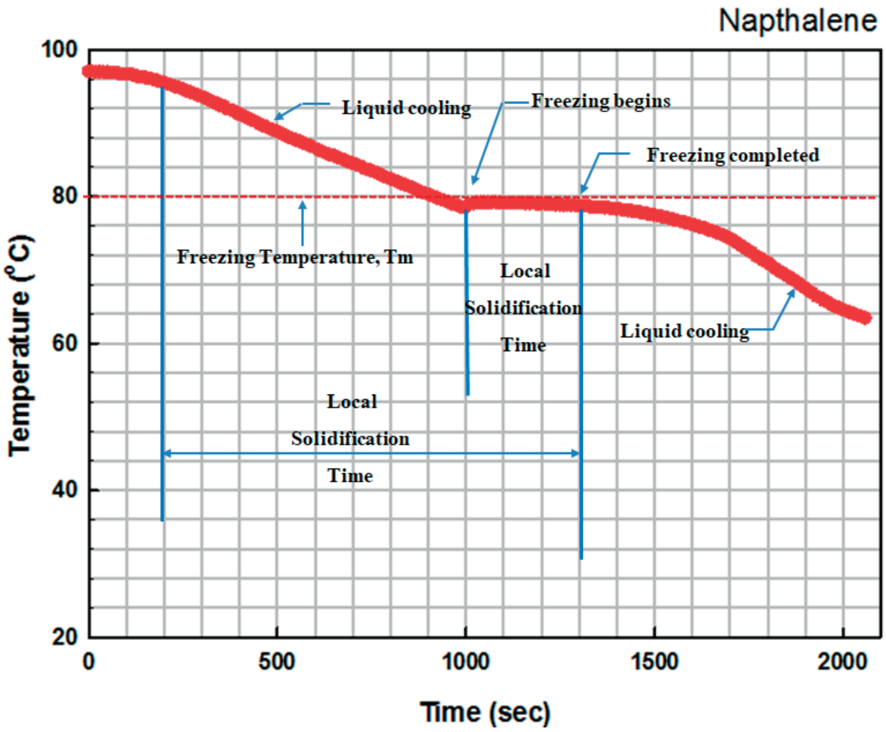


Figure 6. The cooling curve for pure Naphthalene

Table 1 shows the accuracy of the melting point and boiling point of substances by using an experimental set compared with the theory value. The result found 99.87%, 99.75%, and 99.99% accuracy for the experimental set.

Table 1. Comparison of melting and boiling point of substance by using an experimental set compared with theory value

Substance	Melting point from experimental set (°C)*	Boiling point from experimental set (°C)*	Melting point/boiling point from theory (°C)	Accuracy percentage (%)
Naphthalene	80.50 ± 0.06	-	80.60	99.87
Biphenyl	69.03 ± 0.04	-	69.20	99.75
Water	-	100.01 ± 0.01	100	99.99

The melting and boiling point of substances was measured using the experimental set at standard atmospheric pressure (1 atm)
The melting and boiling point of substances from theory was measured at standard atmospheric pressure (1 atm)
*Value are mean ± standard deviation (n=3)

3.3 The efficiency of an experimental set

The experimental set for studying the changing state of matter with smart learning media displayed through the IoT system for the smart lab was evaluated quality by using a suitability assessment form for 3 experts who are chemistry instructors in Thai Universities with more than ten years of experience in teaching and doing research in chemistry. The result revealed that the use of the experiment set for studying the changing state of matter with smart learning media displayed through the smart lab IoT system had a very good quality.

To examine the pre- and post-test in a change of state concept results of the students using an experimental set, a dependent Sample t-test (Paired Samples t-test) was conducted. The mean scores, standard deviations, and t-tests are presented in Table 2.

Table 2. Mean scores and standard deviations of the pre- and post-test in a change of state concept of 30 students

Pre-test					**Post-test**						
Number of students					Number of students						
N	n	n/N (%)	Mean	S.D.	N	n	n/N (%)	Mean	S.D.	t	Sig
30	0	0	3.57	1.591	30	23	77	7.33	1.446	-7.571	.000

N = The number of students who scored above the prescribed criterion of 70%. N = The number of participants.

The criterion of 70% of the full score 10 points, 7 points, was used for passing the test. It was shown that everyone had a pre-test score lower than 7 points. No one passed the pre-test in a change of state concept (n=0). The mean pre-test score of 30 research students was 3.57 (out of 10), which indicated that students had little knowledge and understanding of changing state of matter. After experiencing the new learning via an experimental set for studying the changing state of matter with smart learning media displayed through the IoT system for a smart lab, students achieved much higher scores, around two times higher. Besides, 23 out of 30 students (77%) passed the prescribed criterion, getting scores higher than 70%. The post-test scores were statistically significantly higher than the pre-test scores at the significant level of 0.01, as seen in Table 3. Therefore, an experimental set for studying the changing state of matter with smart learning media displayed through the IoT system for smart lab positively impacts students' understanding of the change of state topic. It can be used as an alternative teaching strategy in school.

3.4 The results from the satisfaction questionnaire

We evaluated students' satisfaction with the learning modules using the satisfaction questionnaire. The questionnaire was composed of 5 items with 5 levels of the Likert scale. The Likert scales were divided as 1 (very poor), 2 (poor), 3 (average), 4 (good), and 5 (excellent). Students were free to select a scale for an item. Students took around 5-10 minutes to fill out this document after finishing the class. The items of the satisfaction questionnaire were analyzed to find what students thought about our learning modules, as shown in Table 3.

Table 3. The satisfaction of students with the learning modules

Items	**$\bar{X}$**	**S.D.**	**Level**
1. Time	4.61	0.57	excellent
2. Atmosphere	4.45	0.59	good
3. Useful in learning	4.53	0.61	excellent
4. Benefit in learning	4.50	0.60	excellent
Total	4.52	0.59	excellent

The result exposed that students were satisfied with this experimental set at an excellent level because it shows accurate values and is easy to connect via wifi internet to the other components. In addition, most students preferred the demonstrations of the experimental set and agreed that the experimental set helped them to learn the change of state concept.

4. Conclusions

An experimental set for studying the changing state of matter with smart learning media displayed through the IoT system for the smart lab was developed in this study to work well in finding the changing state of Naphthalene, Biphenyl, and water. The IoT technology in the experimental set has provided intuitive user interfaces for remotely accessing science laboratories during the COVID-19 pandemic, resulting in improved student engagement and learning in online environments. Furthermore, the advantages of the experimental set are low cost, high accuracy, and ease of linking via wifi to free platforms with iOS and Android applications or other devices. After the instruction, students' learning and satisfaction were evaluated. The finding revealed that the instruction using a learning module, in particular, change of state, facilitated students' learning to a higher level. Most students agree that this learning module helps them to learn about the change of state concept. This study suggests that an experimental set for studying the changing state of matter with smart learning media displayed through the IoT system for smart-lab improves student learning and enjoyment of chemistry, especially the change of state topic

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