Making Counter Clockwise Analog Thermometer Under Project-based Learning Method

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Abstract. The basis of this project was to explore a different kind of thermometer using a semiconductor material with an analog counterclockwise reading. The semiconductor material we used was a negative temperature coefficient (NTC) thermistor, and it was implemented in a deflection-type DC bridge circuit. To complete this project, our group followed some series of steps from Project-based Learning (PBL) method, which are: (i) finding an actual issue as the main objective of the project, Challenging Problem or Question, (ii) enlisting a series of questions to attain the main objective, Sustained Inquiry, (iii) authenticating to ensure that the project applies on existing experimental methods, Authenticity, (iv) determining the extent of the students’ role in the project, Student Voice & Choice, (v) reflecting through all the processes that have passed, Reflection, (vi) gaining critique and revision in making improvements, Critique & Revision, and (vii) creating a product ready to be delivered to public, Public Product. By following a series of the PBL steps, our group successfully produced the desired product, which was Counterclockwise Analog Thermometer. Moreover, our group also gained more skills, such as critical thinking, problem solving, communication, collaboration, and self-management.

1. Introduction
Project-based Learning (PBL) is a method to teach students to acquire knowledge and skills by working for an extended period of time to investigate and respond to an authentic, engaging and complicated question, problem, or challenge [1]. Various studies indicated that PBL has a positive effect on students’ content knowledge and development of skills such as collaboration, critical thinking, and problem solving. It also benefits students by increasing their motivation and engagement. However, PBL is a bit challenging for lecturers to implement because it is hard to balance giving students independence and providing them support [2]. Therefore, lecturers need support to plan and perform PBL effectively, while students need assistance to set up and direct initial inquiry, to organize their time to complete the tasks, and to integrate technology into projects in meaningful ways [3].

The PBL method can be implemented anywhere, one of which is in learning physics. Commonly, people learn physics by attending lectures or reading reference books about physics. Although learning physics theoretically is important to have a deeper understanding of the material, PBL can complement it by allowing students to experience the process of applying their knowledge in a project. After the application of PBL method to a group of students in physics course at University of
Delaware, it was shown that all the students had a better understanding of the content knowledge of the course and their problem-solving skills also developed [4].

In this paper, we will report our project of making a counter-clockwise analog thermometer using the PBL method. Our team consists of three undergraduate students from the Department of Physics, Institut Teknologi Bandung, that have taken the Measurement and Data Processing Techniques course. We have followed some series of steps from the PBL method to complete this project. The thermometer used a thermistor as a sensor, applying the deflection-type DC bridge circuit, and displaying the analog measurement result using a volume unit (VU) meter.

2. Learning Method

The team of three students managed to accomplish this project of making a counterclockwise analog thermometer by applying the PBL method. There are several steps in the PBL method that should be done to complete our project. The first step is finding the actual issue as the main objective of the project. To attain the main objective, a series of questions need to be enlisted and authenticated to establish the most suitable experimental methods for the project. Following that, the students determined the extent of their role in the project and executed it. To make improvement, the students contemplated through all the processes that have passed and received critique or revision from the lecturers. Finally, a product ready to be delivered to the public was created [5].

We found that these steps are important in guiding us through to complete the project. The project was done in four months from January to April 2017 during taking the course.

3. Results and Discussion

3.1. Challenging Problem or Question

Nowadays, measurement instruments are growing rapidly. One of the system measurements of concern is thermometer used to measure temperature. This unit is very significant that it becomes one of the important seven basic units. Ever since it was discovered by Galileo Galilei in the early 1600s [6], the development of the temperature gauge has become an important concern in scientific and engineering applications.

Temperature measurement was one of the parts from various methods and measuring instruments, which is taught in the Measurement and Data Processing Techniques course at Department of Physics, Institut Teknologi Bandung. Throughout the course, we got challenged by the lecturers and tutors to complete a project of making a temperature measuring instruments using a sensor from a semiconductor material, i.e. a thermistor. The primary question that our team must solve was how to make a thermometer using a thermistor as its sensor? We found that this particular question was very appealing to our team.

3.2. Sustained inquiry

The driving question was asked, the profound inquiry was needed to answer the question. The first important point to investigate was what is thermistor? Thermistor is defined as an electrical component which could undergo resistance change as a result of temperature change [7]. In another word, this component can converse temperature unit to an electrical unit, namely resistance. This component is made from a semiconductor material, specifically a mixture of a sintered metal oxide such as chromium, cobalt, iron, manganese, and nickel. Additionally, thorough investigation to determine thermistor type was conducted. The thermistor is classified into two categories: (i) negative temperature coefficient (NTC) and (ii) positive temperature coefficient (PTC) [7]. This classification is based on the thermistor resistance change response caused by temperature. The NTC thermistor will experience a decrease in resistance due to rising temperature [8], while the PTC thermistor will experience the opposite [9]. Both types of thermistors have an exponential resistance-temperature characteristics curve (resistance as function of temperature). The difference is that the NTC thermistor has negative exponential while the PTC thermistor has positive exponential.
The next thing to investigate was how to apply the thermistor to the electrical circuit so that the temperature value represented by the resistance can be measured? It turned out that in order to measure the temperature, the resistance must be converted to voltage first [7]. Instead of answering the question at the beginning of the paragraph, a new question arises, which was how to convert resistance to voltage units? We found several choices of variable converter circuits. One of the most common and easy to apply is the deflection-type DC bridge circuit. This circuit was chosen because it matched our project measurement requirement. In bridge circuits, a common DC voltage source is used to determine unknown resistance while the deflection-type is used to perform regular (non-calibrated) measurements.

Schematically, the deflection-type DC bridge is shown in Figure 1. The main components of this circuit were three resistors, a thermistor, a voltage source and an output voltage measuring device. Another important thing to know was how does the deflection-type DC bridge circuit work? From the literature, we obtained that the working principles of the deflection-type DC bridge were as follows: the thermistor was given 'excitatory' in the form of temperature, the thermistor would convert the temperature to the resistance. Since it was part of the deflection-type DC bridge, the resistance that represented the temperature would produce output voltage. By placing a scaling device (voltage measuring instrument), the output voltage of the circuit could be determined. That is how this circuit worked.

![Figure 1. Deflection-type DC bridge circuit](image1)

![Figure 2. Moving coil meter](image2)

Once the previous problem was solved, the next problem that arose was how to read the voltage measurement? Moving-coil meter is an analog instrument that commonly used to measure voltage because of its sensitivity, accuracy and linear scale as given in Figure 2. The moving coil consists of a rectangular copper roll enclosing a soft iron core that is in the influence of the magnetic field of a permanent magnet. When there is a current flowing in the coil, there will be a Lorentz force in which the torque will be proportional to the current through the coil. Furthermore, one of the electronic devices that work with the concept of moving coil meter is VU meter [10]. The VU meter is usually not equipped with a proper scale and it was necessary to do the measurement and scaling process so that the VU meter was ready to be used to measure the value of various desired quantities such as temperature. Another interesting question was how to make a scale on the VU meter? Based on discussions with lecturers and tutors, they suggested determining the thermistor and the VU meter characteristics first. Hereafter, a series of experiments and data processing using Microsoft Office Excel 2016 will be done and explained in the later part of this paper.
3.3. Authenticity

As already discussed in the previous section, the process of making a VU meter scale began with determining the thermistor characteristic curves. The thermistor characteristic curve was a curve that described the relationship between the measured resistances of the thermistor to the temperature that 'stimulates' the thermistor [11]. In the group discussion, we designed the process to obtain the thermistor characteristic curve. Two glasses of water were prepared with the temperatures of 68 °C and 6 °C, respectively, as the boundary temperature. Then the thermistor was put into the water and connected the output into a multimeter to measure the resistance. As the temperature varies, we got the data of the respective resistance needed to make the characteristic curve of the thermistor. The data was processed using Microsoft Office Excel 2016.

In this project, we used the thermistor NTC 10K type. This thermistor has a negative coefficient, which means that the increase in temperature makes the decrease in resistance. Afterward, by following the experimental procedure, the tabulated data was obtained. The data represented a large measured resistance for various temperatures given to the thermistor. Then, the obtained data was processed. Data processing as in stage 3 was done using Microsoft Office Excel 2016 software. The thermistor characteristic curve was obtained by taking the exponential regression from the experiment data. In the graph, the y-axis represents resistance and the x-axis represents temperature. By rewriting $y$ as resistance $R$ in ohm and $x$ as temperature $T$ in degree Celsius, then the obtained thermistor characteristic curve equation was $R(T) = 30.516e^{-0.043T}$ as shown in Figure 3. The negative coefficient on the temperature part reaffirmed that the thermistor used is the NTC thermistor.

When the thermistor characteristic curve was obtained, the next experiment to be done was characterizing the VU meter. As before, through group discussions, we designed experimental procedures that must be done to achieve this goal. First, the VU meter was connected in series with a potentiometer as the variable resistance to a power supply. Then the resistance of the potentiometer was varied and the output voltage from the power supply was adjusted until the scale in the VU meter indicated the maximum value. From the set of resistance and voltage we measured, the maximum current of the VU meter could be obtained.

Next, the data processing could be done. The table stated the relation of various voltage values to resistance in the VU meter characterizer experiment. Similarly, as the thermistor characterization, to obtain the VU meter characteristic, the data was processed using Microsoft Office Excel 2016 software. The result of the VU meter data regression is given in Figure 4. Furthermore, the equation describing the characteristics of the VU meter was $V(R) = 0.5292R - 0.821$. The units used are volt for electrical voltage and kilo ohm for resistance.

After the thermistor and the VU meter are successfully characterized, the VU meter scaling could be done. Through group discussions, we also developed an experimental plan for this purpose. Our team built a deflection-type DC bridge circuit as depicted in Figure 5. We picked R1, R2, and R3 of 2

![Figure 3. Thermistor characteristic curve](image1)

![Figure 4. VU meter characteristic curve](image2)
kΩ, $R_m$ of 0.886 kΩ and $R_t$ of 182 kΩ. The circuit was connected to a 4.5-voltage power supply, a potentiometer as the substitute of the thermistor, and the VU meter to show the output reading. The potentiometer was set to a certain value and with the thermistor characteristic curve, we could determine the temperature value being measured. The scale in VU meter would move according to the resistance value so we could mark the point where the scale stopped with its temperature counterpart.

![Figure 5. The circuit used in the project](image)

![Figure 6. The scaled VU meter](image)

In accordance with the procedure, the value of potentiometer resistance ($R_u$) was adjusted to be equal to the resistance obtained in the thermistor characteristic curve. Further marking and scaling results are displayed in Figure 6. Starting from the characterization process of scaling the VU meter, there were various decisions which were taken with certain considerations. This would be explained in the next section.

3.4. Student Voice & Choice

While carrying out the project, our group as project actors made decisions based on our knowledge and information from the literature. For example, (i) during characterizing the thermistor and VU meter, our group designed the experimental steps to determine the characteristic of thermistor and VU meter; (ii) to determine the range of measurement, our team decided it by taking into account the purpose of the product in daily life. Temperature range from 20 to 64 °C are common to be found so a thermometer that can measure around those values will be more versatile; (iii) the value for each component used in the tool must be specified to meet the desired range of measurements, component availability and price of the components to be used, (iv) decision made on scaling the VU meter was fixed by considering the convenience to change the position and to replace the components used if a problem occurs. The scaling process was done on the breadboard instead of on the PCB. The ideas and decisions our team developed above made the project participants felt more involved in the process.

3.5. Reflection

During the period of working on the project by applying the PBL Standard Gold developed by Buck Institute of Technology, we learned a lot of things either as a team or individually, (i) PBL made learning felt fun, by interacting with lecturers and tutors or doing challenging physical activities, learning process felt more meaningful than just learning theories; (ii) Gold standard PBL practiced our problem-solving skills. We learned how to collect data to find the most effective and efficient solution of a problem; (iii) PBL successfully trained the project participants ability to work together in solving a problem.

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In addition to some of the points above, the PBL method also succeeded in training the participants some soft skills, which includes the ability to decide and consider something, to evaluate the work progress, and even in developing critical thinking. Besides, PBL also provides valuable experience to project participants on to use a breadboard, as well as soldering which is of course never studied in the classroom.

With the various reflections that have been mentioned above, our team hopes that these abilities can be useful for individual development of each project participants, as well as to develop further the product that we have designed in the future.

3.6. Critique and Revision
Throughout the project, our team received quite a lot of criticisms and advices from lecturers and tutors. These criticisms and suggestions were for the benefit of our current project, as well as its future development. Some of the critics proposed by the lecturers and tutors were: (i) to determine the thermistor characteristics on the first time, the lecturer and tutor inquire our team as to why only a few data have collected for the thermistor characteristic curves. Then lecturers and tutors gave critics and suggestions to use more data. Finally revised so that the data obtained would be more accurate, (ii) in addition, our team had been criticized for not defining the standard deviation correctly. The standard deviation should be found by comparing the product temperature measurement results with some common thermometers, not by using only a single thermometer. Then our group revised by not including this magnitude given the very small difference in the measurement result between a common thermometers with the other thermometers.

Apart the critique from the lecturers and tutors, our team also tried to criticize the products ourselves. The product was not equipped with a regulator to adjust the input voltage to keep it constant. As a result, since the input voltage coming from a battery that always has a voltage drop, then under certain conditions the thermometer will not work properly. This case would be our team's focus of concern in the future.

3.7. Public Products
Before the thermometer was assembled, our team needed to choose the resistance value and input voltage so that the thermometer could measure the temperature in the desired range from 20 to 64 °C. We decided the resistor values of 2 kΩ for R1, R2, and R3 respectively. Next, we connected the circuit to a DC power supply and tried different voltage values so that the desired temperature range was met. When all conditions were met, the circuit would be assembled on a PCB matrix, which was a board with a copper hole. The components were placed inside the PCB matrix holes and soldered. The final set of the project of this temperature gauge is shown in Figure 7.

The product assembly process was complete, the next thing to note from the assembled product was the measurement error at the various temperature measured. It was quite remarkable to know the specification of the developed thermometer. To identify the error from the thermometer, a series of measurements were made using the developed thermometer and an alcohol thermometer for reference. We defined the error as the absolute value of difference between the temperature measured in counterclockwise analog thermometer (CAT) and in the standardized alcohol thermometer. The thermometer measurement error data is given in Figure 8.

Following the success of assembling the counter clockwise analog thermometer and determining the measurement error at various temperatures, the project's main question has been successfully answered. By using Standard Gold PBL method, our team managed to successfully assemble a thermometer that could measure the temperature in the range of 20 - 64 °C.
A product called “counterclockwise analog thermometer” was successfully assembled with a fairly small error measurement, the next process that must be passed to apply the PBL Gold the Standard method was to present the product that has been produced in public. Our team prepared presentation slides and ensured the readiness of the developed thermometer for demonstrations in front of lecturers, tutors, and the fellow students. The chance to demonstrate the outcome of our hard work simply became our motivation to give it our best.

4. Conclusion
The counterclockwise analog thermometer (CAT) has been successfully made by following the seven steps from Standard Gold PBL method. The developed thermometer can be used to measure the temperature of an object in the measuring range of 20 to 64 °C. In addition, through using the PBL method to finish the project, we managed to improve our critical thinking, communication, collaboration, and self-management skills.

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