

Realizing a Deflection-type D.C. Bridge-based Thermometer under Project-based Learning Approach

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Abstract. In addition to conventional learning, project-based learning (PBL) helps students developing skills and becoming more engaged in learning as they have a chance to solve real life problems of actual projects. As the name suggests, PBL is a model that organizes learning around projects. In this paper, the project that will be completed by a group of three students is about making a water temperature measuring instrument using a simple deflection-type d.c. bridge circuit. The project was done in the period of January to April 2015 when they was taking the Measurement and Data Processing Techniques, which is a compulsory course in the fourth semester of undergraduate program in Department of Physics at Institut Teknologi Bandung. With the help of a lecturer and a tutor as facilitators, they have followed this series of steps: 1. Start with a driving question, a problem to be solved, 2. Exploring the driving question by participating in authentic, situated inquiry, 3. Engaging collaborative activities with lecturer and tutor to find solutions to the driving question, 4. Scaffolding with learning technologies that help students participating in activities normally beyond their ability, and 5. Creating a set of tangible products that address the driving question. With this series of steps, the students have become easier to understand the lectures that have been given and the instrument has been realized to measure the temperature of water properly. When realizing the project under the PBL method, we learned other materials beside that have been taught in the course. Due to this project, we have had more skills like designing and soldering as well as problem-solving, teamwork, critical thinking, synthesis and analysis.

1. Introduction

In the 1990s, new assessments of college students had shown that even the best students, those at the top of colleges, often had not acquired a deeper conceptual understanding of materials. The motivation of students to participate in courses and their engagement in learning was modest. To answer these problems, learning scientists were developing new types of curricula, leaning and teaching methods; one of them was project-based learning (PBL) [1, 2]. Project based learning (PBL) is an instructional methodology in which students learn core academic skills and creativity by solving real life problems of actual projects [3]. Students therefore involve in investigation to approach the solutions to the problems by enquiring questions, finding and analyzing information, grabbing ideas, discussing the findings and ideas, developing conclusions, and creating artefacts/products and presenting them [2, 4].



Studies have showed that PBL increased students' motivation and engagement, improved students' critical thinking and problem-solving skills, had a positive effect on the level of students' understanding of the subject content [2, 5].

PBL was applied to many fields. In engineering, PBL offer students a better understanding of their application of knowledge in practice. It was found that graduates of engineering program at Aalborg University were stronger in team skills, generally more adaptable, and higher ability to carry out a total project [6]. Undergraduate students that took chemical course at Israel Institute of Technology used information technology (IT) to constructing computerized molecular models. Results indicated that incorporating IT in PBL into freshman course can enhance students' understanding of chemical concepts, theories, and molecular structures [7]. PBL method that was applied in physics and statics courses at West Kentucky Community and Technical College (WKCTC) served as bridges to connect classroom learning and real-life application. Students are more confident with their understandings of the materials [8].

In this paper, we report an implementation of PBL in making a simple deflection-type d.c. bridge thermometer. The instrument has been realized by a small group of physics undergraduate students (the first three authors) that have taken the Measurement and Data Processing Techniques course at Institut Teknologi Bandung, Indonesia, the period of January to April 2015. It applied a deflection-type d.c. bridge equipped by a volume unit (VU) meter and thermistor and function properly to measure the temperature of water.

2. Learning Method

In completing a project of deflection-type dc bridge-based thermometer, three students (the first three authors) worked in a group using PBL, which is an overall approach to the design of learning environments. There are five key characteristics in the learning environments of PBL as given below [1].

1. Starting with a driving question, a problem to be solved.
2. Exploring the driving question by participating in authentic, situated inquiry. As exploring the driving question, students learn and apply important ideas in the discipline.
3. Engaging collaborative activities with lecturer and tutor to find solutions to the driving question.
4. Scaffolding with learning technologies that help students participating in activities normally beyond their ability.
5. Creating a set of tangible products that address the driving question.

The group of students was taking the Measurement and Data Processing Techniques, which is a compulsory course in the fourth semester of undergraduate program in Department of Physics at Institut Teknologi Bandung. The project was done in the period of January to April 2015.

3. Results and Discussion

3.1. Starting with a Driving Question, a Problem to be Solved

Nowadays, measurement of temperature becomes important in our daily life. One of them is the temperature measurement of water and it is therefore important to have an instrument to measure it. In the Measurement and Data Processing Techniques course, students had been taught various measurement methods and their instruments. During this course, the students had to apply the course's materials to make simple measurement instruments as their projects. To our group, the main driving question of the project is *how to make a simple water thermometer?* As suggested by our lecturer and tutor, we limited the range of temperature that could be measured to be between 0 to 50°C. For the purpose of calibration, the temperature of 0°C as the lowest range can be easily achieved by employing ice while the highest range of 50°C can be reached by heating water.

3.2. Exploring the Driving Question by Participating in Authentic, Situated Inquiry

From the main question, our group found that the main goal of the instrument is to convert temperature into a quantity that can be read. So, the next question is *how to convert temperature to a readable quantity?* Our lecturer and tutor suggest the use of thermistor, which is an electronic component to convert temperature into electrical quantity. From our class textbook [9], our group found that thermistor had a property in which its resistance depends on its surrounding temperature. In addition, there are two types of thermistor, i.e. positive temperature coefficient (PTC) and negative temperature coefficient (NTC). The PTC thermistor has resistance that increases with its surrounding temperature while the NTC thermistor does oppositely. We selected a 1 kilo ohm NTC thermistor, which was purchased from a local electronic component shop. The physical appearance of thermistor is demonstrated in Fig. 1 and its datasheet, which was obtained from googling in the internet, is given in Ref. [10].

Our group found that thermistor's resistance should be converted into electrical voltage. So, the next question is *how to convert electrical resistance into voltage?* From our lecturer and tutor's clue and further findings from the textbook, we got that a bridge circuit is commonly used as a variable conversion element that can detect small capacitance, resistance, inductance, or even impedance. There are two types of bridge circuit, i.e. d.c. and a.c. bridge circuits. By employing an a.c. bridge circuit, unknown impedance can be measured, while for measuring unknown resistance, a d.c. bridge circuit is applied. Moreover, there are two types of d.c. bridge circuit, i.e. null-type used for calibration purpose and deflection-type to compare an unknown resistance with the fixed one or to measure an unknown resistance. As we would measure the temperature of water, the deflection-type d.c. bridge circuit was chosen.

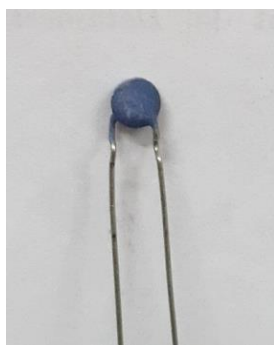


Figure 1. Typical appearance of thermistor.

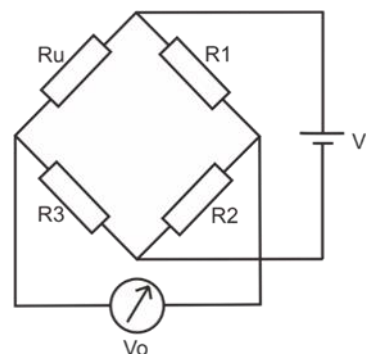


Figure 2. A deflection-type d.c. bridge circuit.

The schematic diagram of this circuit is shown in Fig. 2. The four arms of the circuit are formed by 4 resistors: the same resistances R_3 and R_2 , a fixed resistance R_1 , and an unknown resistance R_u represented by the thermistor. The d.c. excitation is provided by a battery with a voltage V_i . The d.c. output voltage V_o depends on the resistance R_u changing with its surrounding temperature. Therefore, the output voltage of the bridge circuit determines the surrounding temperature. Connecting a meter to the output voltage, we have a temperature meter.

From Ref. [10], we found that the d.c. output voltage V_o value is dependent on the d.c. excitation voltage V_i . Meanwhile, we found that the voltage of a commercial battery drops gradually due to its continuous usage. The next question is *how to maintain a constant value of battery voltage?* From Ref. [11], we got an electronic circuit that can maintain a constant voltage of the battery, regardless of the battery's voltage provided that the battery's voltage higher than the circuit's regulated voltage. The circuit is called as a voltage regulator with its schematic diagram shown in Fig. 3. We picked an AZ1117 regulator that can give a constant output voltage of 3.3 V [12].

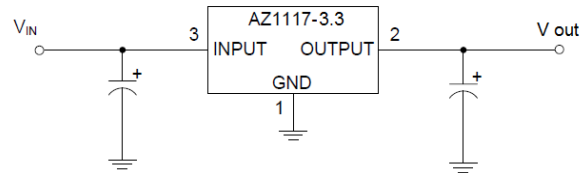


Figure 3. An AZ1117 regulator circuit [11]

Conversion from temperature to electrical voltage had been done. The next question is *how to read an electrical voltage?* From Ref. [9], we learnt that a moving-coil meter is commonly used as analogue voltage meter because of its sensitivity. The moving-coil meter consists of a rectangular wound rounding an iron core that is suspended under magnetic field of a permanent magnet. If we apply current through the wound, the coil will rotate with torque proportional to amount of current. From further discussion with our lecturer and tutor, we realized that a volume unit (VU) meter depicted in Fig. 4 can be used as an analogue moving-coil voltmeter.



Figure 4. A volume unit (VU) meter.

To determine values of temperature, we realized that scales were needed. Scales attached on the VU meter could not be used to determine temperature. The next question is *how to make proper scales for our instrument?* From our group discussion, we concluded that scale can be made from characterization of the device component with the help of Matlab program. We will discuss it in the further step.

3.3. Engaging Collaborative Activities with our Lecturer and Tutor to Find Solutions to the Driving Question

In the process of exploring the driving question, we often did discussion with our lecturer and tutor to find the solution of driving question. The discussion was necessary to ensure that the product is realized. For example, according to Ref. [9], we found that there are many methods including electrical components that can be used to measure temperature. Each of the methods has its own characteristics, difficulty and challenge. Suggestions of our lecturer and tutor helped us choosing the right components for our water temperature meter. The suggestions also helped us guiding the inquiry process to build the meter.

3.4. Scaffolding with Learning Technologies that Help Students Participating in Activities Normally beyond Their Ability

In this project, we used some learning technologies to help us making the water thermometer. As mentioned before, we used google search engine to search information from internet. For characterization purpose, we used Matlab program that will be discussed later. Later in the next step, we used tools like solder and printed circuit board (PCB) to build the device.

As mentioned before and from our tutor's suggestion, we needed to characterize the bridge circuit. The characterization means to find the relations between temperature and readable quantities represented by graphs and equations. There are three relations: i) temperature vs resistance of thermistor, ii) voltage vs current of VU meter, and iii) current vs pointer's deviation of VU meter. From another course we noticed that Matlab program can be used to plot data to be a function or graph. We inputted the data to the program and fitted them to the suitable function with the highest value of r^2 .

Although the thermistor datasheet is available [10], we characterized it again for the calibration purpose. Based on discussion with our lecturer and tutor, the thermistor was characterized with a simple method. The thermistor was connected first to an ohmmeter to read its resistance and it was then dipped into a bowl of water. An alcohol thermometer was used to read the temperature of water. To increase the temperature of water gradually, hot water was poured into the bowl of water. Then, ice is used to decrease the temperature gradually. We got data by reading resistance using the ohmmeter and temperature using the thermometer. With the help of Matlab program, we plotted the data to get the characteristic curve as shown in Fig. 5. From the curve, we got the relation between temperature and the resistance of thermistor as $R(T) = -6.658(\ln \Omega) + 4050 (K \ln \Omega)T$. The curve fitting is very good as implied by R^2 of 0.999.

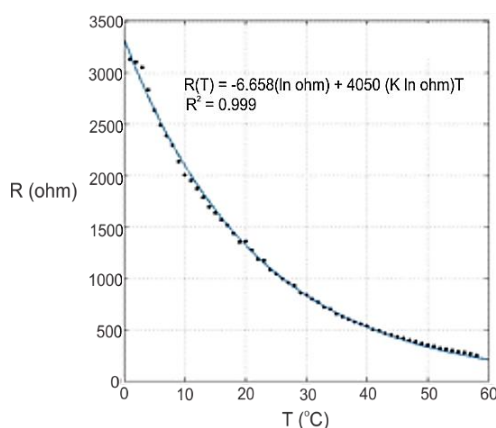


Figure 5. The thermistor characteristic curve.

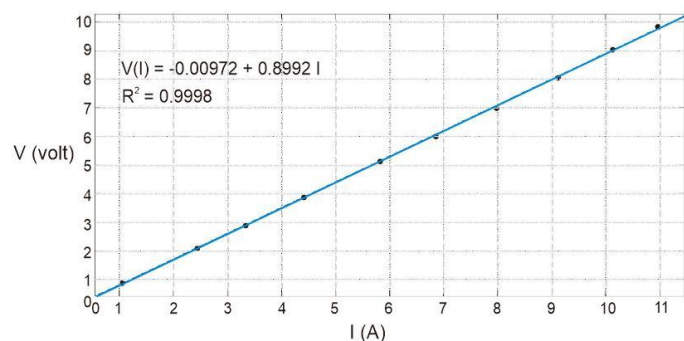


Figure 6. The VU meter characteristic curve.

An important characteristic of a VU meter is its internal resistance. Unfortunately, the datasheet of VU meter bought at local electronics component market was not available. After googling the internet, we also found no datasheet. The internal resistance of VU meter was measured by connecting it in parallel with a variable voltage source and a voltmeter and in series with an amperemeter. We got data by varying the voltage source and reading current using the amperemeter and voltage using the voltmeter. With the help of Matlab program, we plotted the data to get the characteristic curve as shown in Fig. 6. From the curve, we got the relation between current and voltage as $V(I) = -0.00972 + 0.8992I$, where V is in volts and I is in A. The curve fitting is very good as suggested by R^2 of 0.9998. The internal resistance of VU meter is therefore 899.2 ohms.

The last characterization is VU meter's pointer deviation. To find the relation between current and pointer deviation, we connected the VU meter in parallel with a variable voltage source and in series with an amperemeter. To measure the pointer deviation, we attached an arc ruler to the scales of VU meter. We got data by varying the voltage source and reading current using the amperemeter and angle using the arc ruler. With the help of Matlab program, we plotted the data to get the characteristic curve

as shown in Fig. 7. From the curve, we got the relation between current and pointer deviation as $I(\theta) = 62.703 + 137.93\theta$, where I is in mA and θ is in degree. The curve fitting is very good as indicated by R^2 of 0.9985.

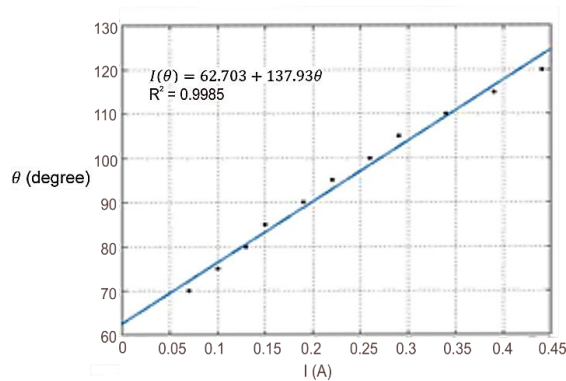


Figure 7. Pointer deviation curve of VU meter.

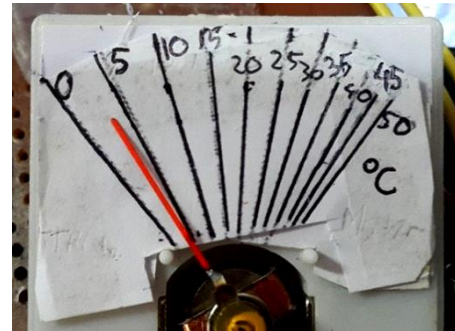


Figure 8. A thermometer display.

From the graphs, we found that the relation between temperature and the pointer deviation of VU meter is exponential. We used the data to create a thermometer display using the VU meter with a reading scale per 5°C as demonstrated in Fig. 8.

3.5. Creating a set of tangible products that address the driving question

Before the meter was built, we selected appropriate resistors for the d.c. bridge circuit, since the pointer deviation was very dependent on current applied to the coil. We connected the VU meter to the d.c. bridge circuit, and selected R_1 , R_2 , and R_3 values so that the pointer deviation can cover the area of meter when the thermistor (R_t) has maximum and minimum values, that is when water temperature is 50 and 0°C. We tested various values of the resistors on a breadboard, along with other components like capacitors, a regulator, and a VU meter. Through a trial and error attempts, we picked R_1 of 5 kΩ, R_2 of 81.7 Ω, and as R_3 of 81.8 Ω. The circuit was then built on a dot matrix PCB, which is a board with copper holes. The components were placed in the holes and soldered. The developed circuit is shown in Fig. 9.

The developed thermometer was compared to an alcohol thermometer in order to know its usefulness. We dipped the thermistor of the developed thermometer and the alcohol thermometer to hot water and read their values. The temperature of water was gradually decreased by adding ice. The complete comparison is shown Table 1. It indicates that the developed thermometer must have smaller scales so that a small change of the pointer can be read. Moreover, the reading differences between the thermometers were due to accumulation of errors of the three step conversion and parallax errors when reading the pointer deviation.

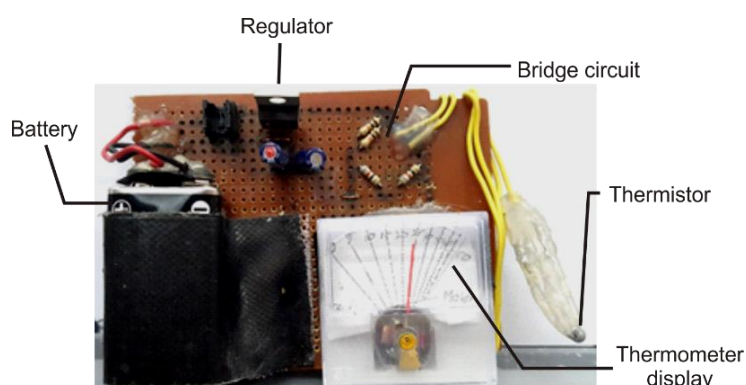


Figure 9. The developed thermometer.

Table 1. Comparison between the alcohol thermometer and developed thermometer.

Alcohol thermometer (°C)	Developed thermometer (°C)
0	2.5
5	5
10	7.5
15	10
20	15
25	20
30	25
35	30
40	35
45	40
50	47.5

4. Conclusions

Following the PBL steps, a thermometer with d.c. bridge circuit has been realized to measure the temperature of water in the range of 0 to 50°C. When realizing it under the PBL method, we learned other materials beside those have been taught in the course. Due to this project, we have had more skills like designing and soldering as well as problem-solving, teamwork, critical thinking, synthesis and analysis.

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