# Teaching Heat to High School Students

ECE 445 Design Document

Team #26

Kaihua Hu, Tianyu Feng, Yongxin Xie, Ziang Liu

Sponsor: Wee-Liat Ong

May 10, 2024

## Abstract

In the middle or high school stages, a versatile thermal teaching aid is still lacking. In this project, we have developed integrated thermal lab platform, which can demonstrate concepts of heat conduction, heat convection, and thermoelectricity. This lab platform is divided into two subsystems: the thermoelectric subsystem and the heat transfer subsystem. Tianyu Feng and I were mainly responsible for the design and manufacturing of the thermoelectric subsystem. We used microcontrollers to process signals from 64 small thermoelectric plates to control an LED array, displaying the temperature distribution on the thermoelectric plates. Notably, students can touch the thermoelectric plates and directly feel the changes in heat. Considering its impressive interactivity and visualization capabilities, this thermal lab platform will be an ideal candidate for future middle and high school teaching aids.

**Key words:** Teaching aid, Thermoelectricity, Heat transfer, Visualization capabilities

# Contents

## 1. Introduction

Various types of experimental teaching aids are widely used in middle and high school stages, with a significant positive impact on stimulating students' interest in learning and enhancing teaching quality. However, there is still a notable lack of versatile thermal teaching aids available on the market. Traditional thermodynamics teaching methods primarily rely on theoretical explanations, making it challenging for students to grasp concepts from some teaching aids effectively as in other subjects. Therefore, the development of a versatile thermal experimental teaching aid can effectively improve the teaching efficiency in the field of thermodynamics.

In recent years, many researchers and educators have been striving to improve thermodynamics teaching methods. For example, Umam et al. [3] designed an experimental device that converts heat energy into electrical energy as a teaching aid, which received favorable feedback from most students, although issues such as lack of intuitive conversion and insufficient enjoyment were noted. Wang et al. [4] introduced advanced mathematical methods in the university heat transfer course, elucidating the fundamental principles of heat conduction through the analytical solution of differential equations, but this method is not suitable for middle and high school classrooms.

In this project, we have developed an integrated thermal experiment platform that effectively demonstrates concepts of heat conduction, convection, and thermoelectricity to students. Unlike traditional thermodynamics teaching aids that simply present knowledge, we focus on enhancing interactivity between the lab platform and students, as well as improving learning efficiency by visualizing thermodynamic concepts. As shown in the block diagram below, the platform is mainly divided into two subsystems: the thermoelectric subsystem and the heat transfer subsystem. To ensure the safety and stability of this lab platform, making it more suitable for using in classroom, we have removed the radiation subsystem originally included in the design. The thermoelectric subsystem consists of a thermal plate array, a control module, and an LED array. When students touch the thermal plate array, the corresponding parts of the LED array light up. The heat transfer subsystem includes rods and heat pipes made of different metal materials, an LED display, thermal sensors, a control module, and a heater. When students touch or activate the heater to heat one end of the rod, LEDs will display temperature differences at different positions of the rod. It is worth noting that students can directly touch the thermal plates and heat-conducting rods to sense heat changes when using this thermal lab platform, enabling them to independently complete thermal experiments without encountering operational difficulties or safety hazards. Combining the intuitiveness and fun of visualizing heat changes through LEDs, this thermal lab platform holds great potential in the field of thermodynamics education.

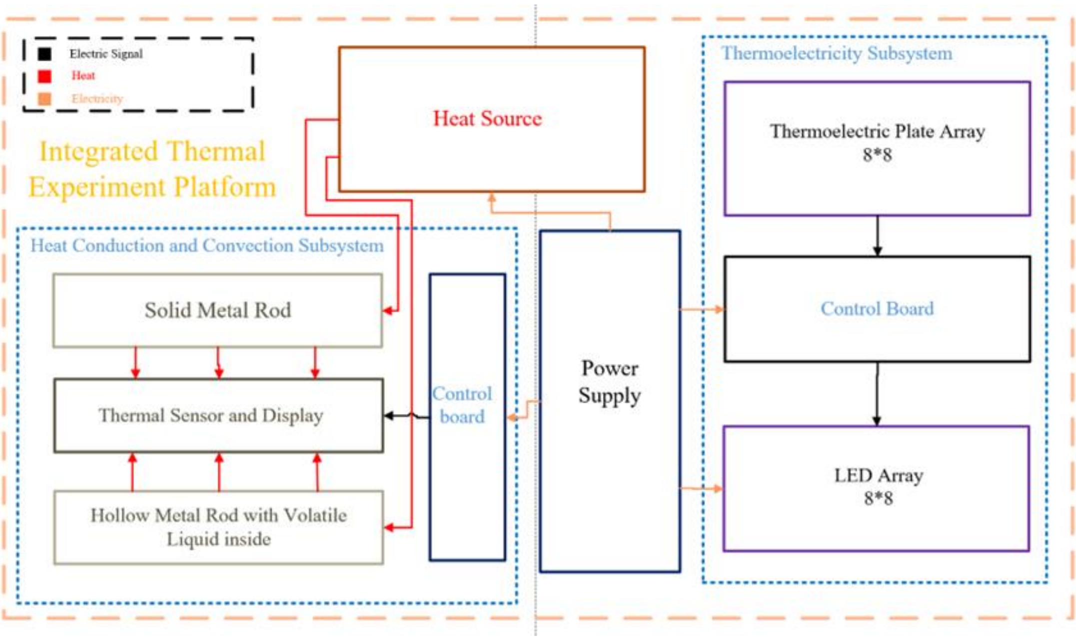


Figure 1.1 block diagram

# 2. Design

## 2.1. Design Procedure

### 2.1.1. Thermoelectricity subsystem

A thermoelectric plate is an element that converts thermal and electrical energy into each other. When it is applied with a suitable value of voltage, it will transfer the electricity to the movement of electronic carriers from up and down, and therefore generate a temperature difference. It is usually used for cooling. Also, when a temperature difference existing on its two side, it will produce a voltage similarly according to Seebeck Effect. So, in this subsystem, we want to visualize this phenomenon and demonstrate it to students in high school or below.

At first, we scheduled to make an easy product, which composed of one large thermoelectric plate and LEDs in shape of 'ZJUI'. In our original conception, when students put their hands or something else with sufficient temperature to produce a high temperature difference on the plate, the LEDs would be illuminated. And by this way we can teach students the principle of thermoelectric plate and Seebeck Effect. However, we found that such a product was actually very common and easy to make, only a thermoelectric plate powering and LEDs illuminating. Also, the similar demonstration device could be found in Taobao or other web commerce platforms. Therefore, we decided to change the design making it unique and more complex and more interesting.

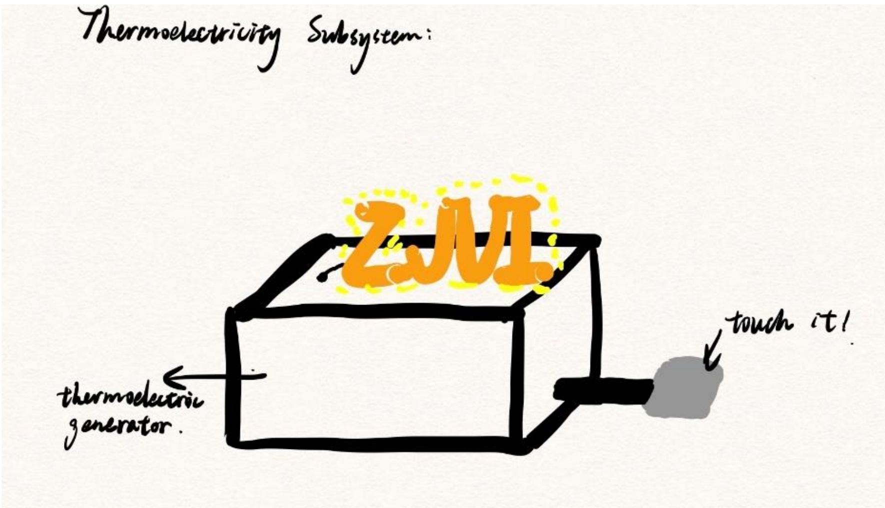


Figure 2.1 Initial Design of Thermoelectricity subsystem

Then we came up with a new design. We plan to change the large one thermoelectric plate into several smaller plate to make up a thermoelectric array. This array is able to control a LEDs array with same number and each plate controlling one corresponding LED respectively. In this new conception, when students put their hands or other heat sources (such as cups filled with hot water) on the thermoelectric plate array, the corresponding LED lights would be illuminating and display the shape of hands or the heat source placing on it. As shown in Figure 2.1, this system mainly consists of a large thermoelectric plate composed of 64 small thermoelectric plates, a control board, and an LED array. When students put their hands or other heat sources (such as cups filled with hot water) on the thermoelectric plate, the LED lights illuminate, displaying the shape of the hand or other heat source. We deem that this idea is better that the one above since this design could better visualize the concept of thermoelectricity and better demonstrate our engineering abilities in this product. Also, this design gives students more freedom to explore and enhances interaction.

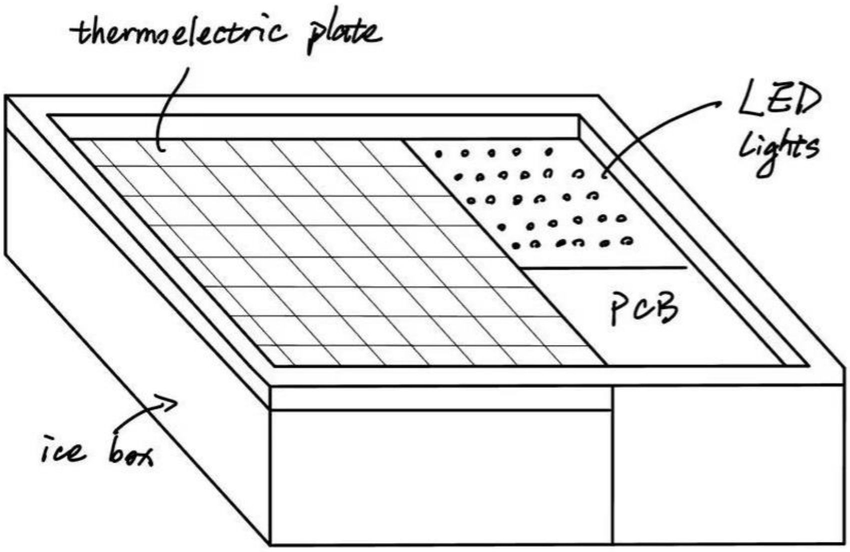


Figure 2.2 Improved Thermoelectricity subsystem

However, we also met some problems when working on this design. Initially, we intended to power the entire subsystem through the electrical energy generated by the thermoelectric plates. However, after testing thermoelectric plates of different types and sizes, we abandoned this idea and decided to add additional power sources. Considering that we need to use this lab platform in middle school classrooms, without using ice blocks, students touch the thermoelectric plate with their hands, resulting in a temperature difference of approximately 5-15 degree Celsius between the two sides of the thermoelectric plate. According to our test results, a 20mm*20mm thermoelectric plate can generate approximately 0.2-0.6v of voltage under these conditions, which is insufficient to power the LED array. To facilitate the daily use of the system, we detect the electrical signals generated by the thermoelectric plates through a microcontroller and use them to control the LED array, thus avoiding the need for ice blocks.

Initially, we intended to power the entire subsystem through the electrical energy generated by the thermoelectric plates. However, after testing thermoelectric plates of different types and sizes, we abandoned this idea and decided to add additional power sources. Considering that we need to use this lab platform in middle school classrooms, without using ice blocks, students touch the thermoelectric plate with their hands, resulting in a temperature difference of approximately 5-15 degree Celsius between the two sides of the thermoelectric plate. According to our test results, a 20mm*20mm thermoelectric plate can generate approximately 0.2-0.6v of voltage under these conditions, which is insufficient to power the LED array. To facilitate the daily use of the system, we detect the electrical signals generated by the thermoelectric plates through a microcontroller and use them to control the LED array, thus avoiding the need for ice blocks.

As for the designing in the microcontrollers, we also changed a lot and encountered several problems in the process. Since we had 64 small thermoelectric plates, each requiring a different interface, while common microprocessors typically have fewer than 20 input ports. Initially, we wanted to use multiplexer to integrate eight signals into one, so 64 ports would become 8 ports. And we originally want to control the switching of each circuit in multiplexers by using three ports in microcontrollers. Our original design in design documents is shown below.

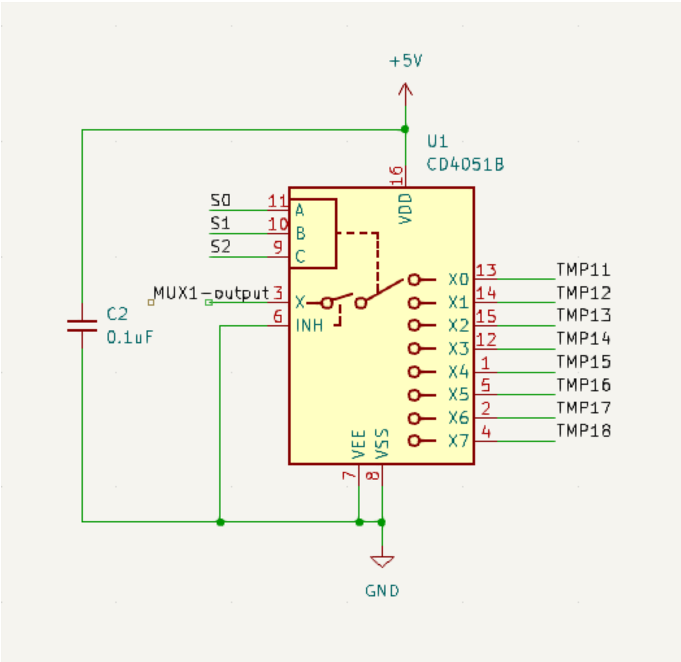


Figure 2.3 Originally Control Board Schematic 1

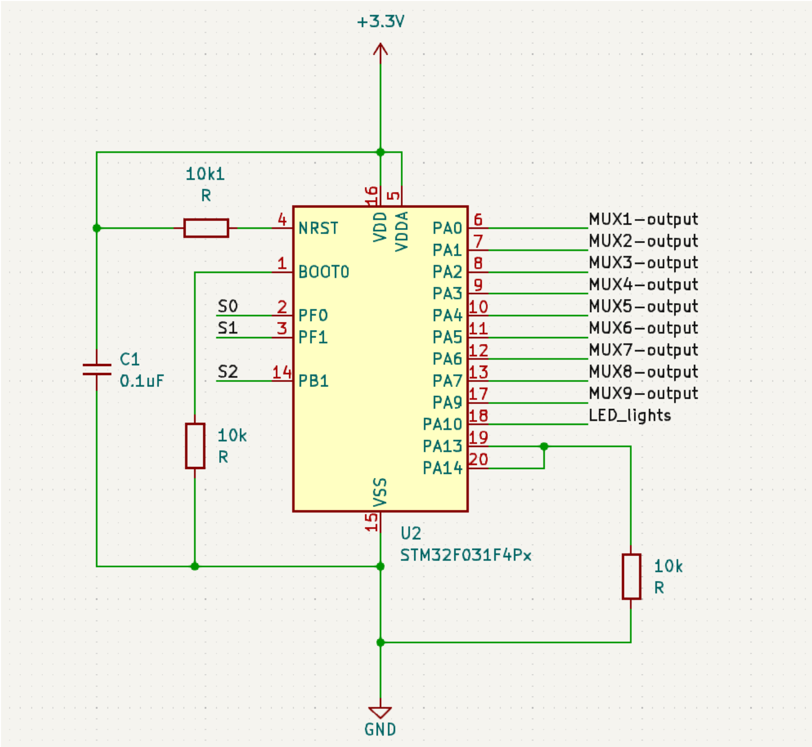

Figure 2.4 Originally Control Board

However, in actual testing, we found that the electrical signals from the thermoelectric plates are very instable, which even worsened after passing through the multiplexer. Besides, the multiplexer did not deliver the original voltage into the microcontroller. It only showed whether it is high or low. Therefore, we abandoned the use of a multiplexer to address the issue of insufficient interfaces. Finally, we used four microcontrollers, with one microcontroller serving as the host, connecting the LED array and 16 small thermoelectric plates. The other three microcontrollers process 16 pieces of data and send them to the host microcontroller.

For the LEDs array, this part also met the same problems as mentioned above. However, controlling LEDs do not require to read its voltage, it only requires about 3 signals controlling RGB. Besides, then in our survey, we found that the WS2812B LED lights have an integrated microcontroller with the LED lights, and each one contains Input, output, 5V and ground. In particular, every LED could control all connected LEDs by one single signal via the input and output port connections. This had greatly solved our problems. Besides, we want the LED Part to show different temperature with different color or different illuminance Initially, so that it is able to display the temperature distribution of hands when we put hands on the plates. But later we found that the signal is extremely unstable and too small than predicted, which may be caused by the smaller temperature difference. Therefore, we just set a minimum threshold. When the thermoelectric plates generate a higher voltage, the LED lights would be illuminating.

### 2.1.2. Heat conduction and convection subsystem

Heat conduction shows students that heat can be conducted through a medium and how the efficiency of heat conduction varies from medium to medium. Our device uses three temperature sensors, microcontroller real-time detection of their temperature, the data will be displayed on the screen. This is to facilitate the display of the specific each sensor temperature, but also easy to tune. At the same time according to the temperature difference and temperature conduction efficiency, the microcontroller controls the LED display different colors for illustration. When students put their hands or other heat sources (such as cups filled with hot water) on side of the conductor bar， temperature conducts from one section to the other and the thermal sensor picks up the temperature and displays it on the screen and the led will light up.

Initially, we started to use a memory metal flower to show the change in temperature. Memory metal flowers will open when they reach a specific temperature, however this is very much influenced by the temperature of the outside environment, which means that it is possible that the high temperature of the environment causes the flowers to open rather than the temperature of the hand coming from the conductor rod. Then we wanted to demonstrate thermal conductivity by connecting the led with a thermocouple. The thermocouple probe reaches a certain temperature the LED lights up. However, the body temperature is 36 to 37 degrees Celsius and the temperature difference between the body and the environment is 10 to 15 degrees Celsius. This is not a large temperature difference and does not visualize the temperature difference very well. So, we use a thermal sensor plus a screen that can display the temperature, which will be more intuitive.

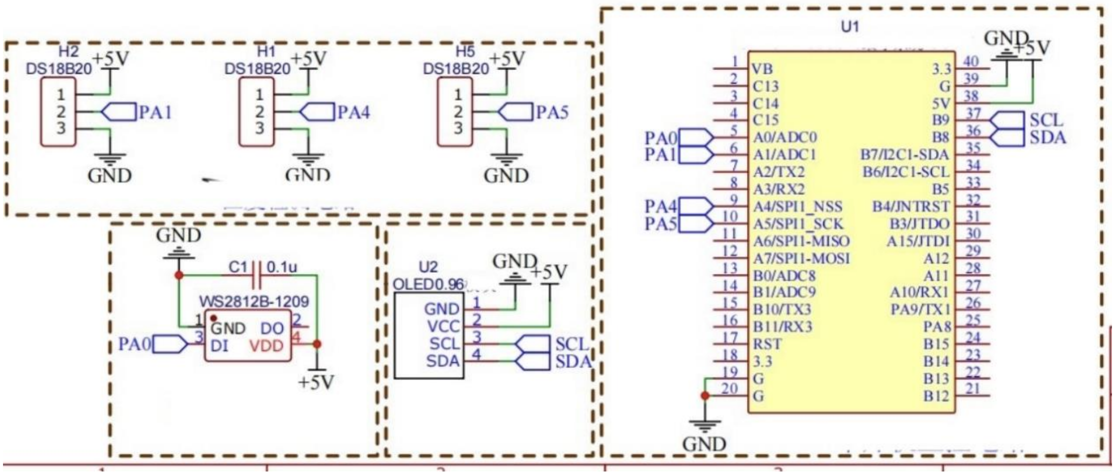


Figure 2.5 PCB Schematic

## 2.2. Design Detail

### 2.2.1. Thermoelectricity subsystem

This subsystem of our teaching program will showcase conversion of thermal energy into electrical energy through thermoelectric materials. When students put their hands or other heat source such as a cup filled with hot water on the thermoelectric plates, the LEDs be lighted displaying a shape of hands and showing the temperature of heat source by different colors.

Inspired by the ability of thermoelectric material to transfer electrical and thermal energy to each other, we decided to utilize the commercially available low power refrigeration plate in the market to make a heat-to-electricity device to transfer heat and then light LED. This subsystem is an 8*8 array of the thermoelectric plates which is corresponding to a LED and can control its light using a microcontroller.

The commercially available thermoelectric plate is usually designed for refrigerating, but it could also produce a voltage with temperature according to Seebeck Effect. After testing the voltages generated by different sizes of thermoelectric plates at different temperature differences, we choose 20mm*20mm*4.1mm thermoelectric plate and combine them into an 8*8 arrays. This choice was made to select the right size in order to generate enough voltages for the microcontroller and also to control the size of the plate in order to increase the number of thermoelectric plates per unit area with the aim of increasing the resolution ratio, thereby obtaining better performance. For our chosen thermoelectric plate, the detailed parameter is shown below.

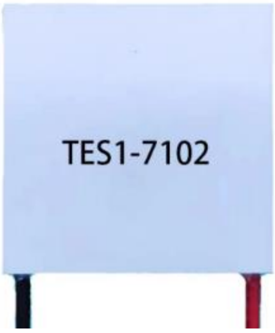


Figure 2.6 Thermoelectric Plate

Table 1. Voltage Generated by Thermoelectric Plate

| Temperature difference(℃) | Open circuit voltage(V) |
|---|---|
| 0 | 0 |
| 10 | 0.43 |
| 20 | 0.9 |
| 30 | 1.32 |
| 40 | 1.76 |
| 50 | 2.21 |
| 60 | 2.67 |
| 70 | 3.15 |
| 100 | 4.42 |

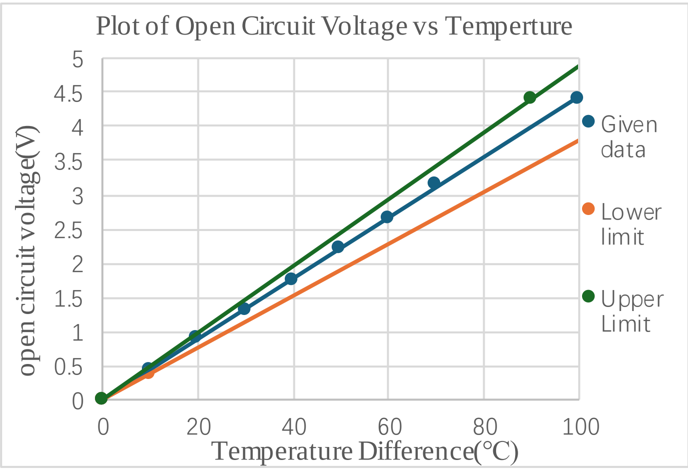


Figure 2.7 plots of specification and limited errors

According to Seebeck Effect, two different electrical conductors or semiconductors can cause a voltage difference between the two substances due to temperature differences. This is since the carrier energy is higher from at the hot end than at the cold end. The equation for the potential difference of Seebeck Effect is:

$$V = \int_{T_C}^{T_H} \left(S_B(T) - S_A(T)\right) dT \qquad Eq.1$$

Where, S_A and S_B are Seebeck coefficient for both materials and T_C and T_H represent their temperature at the end. If S_A and S_B do not vary with temperature or temperature changes in a small range, the above equation can be expressed as follows:

$$V = k(T_2 - T_1) \qquad Eq.2$$

Where k is a constant represents the difference of two Seebeck coefficient. This shows that the voltage is generated linearly with the temperature difference. So ideally, we assume that the Seebeck coefficient difference of two components of thermoelectric plate is k. In the part 2.1.1 we have claimed that the temperature difference of hands in normal condition is 20℃-35℃ and the ice bag could make the bottom of thermoelectric plate to 2℃-8℃, creating a temperature difference about 33℃-12℃. This difference may be growing higher to 90℃ when we put a cup of hot water on these plate array.

So, from the data provided on the product specification, when the temperature difference is 10℃, the open circuit voltage is about 0.43V and is about 3.99V for 90℃ difference. So that as shown in figure 2.1 for low temperature it can tolerate an error of over 13% and for high temperature the error could still be about 10%. These errors are all acceptable for the thermoelectric plates. Considering we still set a 20% input error for the protection of our microcontroller, we can draw a conclusion that this part in our design is able to work successfully both in normal conditions and for heat source lower than boiling water.

For control board, this part is the PCB board that consists of several microcontrollers and the wirings. As it shown in Figure 2.6, this PCB board is quite large and contain 64 blocks which connecting to the corresponding ADC read input in microcontrollers. This module is a PCB board that consists of several microcontrollers, which receive 64 signals from thermoelectric array module and output one signal to control LED array module. Also, it could program on system through ISP interface to better control the multiplexers and circuits. Besides, since it was our first time designing a PCB board and we were not too familiar with the circuitry, we modeled the PCB after the Arduino board that we used for testing and improved it.

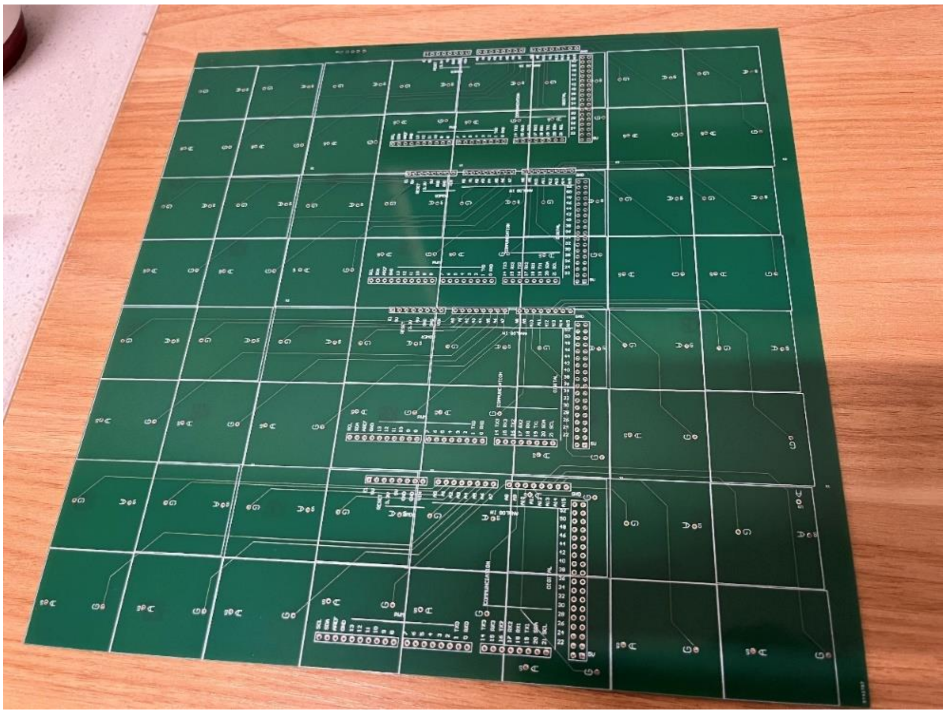

Figure 2.8 PCB Control Board

For LED array, it consists of 8*8 LEDs corresponding to the thermoelectricity plate array. It can receive the signals and data processed by microcontroller and light different colors according to the temperature difference sensed by thermoelectric plate. Therefore, we choose WS2812B which is an intelligent control LED light source. This LED light was chosen for its three primary colors could achieve 256 brightness display, scan frequency not less than 400Hz/s and receive speed at 800kbps. It also integrated LED, control circuit and RGB chips, allowing the circuit to be simpler and easier to assemble.

To control the LEDs, we use the FastLED library in Arduino to control these 64 LED lights. It could easily control the LED light for their colors of RGB and brightness. However, since every LED light is connected in series and the fastLED library require a delay of 10mm to better stable the signals, the delay in response time is longer the further back in sequence the LED bead is.

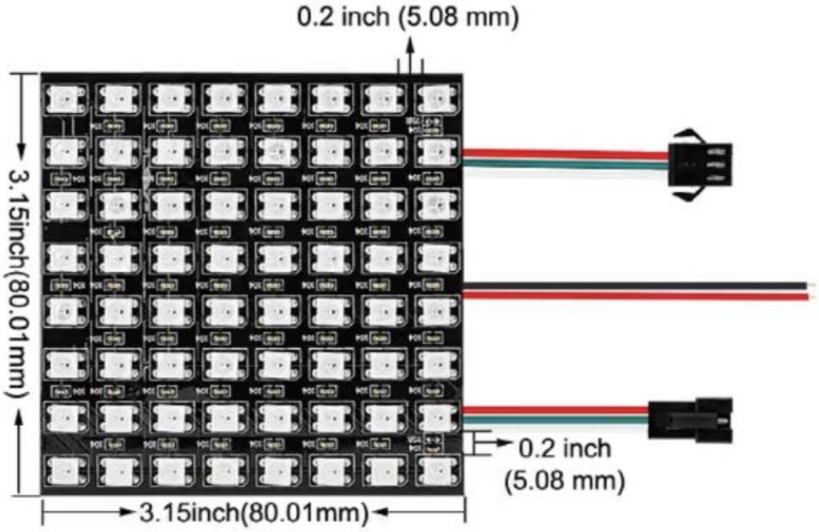


Figure 2.9 LED Array

**2.2.2. Thermal Conduction and Convection Subsystem**

This subsystem will demonstrate that heat transfers and has different effects depending on the material. When the student heats the conductor bar with their hand or other heat source, the display will show the temperature at three different locations on the conductor bar and the LEDs will change color at different temperature differences.

We thought about the different uses of various thermal conductive materials and how easy it would be to show the effect of heat transfer using different materials for the conductor bars. We used thermal sensors to measure the temperature and used lights and display data to show this.

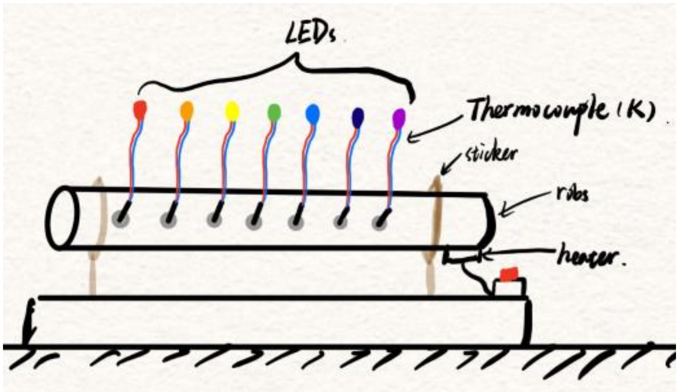


Figure 2.10 Thermal Conduction and Convection Subsystem

# 3. Design Verification

## 3.1. Thermoelectricity subsystem

### 3.1.1. Thermoelectric plate array

In our original design we planned to use ice bags. We thought that the ice bag would increase the temperature difference and thus increase the voltage generated by the thermoelectric plate, and also help to stabilize the current, so that we could get stable data and thus display stable colors. However, we found that the ADC voltage reading function was easily able to detect even small temperature differences. We found that at room temperature, the temperature of the palm of the hand is about 30°C and the temperature of the fingers is about 25°C. However, the body temperature of the hand can vary greatly depending on the ambient temperature and physical condition. However, even without the ice packs, the generated voltage is still at least about 0.1V, which is sufficient for the subsystem. Furthermore, even with the ice packs to stabilize the voltage, since each thermoelectric plate produces slightly different voltages at the same temperature, it is very difficult to use the LEDs to display the colors. Not only that, but the data obtained from the graph below shows that the signal is still present after the hand leaves the thermoelectric plate and is very unstable, so we gave up on the idea of displaying different LED colors for different temperatures. In addition, the extra voltage generated by the system was difficult to power. Combining these three factors, we abandoned the idea of using ice bags. We also made a test, and the results were the same as the calculations. The results are shown below.

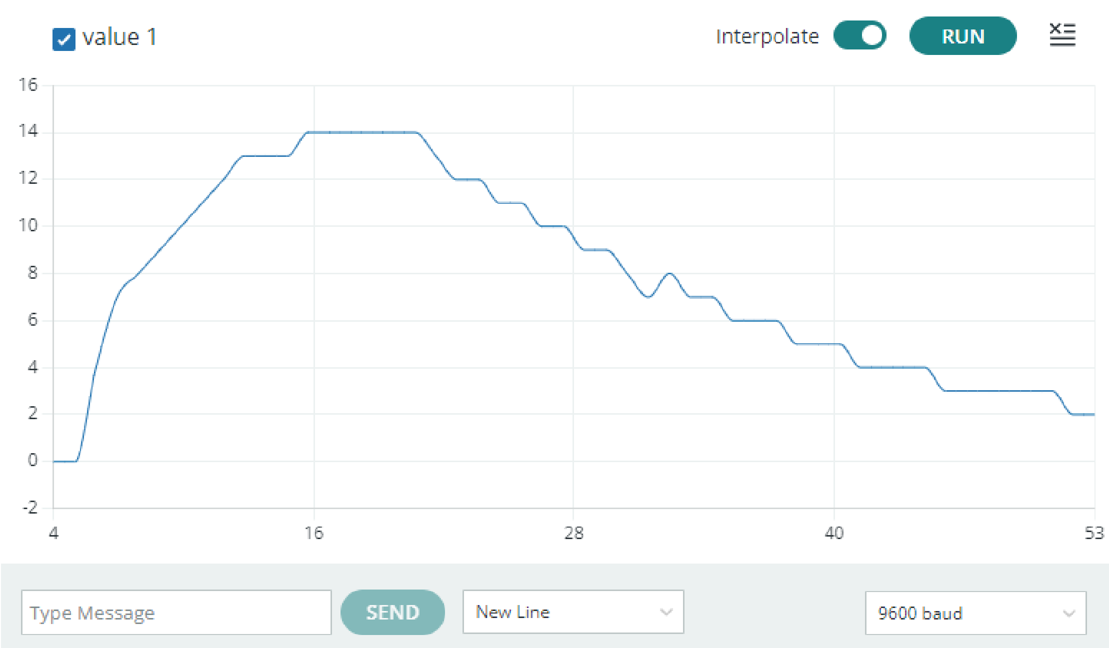


Figure 3.1 Tested Signal in Arduino with x-axis is the time and y-axis shows voltage*5/1024

Therefore, unlike in our Requirement and Verification Table in design document, we discarded the idea of using ice packs and the desired temperature difference has been reduced which is no longer between 0.4V-3V as written in requirement. This requirement changes into output 0.1V open-circuit voltage and this is verified successfully.

For other requirements, the 8*8 boards are connected to the PCB control plate, so we only need a voltmeter to check the voltage at the soldering points when there is a temperature difference on each board separately. The result shows that our array functions very well. As for the delay, it is shown in figure 3.1 that when the hand leaves the thermoelectric plate the temperature difference does not disappear immediately. Instead, it will stay for a really long time, at least 10 seconds. This is not meeting with the requirements for 3 seconds, which is the third requirement. Therefore, we came up with an algorithm to deal with this problem. Considering the data shown in figure 3.1, we set the minimum triggering voltage as 1/1024, which means that once it senses a temperature difference, it would immediately lighten. Even though we found that the response time could still be around one second. This is due to the properties of thermoelectric plate and the low speed of heat transfer, which is hard to increase. Then, the microcontroller first records its highest voltage, and when a continuous decline far lower than the highest value for three seconds, the signal for the thermoelectric would be treated as zero. Also, since the minimum voltage to illuminate LEDs is quite low, so it would work at an environmental temperature of at least 30 degrees Celsius, satisfying the last requirement.

### 3.1.2. Control Board

This module is a PCB board that consists of several multiplexers and a microcontroller, which receive 64 signals from thermoelectric array module and output one signal to control LED array module. For the first requirement, the original design require 8 multiplexers to integrate every 8 signals into one single signal, however, in our new design, we are not using multiplexer. Instead, we will add the number of microcontrollers to solve this problem. Therefore, we modified the first requirement in this module into the statement that microcontrollers could each receives 16 signals and interacts with each other. To verify this , we connect our thermoelectric plate array with the control board as shown in figure 1.1. And then we test whether each microcontroller could output a signal containing 16 elements of ‘0’ and ‘1’, representing the status of 16 thermoelectric plates. And we connect other three microcontrollers to the main one to check whether it could integrate four signals into one signal to output 64 elements of ‘0’ and ‘1’. In our process of verifying, we found that most elements displaying ‘0’ and ‘1’ successfully, but there are some situations where the connection in microcontroller with PCB sometimes has problem, which lead to a constant ‘1’ in signal, especially when the device stay open for a long time. We then take a long time to make a carefully welding work to improve the connection and alleviate this problem.

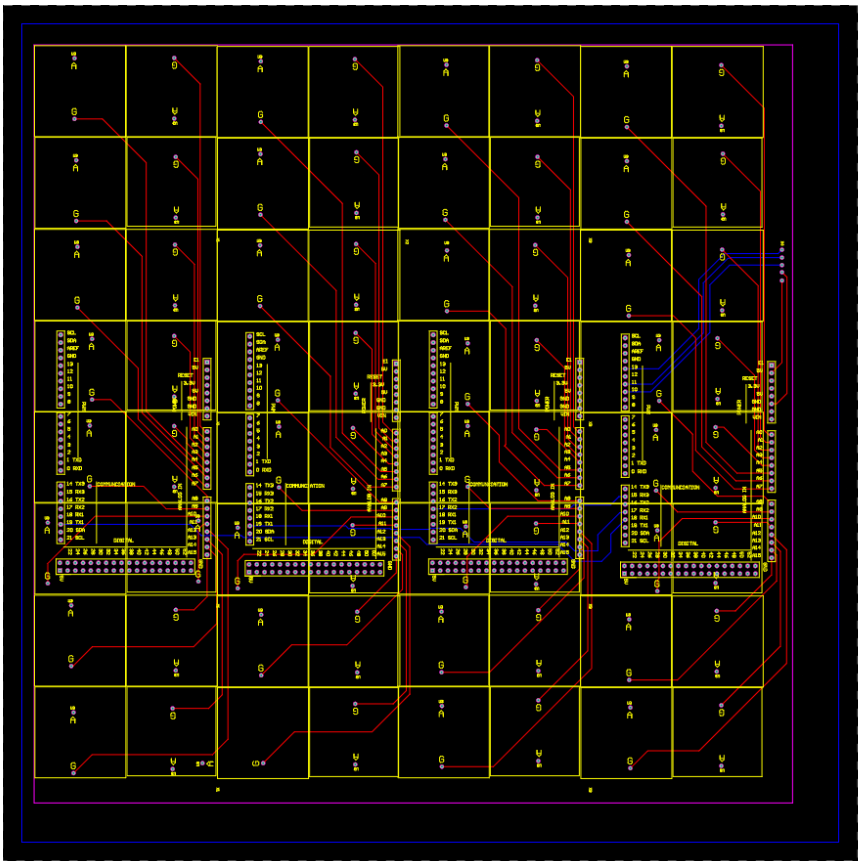

Figure 3.2 PCB layout

Besides, as for the second and third requirements, we choose the program controlling LEDs to verify these two at the same time. This part is almost purely code, and the verification went perfectly and successfully.

### 3.1.3. LED array

In the process of verification, this module works smoothly and has almost no problem. The verification process is similar to the LED programming test mentioned above. To verify the requirements, we write a code with the help of library FastLED. It shows that Each LED light could work smoothly and individually and also display the desired colors controlled by microcontrollers. For its display performance, its luminance is sufficient and even when we decrease the LED is controlled in 1/16 of maximum brightness, the luminance is still enough and could be clearly visible out of 3 meters.

### 3.1.4. Results

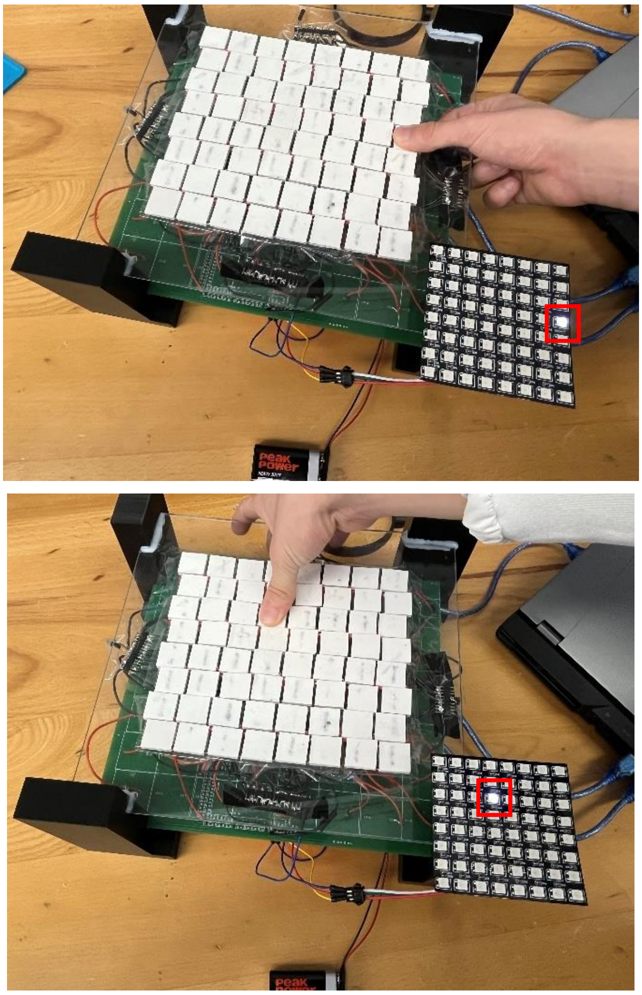

Figure 3.3 LED Verification with One Thermoelectric Plate Heated

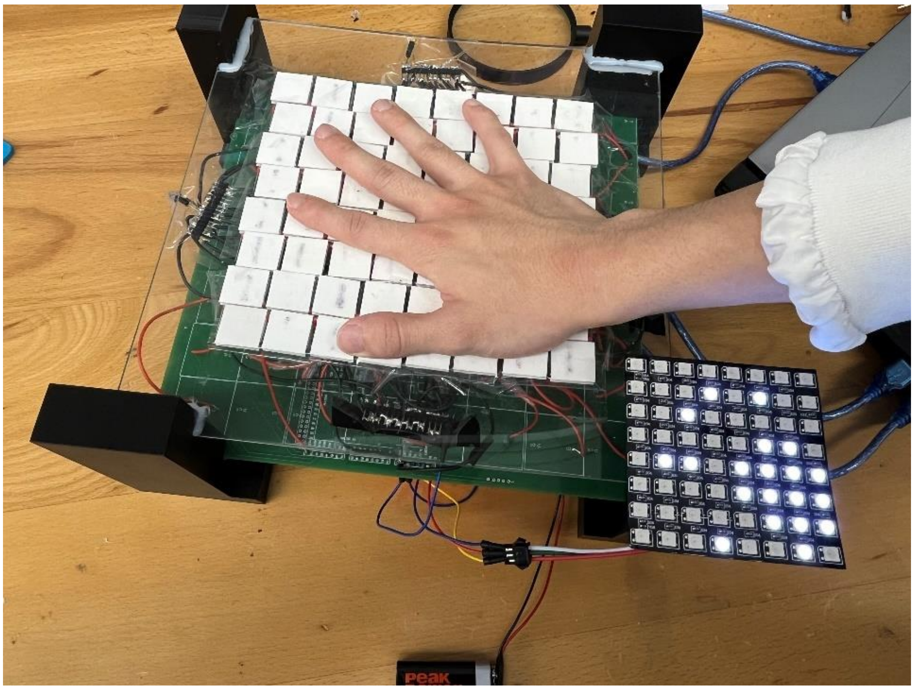

Figure 3.4 LED Verification with Hands Put on

This part is final results of our device. We connect the two arrays with the microcontroller made a final verification. Every thermoelectric plate could work individually and when we put our hands on it, the LED on the corresponding position would then be turned on. In figure 3.3 shows two results in random positions. The results are stable, and the response time and delay are as expected. It is shown that every individual part work successfully with one signal input. However, when we tried to put our hands on it, as shown in figure 3.4, we found that it is not very clearly displaying the shape of hands, only showing a vague shape of the palm and fingers. This is mainly because the 8*8 resolution ratio is not sufficient to clearly show the shape of hands.

## 3.2. Heat conduction and convection subsystem

The rate of heat conduction in solids, also known as thermal conductivity, is the amount of heat transferred per unit time, per unit thickness of solid material, per unit temperature difference. The formula is as follows: $k = Q/(A * \Delta T * t)$ where: k is the thermal conductivity in W/(m-K); Q is the amount of heat transferred in J; A is the area of heat transfer in $m^2$; $\Delta T$ is the temperature difference in K; and t is the time. Suppose we have a metal rod of length L and cross-sectional area A. A power P is applied at one end and a temperature change needs to be detected at the other end. The heat transfer problem can be approximated as a linear heat transfer problem by considering the bar as a rectangular column. First, calculate the heat Q from the power and time: $Q = P * t$. Then, calculate the heat conduction velocity k from the heat conduction equation: $k = Q / (A * \Delta T * L)$ where $\Delta T$ is the temperature difference between the two ends of the bar. Next, based on the heat transfer rate k, we can estimate the time it takes for the other end to sense the temperature change: $t' = L / (k * \Delta T)$ Substituting the known data into the formula, we can calculate the time t' it takes for the other end of the metal rod to sense the temperature change.

### 3.2.1. Thermocouple

The DS18B20 is encapsulated with a sealant with high thermal conductivity, which ensures high sensitivity of the temperature sensor and very low temperature delay. The temperature sensor supports a "1-wire" interface and measures temperatures from -55° to +125° with an accuracy of 0.5° cover a range of -10 to +85°C. The field temperature is directly transmitted as a "1-wire" digital signal. Digital

The field temperature is directly transmitted in a "one wire bus" digital way, which greatly improves the system's anti-jamming property. Suitable for field temperature measurement in harsh environments. This is different from the beginning of the choice of thermocouple temperature measurement, due to the field temperature is more difficult to measure we choose to use DS18B20.

### 3.2.2. Control board

We used an STM32F103C8T6 microcontroller as the core and three circuits including a temperature detection circuit, a display circuit and a WS2812 circuit. Due to the poor results of the previous experiments, we chose to visualize the temperature size directly on the display.

# 4. Cost

## 4.1. Parts

The table below shows the estimated cost of various parts. We estimate that it will cost us 132.09$ for one, and if we mass produce it, the cost is expected to drop to 106.8$.

Table 2. Cost of parts

| Part | Manufacturer | Retail Cost($) | Bulk Purchase Cost($) | Actual Cost($) |
|---|---|---|---|---|
| Thermoeletric Plate (TES1-4903) | Jiequ Trading Co. | 0.94*64=60.16 | 0.7*64=44.8 | 0.9*64=57.6 |
| PCB | Jiepei PCB Co. | 10.5 | 7 | 10.5 |
| LED array (MAX7219) | Pairui Lianhe Technology Co. | 0.76 | 0.7 | 0.76 |
| Resistors, Capacitors, Crystals, Ics | TeleSky Co. | 5 | 3 | 5 |
| Microcontroller (ATmega2560) | Xinwei Electronic Technology Co. | 9.13*4=36.52 | 8*4=32 | 9.13*4=36.52 |
| Universal board | TeleSky Co. | 2.1 | 1.5 | 2.1 |
| Microcontroller (STM32F103C8T6) | TeleSky Co. | 6.3 | 5.8 | 6.3 |
| OLED | TeleSky Co. | 4.8 | 4.5 | 4.8 |
| Thermal probe (DS18B20) | Dallas Semiconductor Co. | 1.7*3=5.1 | 1.5*3=4.5 | 1.7*3=5.1 |
| LED RGB light (WS2812) | XGBTEL Co. | 3.5 | 3 | 3.5 |
| **Total** | | 134.74 | 106.8 | 132.09 |

## 4.2. Labor

Our fixed development costs are estimated to be 7$/hour, 10 hours/week for four people. Ignoring some additional labor costs, our R&D costs are approximately:

$$4 * \frac{7\$}{hr} * \frac{10hr}{wk} * 16wks * 2.5 = 11{,}200\$$$

## 5. Conclusion

### 5.1. Accomplishment

In summary, we have innovatively developed a thermal lab platform suitable for middle and high school classrooms, which effectively demonstrates the concepts of heat convection, conduction, and thermoelectricity to students. By visualizing heat changes through LEDs, students gain a more vivid and concrete understanding of thermodynamic concepts. The LED displays the temperature distribution on the thermoelectric plate and the heat-conducting rod, thus dynamically changing in real-time as students perform different operations, enhancing interactivity. By increasing the accuracy and sensitivity of thermal sensors, the lab platform can demonstrate excellent experimental results at room temperature. Combined with the electrical safety resulting from reasonable encapsulation and appearance design, the thermal lab platform ensures high safety levels, with minimal risk of injury to students even when operating independently. Its application in middle and high school classrooms is highly appealing due to its safety and effectiveness.

### 5.2. Uncertainty

It's worth noting that in the thermoelectric subsystem, the relatively large area of the small thermoelectric plates we use (20mm*20mm) can result in graphics with rough edges and insufficient clarity. This issue can be effectively addressed by reducing the size of the thermoelectric plates to increase the number of thermoelectric plates per unit area. Also, the corresponding increase in the number of LED arrays is necessary to significantly enhance the resolution of the LED display screen, thus better illustrating the thermal distribution on the large thermoelectric plate.

In the heat transfer subsystem, we currently only use three thermal sensors simultaneously and utilize LEDs to display the temperature differences between these sensors. However, this approach does not adequately capture the overall temperature curve inside the heat-conducting rod. By increasing the number of thermal sensors and introducing a display screen to showcase the temperature curve inside the heat-conducting rod, we can better demonstrate the diverse thermal conductivity properties of different materials.

### 5.3. Ethic and Safety

In developing a thermoelectric teaching aid, it is crucial to adhere to ethical standards set forth by the IEEE [5] and ACM [6] by ensuring the design prioritizes public safety and environmental sustainability. The highest voltage is set to only 5V in our design, which is no harm to human body. Also, the material and components are choosing to consider their environmental sustainability and would not be discarded randomly. We should transparently disclose any potential conflicts of interest and respect intellectual property rights through proper acknowledgment and licensing of all hardware and software components. Rigorous testing should be conducted to maintain high standards of quality and performance, with honest representation of the aid's capabilities and limitations to avoid misleading users. Moreover, we should aim to enhance educational outcomes in STEM and promote professional development, ensuring that the benefits of the teaching aid are accessible without discrimination, thereby supporting an inclusive learning environment. This comprehensive approach will not only uphold ethical engineering practices but also contribute positively to societal and environmental well-being.

### 5.4. Future Work

In future work, we can continue to enhance the thermal lab platform to further improve its performance and functionality. In our thermoelectric subsystem, we currently use an external power source to supply power to the microcontroller, which to some extent does not demonstrate the concept of converting heat energy into electrical energy. Thermoelectric plates can generate electricity with temperature difference. However, due to limitations in the efficiency of thermoelectric plates and the relatively small temperature difference from sources such as the human body and room temperature, we currently only utilize this energy to generate signals and display them on LEDs. However, if we could improve the thermoelectric plates and use microcontrollers and LED displays with lower power consumption, the thermoelectric subsystem could potentially power itself through the electricity generated by the thermoelectric plates, thereby better illustrating the concept of thermoelectric conversion.

Furthermore, this thermal lab platform aims to enhance the quality of thermodynamics teaching in middle and high school classrooms. To achieve this goal, it is necessary to develop corresponding teaching support materials and resources. For example, when using the heat transfer subsystem, teachers could play instructional videos explaining Fourier's law of heat conduction. Through continuous improvement and innovation, the thermal lab platform will become an essential tool in future teaching, providing students and teachers with richer and more in-depth learning and teaching experiences.

## References

[1] Ordu, U. B. A., “The role of Teaching and Learning AIDS/Methods in a changing world.,” *Bulgarian Comparative Education Society.*, 2021.

[2] J. S. Lee, “The relationship between student engagement and academic performance: is it a myth or reality?,” *The Journal of Educational Research*, vol. 107, no. 3, pp. 177–185, Nov. 2013, doi: 10.1080/00220671.2013.807491.

[3] S. Wang *et al.*, “Integration of recent developments in transient heat conduction and mass transfer for solid sphere into teaching,” *Computer Applications in Engineering Education*, vol. 30, no. 5, pp. 1526–1546, Jun. 2022, doi: 10.1002/cae.22542.

[4] D. K. Umam, S. Saehana, A. Kade, and Yunanli, “Development of Thermal Energy Conversion Devices into Electrical Energy as Physics Learning Teaching Aids,” *Journal of Physics: Conference Series*, vol. 2126, no. 1, p. 012011, Nov. 2021, doi: 10.1088/1742-6596/2126/1/012011.

[5]IEEE, “IEEE Code of Ethics,” ieee.org, Jun. 2020. https://www.ieee.org/about/corporate/governance/p7-8.html

[6]“The ACM Code of Ethics arose from the experiences, values and aspirations of computing professionals around the world, and captures the conscience of the profession. It affirms an obligation of computing professionals to use their skills for the benefit of society.,” www.acm.org. https://www.acm.org/about-acm/code-of-ethics-in-chinese (accessed Apr. 15, 2024).