Hwa Chong Institution Project Work Category 3 Inventions Log Book

Title of Project: **Self Heating Lunch Box**
Project Number: 3-42
Group Members: 1) Benjamin Tay Tze Min (Leader) 2) Alastair Xu Shao Ze 3) Chu Qingyan 4) Chua Rui Heng

1. Problem Finding

1 A Problems we have identified

1. People not being able to water their plants while their away
2. Phones overheating
3. People eating cold food in lunch boxes

1 B What we considered when identifying the problems

- Technical Feasibility
- Market Potential
- Production Cost

1 C Problem Evaluation Grid

Considerations for Selection	Problems		
	#1 Automatic Plant Waterer	#2 Colour Case 2.0	#3 Self- Heating Lunch Box
Technical Feasibility	5	4	4
Market Potential	2	3	4
Production Cost	2	2	3
Total Score	9	9	11

*The higher the score, the better

Thus, the Self-Heating Lunchbox wins.

2. Define the Problem

2 A Extent of problem (Research and discuss the problem and write down the problem statement)

Students do not have enough healthy food choices in the canteen. The food sold might be too expensive for students who are financially challenged. Students who have special needs such as allergies and special diet requirements may not find food that suits them in the canteen. There might also be long queues in the canteen, leaving not enough time for them to eat.

Food safety is also an issue. Food must be stored at 5 degrees Celsius or lower or above 60 degrees Celsius or higher to ensure food safety. Food that is stored for longer than 4 hours at food safe temperatures must be disposed of as the food is no longer safe for consumption. Although pre-ordering is a viable option, the food is usually cooked before the first round of recess, so the food that is pre-ordered might be sitting out for over 4 hours before consumption, leading to non-food safe conditions.

2 B Compare and contrast the existing or similar solutions.

Solution	Pros	Cons	Price	Ref
	• Easy to use • Big storage space	• Not be able to keep food warm for long periods of time • Not able to heat up food when you want to eat • Heavy to carry • Unable to keep food in food safe temperatures	US $86.80/ SGD $117.43	[1]
	Portable	• Unhealthy • Not fresh • Limited catering to individuals with special diet restrictions	$4.50	[2]
	• Portable • Easy to use • Lightweight	• Limited storage space • Flimsy • Cannot control temperature of food • Dangerous - Hot • Needs electricity from wall socket	$36.72	[3]
	• Easy to use • Has good insulation	• Not portable • Heavy • Needs electricity from wall socket • Flimsy	$36.85	[4]

Product	HOMMAT Thermos	Hai Di Lao self-heating soup base	TAYAMA electrically heated lunchbox	Aotto electric heated heater plate with thermal insulation pack
Price	$117.43	$4.50	$36.72	$36.85
Temperature control/limit	1	1	1	1
Usage safety	5	2	3	4
Reusable	5	1	3	5
Efficiency	1	3	3	3

Legend for ratings: 1 - non-existent, 2 - poor, 3 - average, 4 - good, 5 - excellent

3. Our Idea

3 A Describe your proposed invention.

Our product is a self-heating lunchbox with the following features:

1. Portable and light.
2. Electrically safe - protected by safety fuse (no explosions like Samsung) and temperature limit (plastic will not melt so this is food safe)
3. Conveniently powered by a power bank or a standard USB wall charger
4. User settable temperature limit of the heater using the slider.
5. Monitor the actual food temperature and the desired temperature setting through the OLED display.
6. Energy efficient design with automatic heaters and thermally-insulating box.
7. Accommodates a variety of food containers.

3 B Explain the purpose of your proposed invention and the potential benefits to users.

1. Users need not spend time queueing for food, giving them more time to eat.
2. Users are able to eat healthily as they can pack whatever they want to eat.
3. Users are able to save money as eating out can be quite costly
4. Food will be food safe as the heater will reheat the food the 60°C, killing of all bacteria that has grown.

3 C In what ways would your proposed invention be different and/or better than existing solutions, if any?

1. Users will be able to see the temperature of the food on an OLED screen and the temperature is updated every 2 seconds, more user-friendly than expensive market solutions that can only set timers.
2. Users are able to adjust the temperature limit of the heater to their own preference and needs.
3. Once the heaters have reached the desired temperature, the heaters will turn off and will only turn on again when the temperature of the heater drops below the temperature limit. This will save energy, unlike other products which will continue to heat as long as there is power being supplied constantly.
4. Our prototype is able to supply heat while losing the least heat among all the products available

3 D What are some problems you expect in the course of your proposed invention?

1. The heater may not be able to reach 60°C as the battery pack is small to be portable and the power output may be small.
2. There may not be enough heat to maintain the food at 60°C for long periods of time.
3. Battery pack of enough power may be too big to fit into the container.

3 E What and when are the major milestone (project timeline) in your invention?

	Mar		Apr					May				Jun				Jul					Aug			
Milestones	18	25	01	08	15	22	29	06	13	20	27	03	10	17	24	01	08	15	22	29	05	12	19	26
Planning & research	x	x	x	x	x	x	x	x																
Build prototype #1									x	x														
Feedback and review #1											x													
Build prototype #2												x	x											
Feedback and review #2														x										
Mid-year review																	x							
Build prototype #3															x									
Feedback and review #3																x								
Build final prototype																	x	x	x					
Feedback and review																				x				
Documentation and Report																					x	x		
Final review																							o	

Legend

o	Not yet done
x	Completed

4. Construction Process

4 A Explain how and why the materials were chosen for the prototype/ product of your invention.

1. First prototype
    a. A chemical pack was used for the first prototype. However, the reaction in the chemical pack could not reach the required food safe temperatures.
2. Second prototype
    a. The chemical pack was replaced by electrical heater pads to heat the water. The heater pads were pasted to a metal container using a temperature-resistant tape known as Kapton tape which is able to withstand temperatures up to 400°C.
3. Third prototype
    a. A micro:bit was used with a temperature sensor and an OLED display to show the temperature. **Please refer to Appendix 3 for details on the calibration of the temperature sensor**
    b. A fuse was implemented to prevent too much current from flowing in in case the heaters burn out and short circuit if users choose to plug the invention into a usb socket.
    c. A sliding potentiometer was also added so that users are able to set the desired temperature at which to keep the food warm.
    d. In order to save energy, a relay was added. The relay will cut off the power to the heater when the temperature of the heater crosses the temperature limit and will only turn back on when the temperature drops below the limit. This will help to maintain the temperature while using less energy, unlike other products which will continuously provide heat energy once turned on.

4. Final prototype
    a. A operational amplifier was used instead of a micro:bit as it was smaller and the micro:bit had features that were unnecessary for our use that contributed to the large size of the micro:bit
    b. A fuse holder was added to the front of the box so that users can change the fuse by themselves
    c. Three LEDs were added as indicators to indicate when the food is safe, when the heaters are on and when the food is not safe for consumption.
    d. The heater plate was cut to avoid contact with the sides of the box to reduce heat loss by conduction.
    e. The box was lined with aluminium tape to reduce heat loss by radiation.
    f. Tiny aluminium cuboids were added to allow users to use the prototype with other boxes that have ridges at the bottom.

4 B Explore these considerations that may guide the construction of your prototype/ product.

1. The type of energy source that will be used to supply heat energy:
    a. Chemical - not feasible as reusable chemical packs cannot reach food safe temperatures. Existing products based on the exothermic crystallization reaction of a supersaturated sodium acetate solution has a temperature limit of 58.4 degC above which the sodium acetate trihydrate crystals will begin melting. **Please refer to Appendix 1 for more details on the chemistry of sodium acetate**

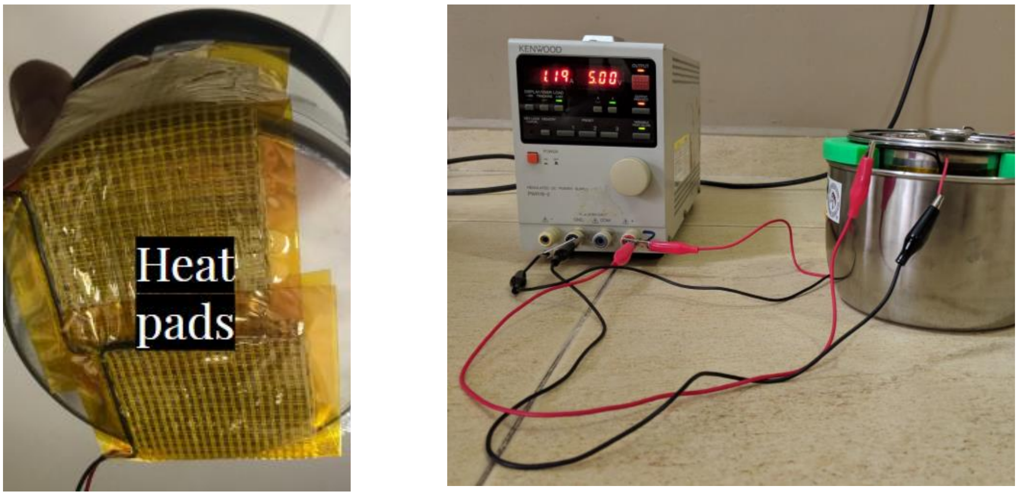
   b. Electrical - highly feasible because as long as there is a current, the heaters can continue to heat up and increase in temperature. USB wall chargers and portable power banks provide a convenient and reusable means of operating the prototype. It also has an added advantage of controllable rate of heating.
2. Cost of product
   a. Initial prototype is expensive (> $80):
      i. The use of micro:bit and its accessories can be costly. The micro:bit core board is already $30. However, as a development platform, it has many accessories to speed up experiments and test the assumptions that we have.
      ii. The product is powered by existing commercial power banks. A recommended minimum capacity is 9,000 mAh. A 10,000 mAh power bank from a reputable manufacturer such as Anker costs around $90 **Please refer to Appendix 2 for details on how the minimum power needed was calculated**
   b. Production design will cost less than $50
      i. By using an operational amplifier and three LEDs instead of a micro:bit and the microbit accessories, the price of the electronics was reduced to less than $10
      ii. 70°C PTC heaters were used to avoid risk of overheating.
      iii. More heat efficient PTC heaters that cost more were used and more heaters were implemented, raising cost of heaters to around $12.
      iv. The power bank can be an optional purchase so that users can use their own existing power banks or plug into USB wall chargers.
3. Materials used
   a. The aluminium metal plate holding the heaters is light and conducts heat well from the heaters to the food.
   b. The external box is made from plastic (ABS) which is a poor heat conductor, making it suitable for touch. However, the box fits the heating metal plate exactly and is in contact with the edges of the plate. As a result, some heat is lost to the surrounding air through the box, thus increasing energy usage. Next iteration will incorporate an air gap to mitigate this heat loss mechanism.
   c. A separate box holding the electronics is located at the bottom of the product. This is to separate the electronics and power bank from the high temperatures inside the lunch box. However, in the initial prototype, this box is too big and bulky as it needs to accommodate the micro:bit boards and accessories which are rather large. In future iterations when the micro:bit is replaced by dedicated electronics, this box can be much smaller and perhaps located at the side.
   d. The inside of the box is lined with aluminium tape to prevent heat loss by radiation.

4 C **Document the prototype/ product development stages. You may use drawings, photographs or videos.**

1. **First prototype based on chemical heater pack**

Fig 4.1. First prototype using a chemical heat pack manufactured by EZI innovations based on the exothermic crystallization of sodium acetate trihydrate (CH3COONa.3H2O).

2. **Second prototype based on electrical heater pads**



(a) (b)

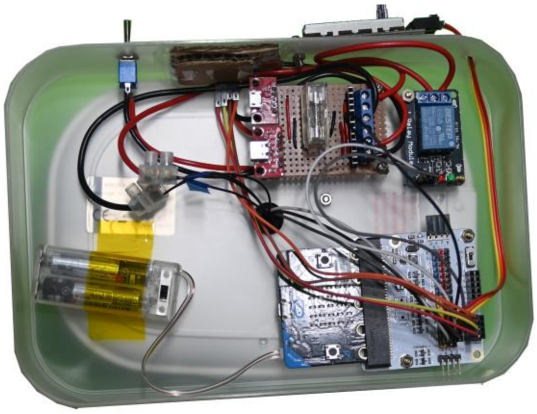
Fig 4.2 (a) Second prototype using electrical heater pads at the sides on the inner lining of the lunch box. Electrical heater pads were constructed using a mesh of polyester filament and micro-metal conductive fiber folded into a protective polyimide film (kapton tape). The heaters were fixed onto the sides of the lunch box using Kapton tape. (b) Test setup of the second prototype with an external power supply and the inner lining of the lunch box inside the external lunch box body.

3. Third prototype based on electrical heater plates

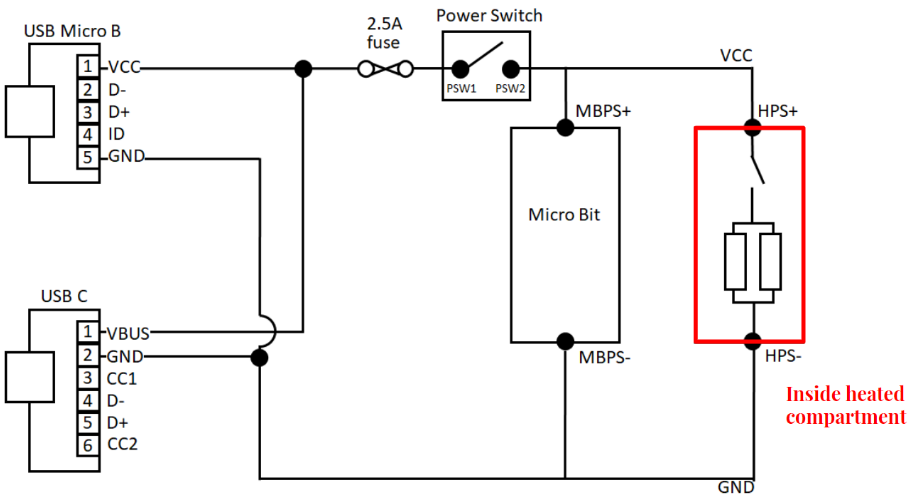
(a)

(b)

(c)



(d)



(e)

Fig 4.3

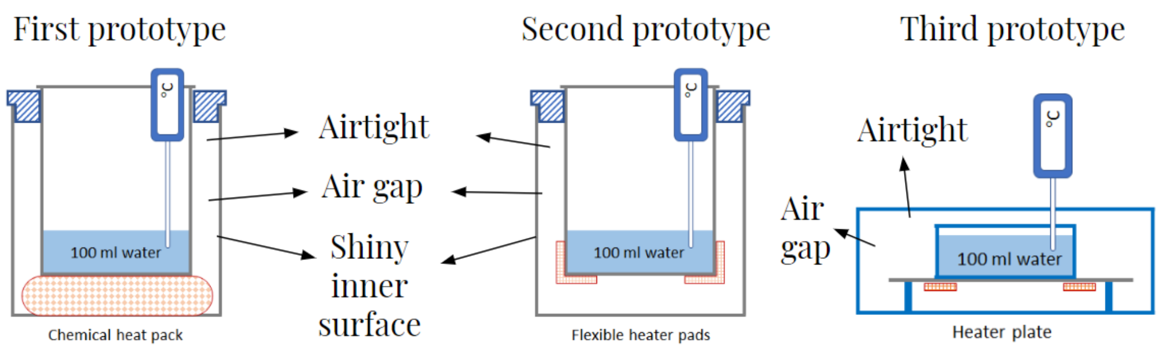
(a) Overview of the third prototype consisting of the power bank, usb cable, lunch box with cover.

(b) The lunch box consists of a heating container above a temperature control compartment

(c) View of the top heating container which holds the heater plate with two heaters and one temperature sensor. The container and heaters are taken from an existing heated lunch box.

(d) View of the control compartment holds micro:bit controller and electronic components.

(e) Schematic diagram of the circuit for the micro:bit and heaters.



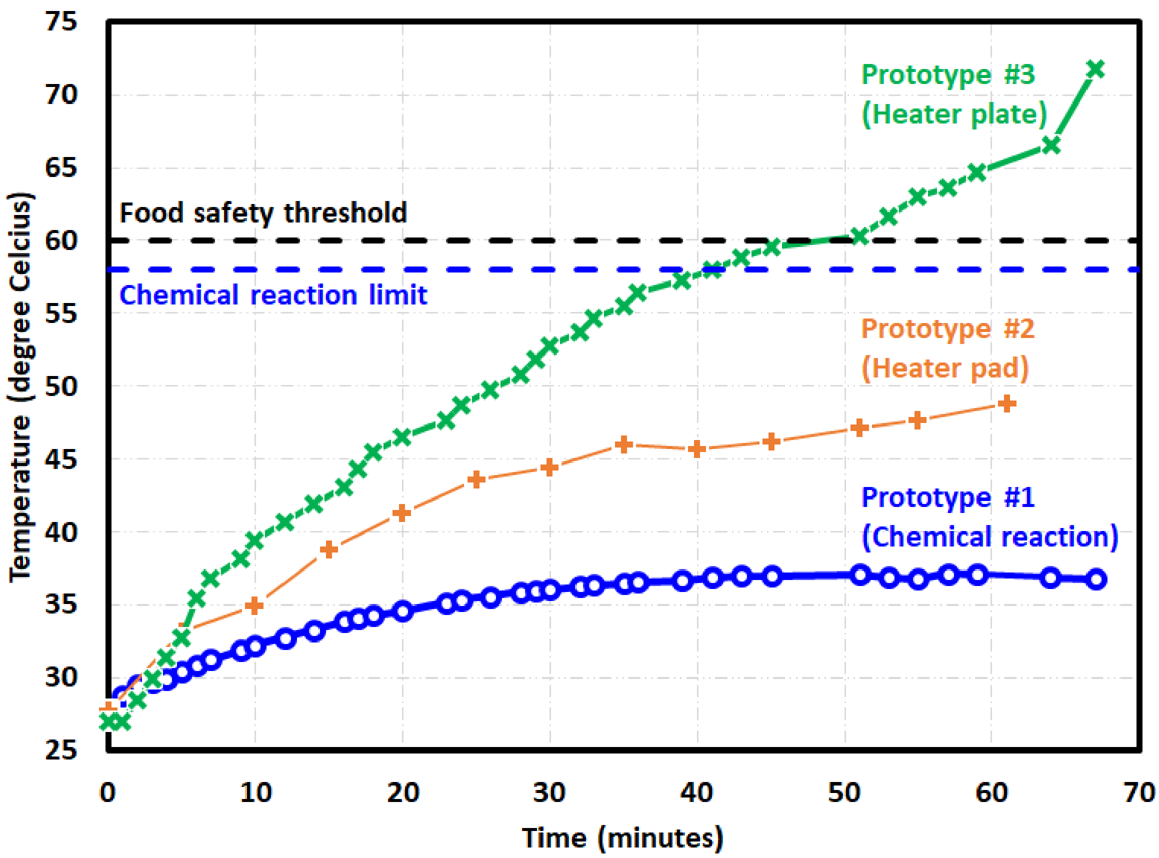
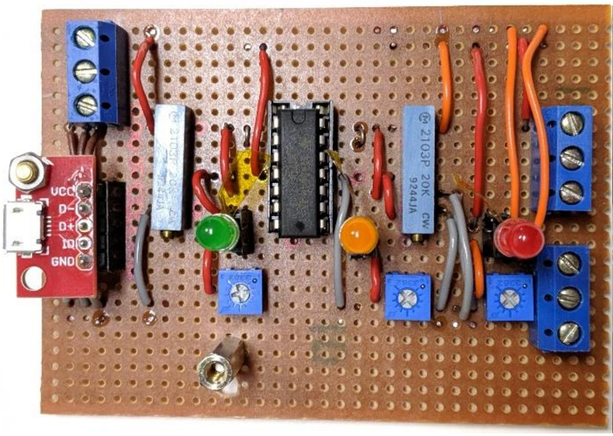


Figure 4.4 Comparison of heating performance between prototypes 1, 2 and 3. The simplified cross-section of the prototypes are shown on top. Among these prototypes, only prototype 3 was successful in reaching the food safety temperature threshold.

4. **Final prototype**

(a)

(b)



(c)

(d)

Figure 4.5

(a) front view of the lunch box with LED indicators and on/off switch
(b) the inside of the lunchbox, which is lined with aluminium tape
(c) top view of the vero board used
(d) view of the aluminium cuboid to improve contact area with commonly used food containers that have a ridge at the bottom.

The final prototype in **Fig 4.5** incorporates the lessons learnt from prototype 3:

1. Improved heat insulation to improve efficiency:
    a. Heater plate has an air gap from sides of the box
    b. Inner surface of the box lined with reflective aluminium tape to reduce radiation losses
    c. Added aluminium cuboids to the heater plate so that users can use their own lunchboxes and still heat up at the same rate despite the ridge which causes air gaps
2. Reduced weight and bulkiness of the box by using a operational amplifier that is a lot smaller and lighter compared to the micro:bit circuit.

5. Modification and Evaluation

5 A Write down your prototype/ product test criteria and check against it if it works. Identify areas of weakness for modification. Indicate the test iteration and date of test.

Test Iteration: changing to heater pads from chemical pack	Tick			Remarks
Test Date: 31 May	Pass	Fail	Potential Failure	
How effective was the heater			✓	Heater was slow in heating up although being fed a high current.
Was it user friendly (eg. easy to use - outside hot/ easy to turn on)	✓			Will work once plugged into power
Is it feasible		✓		Users will have to wait a long time before their food is heated up.

*Add more rows for more criteria

** Repeat table for next test iteration

Test iteration: changing from heater pads to heating module	Tick			Remarks
Test Date: 19 June	Pass	Fail	Potential Failure	
How effective was the heater.	✓			Heater could heat up relatively quickly
Was it user friendly (eg. easy to use - outside hot/ easy to turn on)	✓			Users can set the temperature limit and the heaters stop when the limit is reached and will on when the temperature is below the limit, saving energy. However, the metal plate holding the heaters touched the lunchbox, causing unnecessary heat loss, wasting energy.
Is it feasible			✓	This prototype can be used, however, there is currently still a limit on the rate of heat gain as heat needs to be transferred from the heater to the metal plate to the lunchbox and then to the food. Users may not want to wait so long to heat up their food.

Test iteration: using PTC heaters instead of regular heaters	Tick			Remarks
Test Date: 21 July	Pass	Fail	Potential Failure	
Was the heater more effective.	✓			With insulation, the heaters could go up to 70°C at an average time of around 3-4 minutes
Was the heater able to heat up the same with the same amount of energy	✓			With the same amount of energy or less, the heater was able to heat up to high temperatures quicker.
Is this feasible`			✓	This may still fail if users do not have enough power in their powerbank to heat up their food completely.

Test iteration: added aluminium cuboids	Tick			Remarks
Test Date: 1 Aug	Pass	Fail	Potential Failure	
Was the heater more effective?	✓			Yes, with better contact area with the bottom, a standard food container was able to heat up faster.
Was the contact area improved for any general food container?			✓	The ridges for some containers were too tall for the cuboids.
Is this feasible?	✓			The height of the cuboids were ideal for most containers tested (e.g. Lock & Lock and Tupperware are commonly used by households)

6. References

Read http://www.bibme.org/citation-guide/apa/ on how to cite references.

6 A Cite the references you have used for your project work. Your source of reference should come from different types (eg books, magazine, websites, journal articles, interview, photographs, product brochure, reviews etc.)

[1] HOMMAT stainless steel thermos lunchbox. (n.d.). Retrieved June 22, 2019, from https://www.aliexpress.com/item/Free-Shipping-Double-Layer-Vacuum-Stainless-Steel-Lunch-Box-with-Bag-Thermos-Food-Container-Tableware-Dinnerware/630025386.html

[2]Hai Di Lao Self-Heating Hot Pot. (n.d.). Retrieved June 22, 2019, from https://www.fairprice.com.sg/product/hai-di-lao-vegetarian-self-heating-hot-pot---spicy-13146167

[3] TAYAMA EBH-01 electrically heated lunchbox. (n.d.). Retrieved June 22, 2019, from https://www.amazon.com/EBH-01-Electric-Heating-Lunch-Light/dp/B00A4A0UII

[4] Aotto electric heated heater plate with thermal insulation pack. (n.d.). Retrieved June 22, 2019, from https://www.amazon.com/dp/B07PQWDQ8L/ref=sspa_dk_detail_5?psc=1&pd_rd_i=B07PQWDQ8L&pd_rd_w=ZCSv8&pf_rd_p=8a8f3917-7900-4ce8-ad90-adf0d53c0985&pd_rd_wg=sTiSX&pf_rd_r=TRAPD2WFCZKE263E3AB3&pd_rd_r=79c7f30b-94b1-11e9-84e1-bba4be2e9296

[5] #82931, M. (n.d.). Heating Pad - 5x10cm. Retrieved June 29, 2019, from https://www.sparkfun.com/products/11288

[6] Kapton. (2019, June 27). Retrieved June 29, 2019, from https://en.wikipedia.org/wiki/Kapton

[6] Anker Power Bank. (n.d.). Retrieved June 30, 2019, from https://www.lazada.sg/products/anker-powercore-ii-slim-10000mah-ultra-slim-power-bank-upgraded-poweriq-20-up-to-18w-output-fast-charge-for-iphone-samsung-galaxy-and-more-i162087815-s206843496.html?spm=a2o42.searchlistcategory.list.2.35c57404q2EeSS&search=1

Appendix 1

Temperature limits and physical change of state of sodium acetate trihydrate (saturated sodium acetate)

If you attempt to dissolve sugar in water, you reach a point where you cannot dissolve any more sugar. This is called a saturated solution. However, if you heat this solution, more sugar will dissolve allowing you to add extra sugar. When the solution is cooled, the sugar will remain in solution. This is called a supersaturated solution, which is very unstable and will crystallize easily.

Supersaturated solutions are formed when solute is added until any more solute cannot be dissolved.

When you pour the solution onto an additional crystal, the new crystal acts as a nesting site for one crystal deposited from the solution and all of the other salt crystals fall out instantly. The process of crystallization gives off heat. It is said to be exothermic. That's why the solution is used in hand warmers (the old-style liquid-type of hand warmers). When solid sodium acetate trihydrate is heated above 58°C it loses its water of hydration and begins to dissolve in that water. The salt becomes completely dissolved at 79°C. When the solution is cooled back down to 20℃, it is unsaturated with respect to anhydrous sodium acetate, but it is supersaturated with respect to sodium acetate trihydrate. When a seed crystal of sodium acetate triacetate is added, sodium acetate trihydrate crystallizes out. The heat of solution of sodium acetate trihydrate is 19.7 kJ/mole (an endothermic process) while the crystallization is exothermic. Thus it can be seen that sodium acetate trihydrate can only go up to 58°C as the sodium acetate trihydrate will have completely solidified and there will no longer be any more heat that can be produced, making sodium acetate trihydrate an unsuitable method for heating up food.

Chemical equation for exothermic reaction of sodium acetate trihydrate:

$C_2H_3NaO_2(s) + 3H_2O(l) \rightarrow C_2H_3NaO_2 3H_2O(s)$

Sodium Acetate Reaction. (n.d.). Retrieved June 30, 2019, from https://docplayer.net/9766288-Article-in-press-abdelmalek-bouazza-a-stephan-jefferis-b-c-thaveesak-vangpaisal-d.html

Appendix 2

How to calculate energy needed to heat up 350ml of water:

4.2kJ needed to heat up 1 kg of water per degree Celsuis

Formula :

1. Energy (J) = Power (Watts) x Time (seconds)
2. Power (Watts) = Voltage (Volts) x Current (amperes)

1000 mA.h = 1 Ampere x 1 hour

How much energy is needed to heat 350 ml of water? （Around a soda can of liquid)

The specific heat capacity of water is 4,200 Joules per kilogram per degree Celsius (J/kg°C). This means that it takes 4,200 J to raise the temperature of 1 kg of water by 1°C.

350 ml of water is 350 g = 0.35 kg

350 ml of water needs 1260 J to raise its temperature by 1 degC.

Energy (Joule) = Power (Watt) x Time (seconds)

Heater is rated 40 W by the factory. Our measurements show input power = 5 V x 0.8 A = 4W.

Time needed to raise 1 degC = 1260 J / 4 W = 315 seconds

From room temperature (25 degC) to food safe temperature (65 degC), difference of 40 degC.

Time needed = 40 x 315s = 12600 seconds = 210 minutes.

This assumes all energy from the heater goes into the water.

During energy transfer, energy is lost through three mechanisms: conduction, convection & radiation to surroundings

By minimizing this losses, we can have an efficient system to maintain heat within the food container.

Use cases

1. **Ideal case scenario**: heat for exactly 3.5h

   Heater current = 0.8A

   Amount of mAh needed: (3.5 x 0.8 x 1000) mAh = 2800mAh

   To heat food to 65 degrees Celsius needs 2800mAh,

   assuming that there is completely no heat loss, food can be maintained at 65 deg

2. **Case scenario 2**: User leaves home at 7am and has lunch at 2pm, there is a 30% heat loss to surroundings, and heater has to be on throughout the entire time which is around 8h.

   Amperes : 0.8A

   Amount of mAh needed : 8 x 0.8 x 1000 x 130% = 8320mAh

Conclusion: minimum battery size should be at least 9000mAh

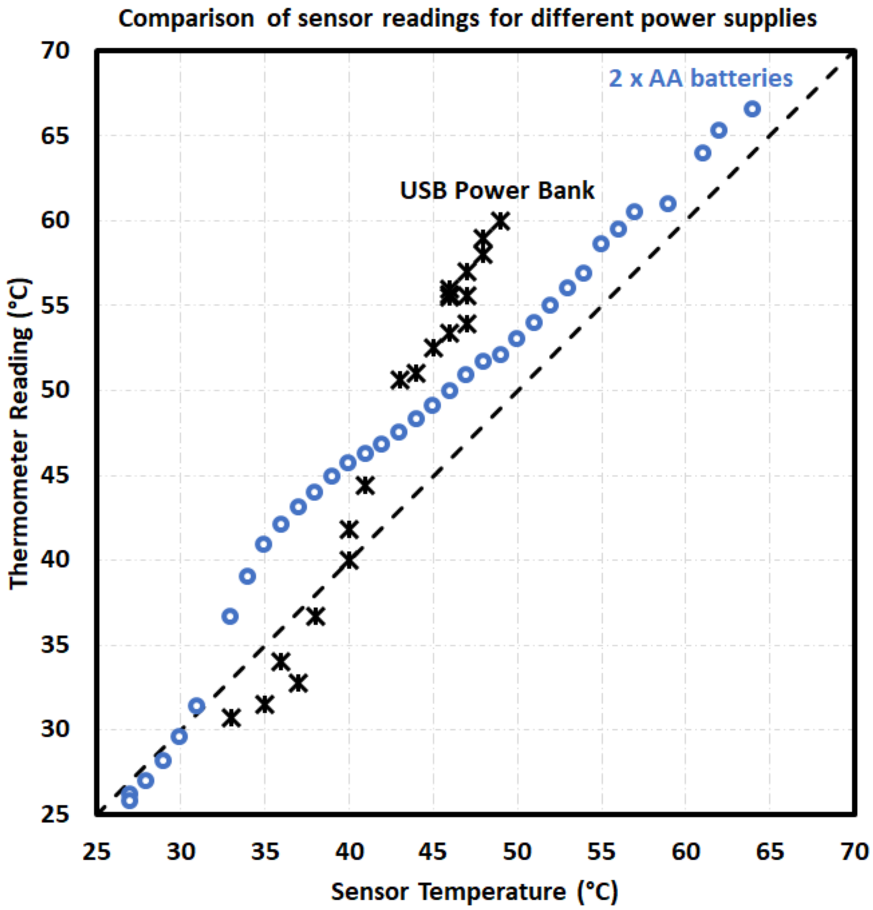
Appendix 3

Temperature sensor selection and calibration

- The sensor can be supplied with a voltage of 2.7 to 5.5 V - this is ideal because the micro:bit can be operated by 2 AA batteries or a USB power bank.
- The sensor will survive an ambient temperature of 125°C making it suitable to be placed near the heat source.
- The sensor is specified a signal output of 0.75 V at 25°C with increase by 0.01 V for each degree increase.

The analog input of the micro:bit returns an integer between 0 to 1023 corresponding to a voltage range of 0 Volts to the board supply voltage. The micro:bit takes power from either a pair of AAA batteries (3.3V) or a standard USB power (5V), which corresponds to a board supply voltage of 2.567 and 3.224 V respectively. This means that the supply voltage may vary depending on the type of power source used, as well as how fresh the power supply is. For example, a pair of AAA batteries would give 3 V when it is new, and slowly reduce towards 2.5 V as it ages. This degradation of voltage will affect the accuracy of the temperature scaling over time.

The accuracy of the temperature scaling can also be affected if the same scaling equation is used with two different sources of power supply as shown in Figure 1 below for the case of a pair of AAA batteries (3V) and a USB power bank (5V). As the full scale of the USB power supply is larger than that of the AA batteries, the scaled output value of the sensor will be lower when operated from the USB power supply.



To avoid the ambiguity of scaling errors, we decided to operate the heaters and micro:bit directly from USB power supplies. This is because of a smaller range of fluctuation in power supply voltage from USB power banks will limit the scaling errors for temperature reading. From our tests, the USB power bank is well regulated from 4.9 to 5.1 V while AAA batteries can vary from 1.65 x 2 = 3.3 V (when fresh) to 1.4 x 2 = 2.8 V (when dead).

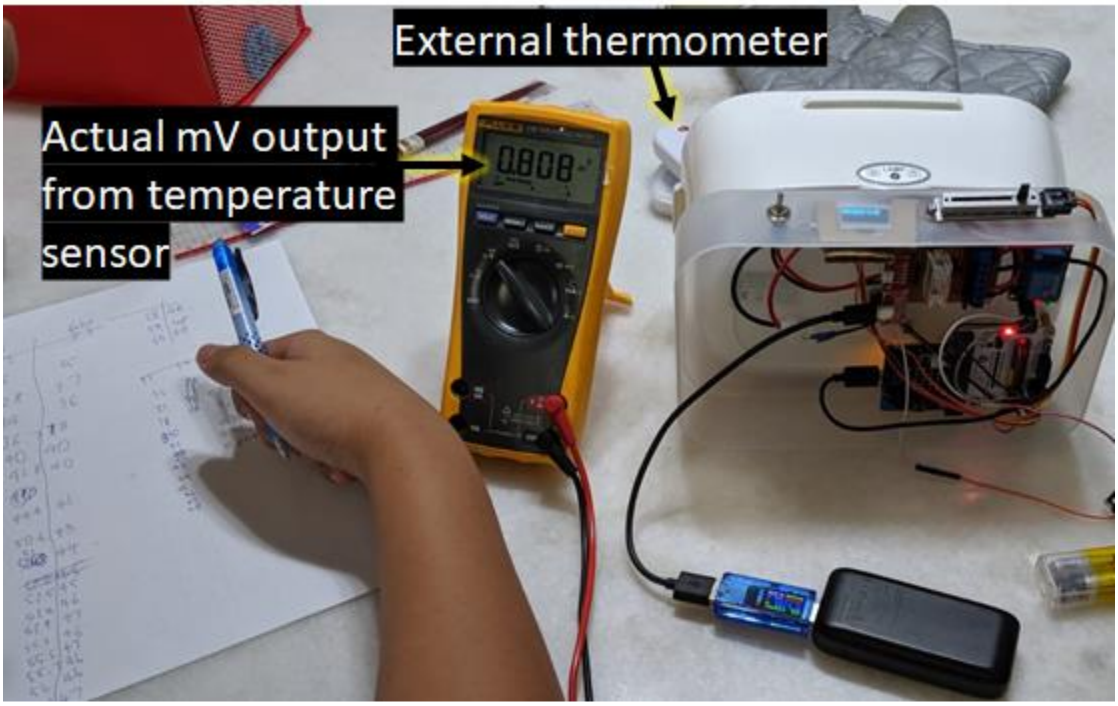


Figure 2. Measuring the actual output signal from the temperature sensor using a multimeter and comparing the value against the external thermometer reading.

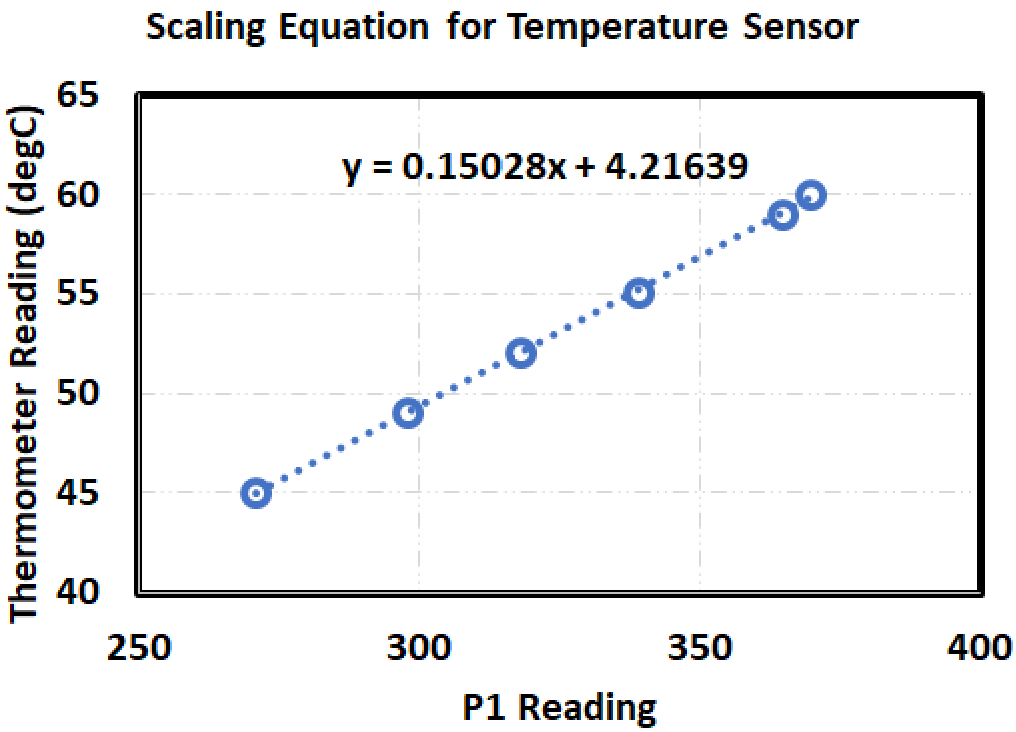


Figure 2. Scaling function for temperature sensor based on measured values.

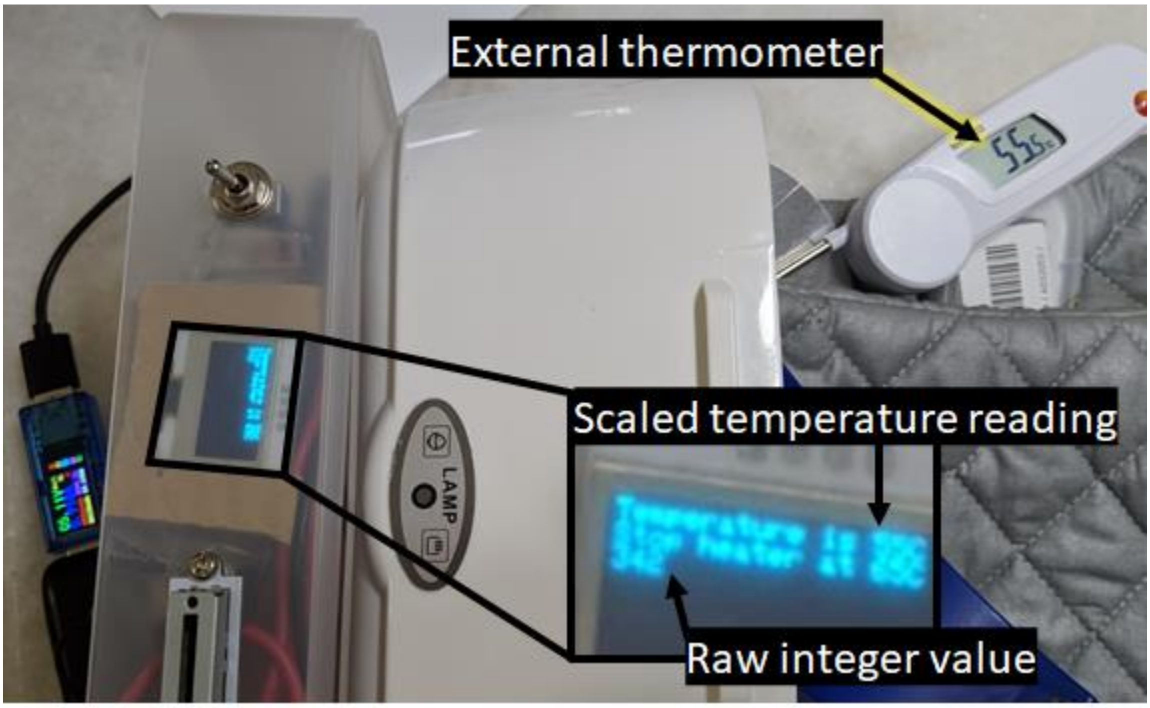


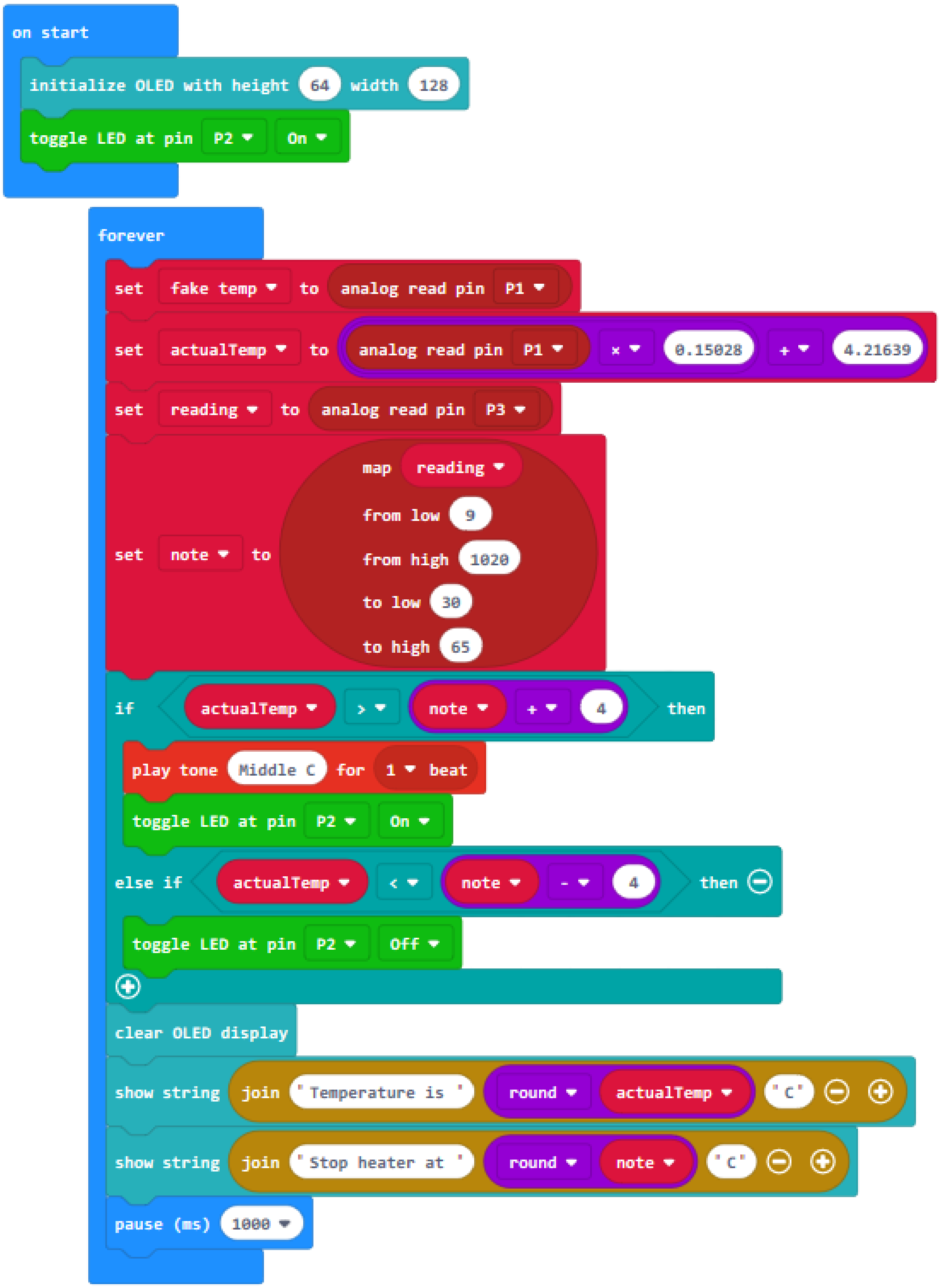
Figure 3. Accuracy comparison of scaling function against the measured temperature using external thermometer. The scaled value is calculated to be 55 °C which is close to the actual thermometer reading of 55.5 °C. Over the range of 30 to 65 °C, the accuracy of the scaling function is found to be within +/- 3°C.

Analog Devices TMP36 Datasheet. (n.d.). Retrieved June 30, 2019, from https://www.analog.com/media/en/technical-documentation/data-sheets/TMP35_36_37.pdf

Appendix 4

Coding of the microbit

A ElecFreaks breakout board was used to connect the parts to the microbit. The user guide is available at https://www.elecfreaks.com/learn-en/microbitExtensionModule/octopus_bit.html



ElecFreaks. (n.d.). ElecFreaks micro:Bit add on. Retrieved June 30, 2019, from https://www.elecfreaks.com/learn-en/microbitExtensionModule/octopus_bit.html