Abstract

This research project was intended to determine the effect of my partner placing a mug of tea in the fridge in summer. The experiment investigated the effect of placing a ceramic mug of water at 70°C, 60°C and 50°C in a refrigerator on the temperature of the water and on the ambient temperature of the refrigerator, over 3 x 3 minute intervals. This indicated that the water placed in the refrigerator reduces in temperature, at all three temperatures and across all time intervals. The temperature of the water at the start of the experiment affected the rate of temperature change during the experiment. Finally, the ambient temperature of the refrigerator reduced from the time the mug was placed in the refrigerator until the end of the experiment. However, there are a range of limitations to the method and were a range of errors, measurement problems and equipment problems in this experiment which limit my confidence in the findings from this research.

1. Introduction

In summer, my partner often places a mug of tea in the fridge for a few minutes after boiling water and pouring the water over tea leaves. My research investigated three questions related to this:

1) What effect does placing the tea in the fridge have on the temperature of the tea?
2) What effect does placing the tea in the fridge have on the ambient temperature of the fridge?
3) How does the answer to (1) or (2) differ based on the starting temperature of the tea (i.e. if one lets the tea reduce in temperature outside for a few minutes before placing in the refrigerator)?

Using Proust and Newell (2020) as a guide, I started my research by mapping mt understanding of the fridge system as it related to the research questions using a causal loop diagram (see Fig. 1 below).

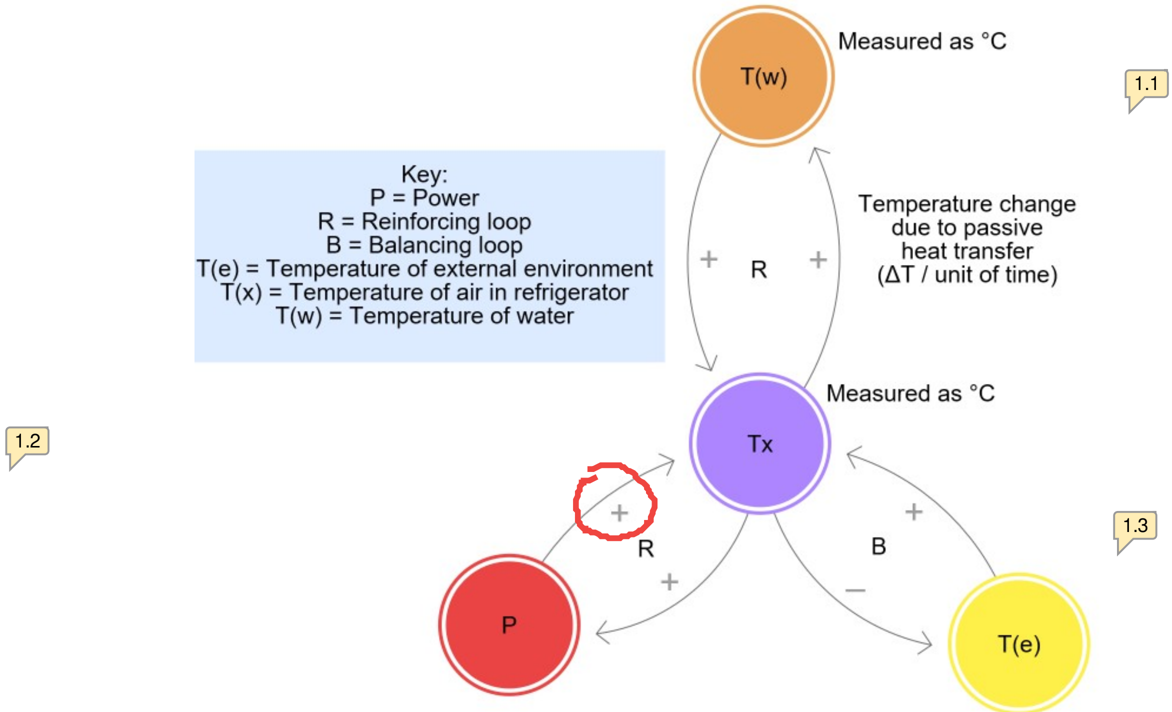

Figure 1: Initial causal loop diagram

Based on this diagram I formed hypotheses that (2) placing the tea in the fridge would reduce the temperature of the tea and (2) increase the ambient temperature of the fridge initially before it reduced over time. In addition, based on Newton's law of cooling (Winterton 1999) I assumed that tea with a high temperature would reduce in temperature at a faster rate than tea with a low temperature.

2. Methods

As identified in Fig. 1, I intended to measure the change in two state variables in degrees Celcius (°C) over a time period through my experiment – the temperature of water and ambient temperature in the fridge. In addition, I intended to use measurements of the temperature of water to calculate the rate of change in the water temperature. The equipment used and procedure employed to conduct these measurements is outlined below.

2.1 Equipment:

- Ceramic mug
- Kettle
- Choi family refrigerator
- Milk Frothing Thermometer
- Circuit Playground Express (CPE)
- Battery Holder and 3 x AAA batteries for CPE
- Stopwatch / timer
- Laptop

I used a ceramic mug rather than a plastic mug, or a mug of other material, as this reflected the mug material used by my partner when having a tea. All other items were chosen based primarily on availability. I attempted to keep all materials consistent across the three recordings (including the contents of the Choi family refrigerator).

2.2 Procedure:

1. Boil 200ml of water in a kettle and pour water into a ceramic mug
2. Place thermometer in the mug and wait until water reduces to 70°C and record the value.
3. Place water with thermometer in refrigerator, start recording ambient refrigerator temperature using CPE and start timer.
4. After 3 minutes open refrigerator. Observe and record temperature value displayed on thermometer.
5. After 6 minutes open refrigerator. Observe and record temperature value displayed on thermometer.
6. After 9 minutes open refrigerator. Observe and record temperature value displayed on thermometer. Stop recording ambient refrigerator temperature using CPE and stop timer.
7. Repeat steps (a) to (f), waiting until water reduces to 60°C at step (b)
8. Repeat steps (a) to (f), waiting until water reduces to 50°C at step (b)
9. Connect CPE to a laptop and view temperature data captured on CPE.

I chose 200ml of water to reflect a mug of tea. I conducted the first recording using water at 70°C as this was the temperature I observed on the thermostat after I placed it in the water immediately after pouring the water from the kettle in the mug. I used 60°C and 50°C for the second and third recordings, respectively, to create a temperature buffer between the recordings that I thought would be sufficient to demonstrate some difference in the measurements. Finally, I chose 3, 6 and 9 minute intervals to test time periods my partner often leaves a tea in the fridge.

2.3 Limitations:

My research did not include any repetition of the experiment, which limited my ability to calculate standard deviation and add error bars to any figures. I also did not investigate whether the same or similar results could be replicated with the same experiment using, for example, different materials (i.e. plastic mug, with lower thermal conductivity than a ceramic mug, or another refrigerator), different starting temperatures, or different time intervals. These two factors limit my confidence in any findings from the research.

My experiment did not involve any testing of the accuracy of the thermostat or the thermistor on the CPE prior to conducting the experiment. I also did not use any additional sensors to verify the data from either the thermostat or the thermistor on the CPE.

2.4 Assumptions

The first assumption I made when designing my experiment to answer my research question were that: (1) the effect of placing water in the fridge and tea (i.e. water infused with tea leaves) on the temperature of both liquids is consistent, as is the effect on the ambient temperature. If I had my time again I would redo the experiment using tea rather than water. 3.1

Additionally, my research assumed that the external environment to the fridge is consistently a greater temperature than the ambient temperature in the fridge. Were the experiment to be conducted in an environment colder than the refrigerator, I would need to review the system map in Fig. 1.

3. Analysis

3.1 Temperature of the water

The water placed in the refrigerator reduced in temperature in all three recordings across all time intervals – at 70°C, 60°C and 50°C (see Table 1). The first recording using water at 70°C at commencement produced the greatest rate of temperature change, followed by the recording at commencing at 60°C and then 50°C recording. These results align with my hypothesis and Newton's law of cooling. See Figure 2 for a graphical representation of the data in Table 1.

Table 1: Temperature of water and rate of temperature change

Recordings	**Temperature (°C) at time intervals**				**Rate of temperature change** *(over 9-minute experiment)*
	0 minutes	*3 minutes*	*6 minutes*	*9 minutes*	
Record 1 (70°C water)	70	56	49	43	- 3 °C / minute
Record 2 (60°C water)	60	50	46	42	- 2 °C / minute
Record 3 (50°C water)	50	42	38	35	- 1.67 °C / minute

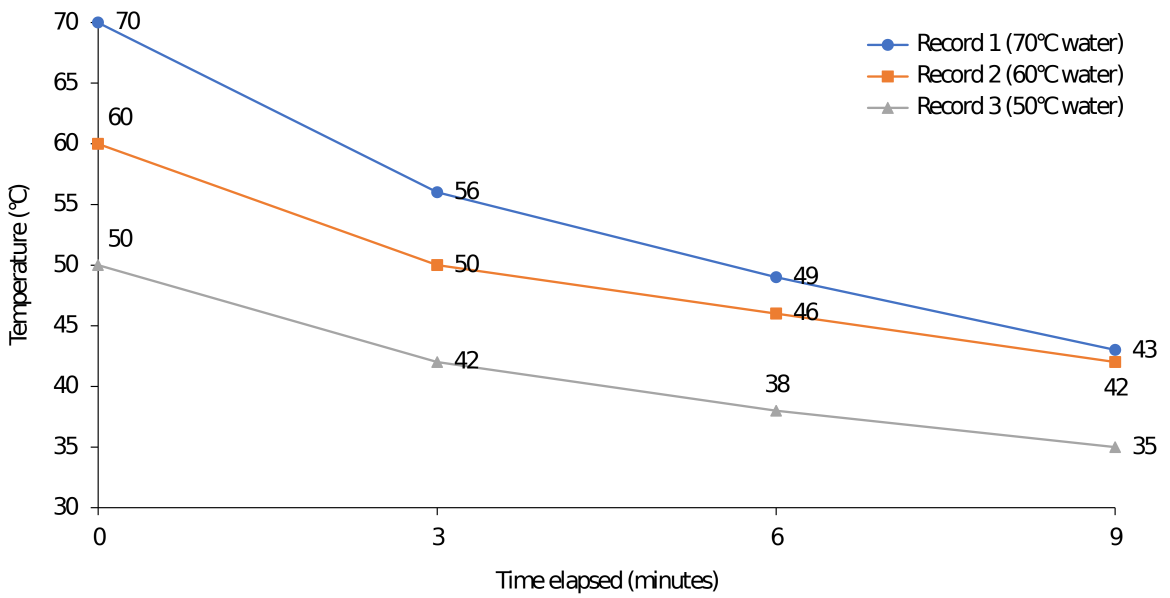

Figure 2: Temperature of water over time

3.1.1 Measurement problems

Opening the door of the refrigerator at each three-minute interval may have affected the temperature of the water I observed on the thermometer at each point. Assuming the external environment was a higher temperature than the temperature of the water and the ambient temperature of the fridge, this is likely to have increased the recorded temperature at these points (see Fig. 1 for causal loop of this phenomenon.

3.1.2 Errors

The origin of the thermostat used for recording the temperature of water in this experiment is uncertain, and all recordings were based on manual observations of the thermostat. This impacts the reliability and accuracy of the results.

3.2 Ambient temperature of the refrigerator

The ambient temperature of the refrigerator reduced from a high of around 19°C at commencement in all three recordings, to a low between 8 – 9.5°C in all three recordings.

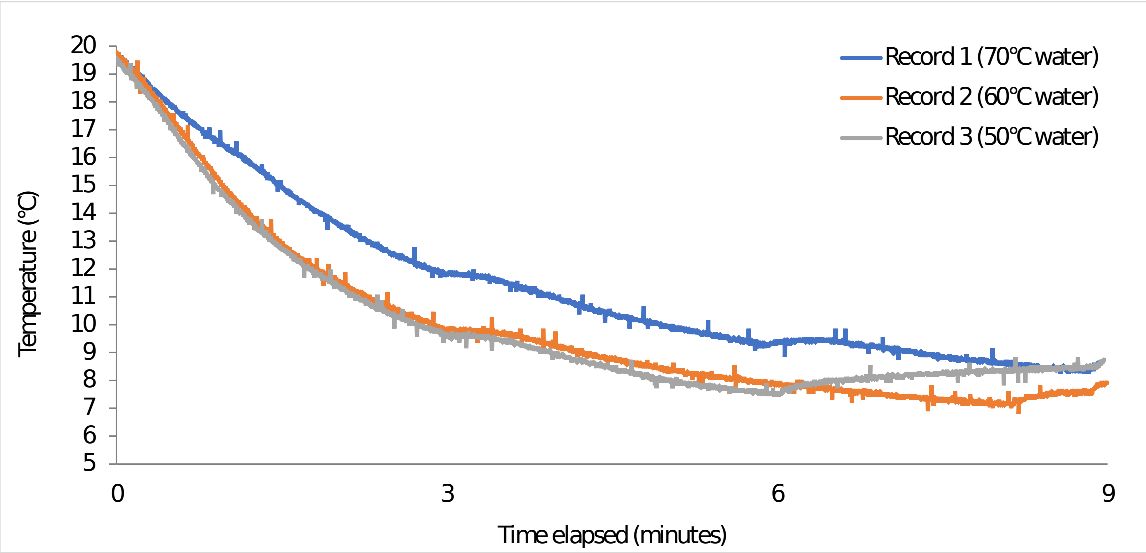

Figure 3: Ambient temperature of the refrigerator over time

3.2.1 Measurement problems:

The thermistor on the CPE does not record the ambient temperature, but instead records the temperature of the board (Adafruit 2017). The temperature recordings in Fig. 1 appear higher than I expected the ambient temperature to be when I started the experiment, based on the fridge specifications and settings.

My experiment also did not include any measurement of the ambient temperature of the refrigerator before the mug was placed inside. As such, it is not possible from the experiment to determine the immediate effect of placing the mug inside the refrigerator on the ambient temperature of the refrigerator.

As in 3.1.1, opening the door of the refrigerator at each time interval may have also affected the ambient temperature of the refrigerator. These spikes in temperature appear observable in Fig. 3.

3.2.2 Errors

Fig. 3 indicates that Record 3 increased in temperature between the 6 and 9 minute interval, which did not align with my hypothesis for this experiment. There may have been a error in the last interval for this recording.

3.2.3 Equipment problems:

I was not able to write temperature data from the temperature sensor on the CPS to the storage on the board. As a result, I connected the laptop to the CPE for power, and wrote data from the CPE to an .csv file saved on the laptop. Using a laptop instead of the battery pack increases the thermal energy added to the fridge from this experiment, which would affect the ambient temperature of the fridge during the experiment (assuming the laptop has more thermal energy than the battery pack).

4. Results / Discussion

The results presented in Section 3 reflect my hypotheses for the research. However, there were a range of limitations to the methods for this experiment and measurement problems, errors and equipment problems with the experiment as conducted which limit my confidence in the findings of the research.

Nonetheless, the experiment enabled me to review and update the system map created at the start of the research. After discussions with staff, it became clear that the original system map did not correctly represent the relationship between two state variables – the temperature of air in the refrigerator and the power for the fridge. To update the map I added a state variable for the 'target temperature' (altered by shifting the thermostat in the refrigerator) and for 'absolute temperature delta', along with feedback loops to demonstrate how these state variable interacted with power requirements to regulate the temperature of air in the refrigerator (see Fig. 3). Correcting the system map with the addition of these state variables and feedback loops adds the potential for new measurements (e.g. power requirements at different target temperature settings) and new research questions!

5.1

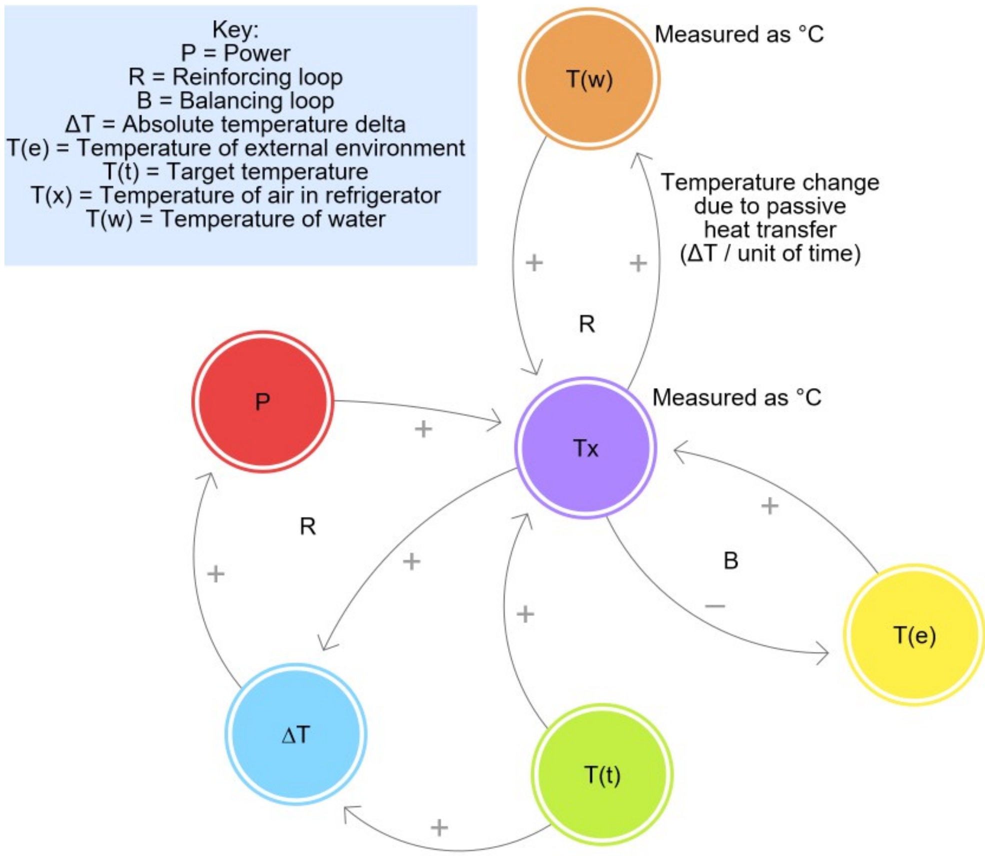

Figure 4: Final system map

References

Adafruit Industries. 2017, 'Adafruit Circuit Playground Express'. https://learn.adafruit.com/adafruit-circuit-playground-express/playground-temperature?view=all. [Accessed 6 August 2020].

Proust K, and Newell B., 2020, 'Constructing Influence Diagrams & Causal Loop Diagrams' ANU Open Research Repository, Canberra ACT.

Winterton R. H. S. 1999, ‘Newton's law of cooling’, *Contemporary Physics*, 40:3, 205-212.

Index of comments

1.1 There are some assumptions built in here re: relative temperatures, which also are likely to lead to some issues with the polarities (e.g. the link between T(x) and T(w)). In future, it'd be good to note these assumptions when you introduce the diagram.

1.2 As power consumption increases is the temperature of the air in the fridge likely to increase or decrease?

1.3 Is there a link between the temperature of the external environment and power consumption?

2.1 Nice justification of why you chose a particular container type. Explaining *why* you made choices like this is useful for understanding how your research question, as expressed, maps to your experimental design choices.

2.2 This is excellent as well -- very clear.

3.1 Very clear articulation of the assumptions you made in your experiment (and in your map).

4.1 Thermostat or thermometer? This is ok. Can you think of some ways you could have verified the calibration of the thermometer, if needed?

4.2 Could you have taken a baseline measurement of the internal temperature of the fridge with the thermometer?

5.1 Adding these two variables is useful, but I'm going to suggest making sure you clearly define all new variables (your definition for delta T in this case has to be inferred). The same comments re: polarities from your first diagram apply here.