TEMPERATURE MONITORING SYSTEM USING ARDUINO

SISTEMA DE MONITORAMENTO DE TEMPERATURA USANDO ARDUINO

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ABSTRACT

This article presents a temperature measurement system using a microcontroller connected to a circuit with operational amplifiers and a Pt100 sensor. The project discusses introductory aspects of instrumentation and its potential for developing interdisciplinary knowledge in the STEM field. The prototype consists of an electronic circuit, associated with a supervisory system in Labview software, capable of monitoring the temperature of the sensor, which is kept in a recipient with a liquid. The microcontroller circuit monitors the temperature using data from serial communication. The project can be enhanced as a teaching activity to consolidate prototyping concepts and equations related to temperature variation, such as Newton's Law of Cooling, which involves the concept of the derivative. This allows students to visualize how abstract mathematical concepts, such as the derivative, are observed in the real world, as the temperature of the liquid decreases over time in contact with the environment. Therefore, knowledge related to instrumentation and data monitoring using digital systems were discussed.

Keywords: Temperature, Arduino, Monitoring, Didactic.

RESUMO

Este artigo apresenta um sistema de medição de temperatura utilizando um microcontrolador conectado a um circuito com amplificadores operacionais e um sensor Pt100. O projeto discute aspectos introdutórios de instrumentação e suas potencialidades no desenvolvimento de conhecimentos interdisciplinares no campo de STEM. O protótipo é composto por um circuito eletrônico, associado a um sistema supervisório no software Labview que é capaz de monitorar a temperatura do sensor que está mantido em um recipiente com um líquido. O circuito microcontrolado monitora a temperatura pelos dados provindos da comunicação serial. O projeto pode ser aprimorado como uma atividade didática para consolidação de conceitos de prototipação e sobre equações ligadas à variação de temperatura, como a Lei do Resfriamento de Newton, que envolve o conceito de derivada. Dessa forma, é possível para o aluno visualizar como conceitos abstratos da matemática, como a derivada, se observam no mundo real, pois a temperatura do líquido diminui ao longo do tempo em contato com o meio ambiente. Devido a isso, foram discutidos conhecimentos relativos à instrumentação e monitoramento de dados utilizando sistemas digitais.

Palavras-chave: Temperatura, Arduino, Monitoramento, Didático.

1 INTRODUCTION

Since ancient times, the control of heat sources, as flames or candles, has allowed the illumination of spaces and expanded the human ability of interaction with surroundings. In urban societies, systems that monitor the temperature of objects or environments became each time more frequent, in a process intensified by the industrial expansion.

In the STEM (Science, Technology, Engineering, and Mathematics) field, the need to train people for complex projects has led engineers to create educational prototyping kits. One of these, a low-cost one, is called Arduino and is designed for familiarizing students with C++ programming. With practical projects, it is possible to perform low-level programming, which involves controlling inputs and outputs, integrated with more complex computer-processed systems. Experimental activities can develop the ability to collect and interpret data, formulate hypotheses, and create models.

Prototyping with Arduino is a practice that can support in understanding content covered in theoretical classes. In this sense, appropriate experimental resources can help achieve better results in electronics, computing, physics, mathematics and other sciences.

An algorithm can be described as a sequence of computational steps that transform input into output (Cormen, 2009). By this definition, any computational procedure that receives a value or set of values as input and produces a value or set of values as output can be considered an algorithm. In the field of computing, an algorithm is thought of as a "tool for solving specific computational problems" (Cormen, 2009).

For a proposed solution to be efficient, the algorithm must be optimized in terms of memory requirements and computable within a runtime that can also be processed by the microcontroller. To be run on an Arduino, the algorithm cannot be demasiate complex. Complex algorithms are generally developed for other more robust microcontroller models or for a personal computer (PC). An algorithm designed to run on an Arduino must take into account the hardware's characteristics. Therefore, it must consider the device's memory limitations.

The performance of an algorithm depends on several factors, not limited to its theoretical complexity. It is possible to measure the computational time required for each problem, as well as the number of failures and the solution's error (Cormen, 2009).

This project involved a practical temperature measurement project, and aimed to discuss topics related to the use of the Arduino microcontroller for measuring physical quantities and as a didactic tool in engineering. Furthermore, its potential for laboratory activities is discussed.

The economic matrix of countries has changed substantially in recent centuries, and emerging economies have increasingly become less dependent on agricultural activities, with economic diversification occurring. In the case of some countries, economies with a strong role in information, engineering, and technology have become possible.

Currently, society is witnessing an expansion of productive activities linked to technology, science, and engineering. Interdisciplinary activities, which combine concepts from different disciplines, enable more effective learning, which also results in students being better prepared for the analytical and projective challenges of different areas. Following certain trends, multidisciplinary projects have been implemented to build knowledge in elementary schools, offering experiences with prototyping, design, model and hypothesis evaluation, and the development of applied solutions. On the other hand, conducting experimental activities with introductory science topics is challenging.

With a simple project involving Arduino and its most fundamental modules, a temperature meter can be proposed. The project is extensively documented in the literature and is not original to this text. However, such an activity can lead to a discussion with specificities, which are presented in the following text.

To understand what temperature is, it is necessary to go through a historical line that involves contributions from different individuals. During centuries, the relationship between hot and cold was used in Hippocratic-Galenic medicine. During the Renaissance, the Latin term "*temperatura*" was used to describe the mixture of qualities involving hot and cold. The first experimental temperature measurements occurred in the XVI and beginning of XVII century, inspired by experiments by the Greeks Philo and Hero (White, 2020, p. 257).

At the end of the XVI century, it was developed the “thermoscope”, a precursor to the thermometer. It was a device designed to indicate temperature variations based on the expansion and contraction of air. Although it lacked a numerical scale, it allowed for the visualization of thermal changes through the movement of a liquid in a glass tube. During this period, Galileo Galilei is believed to have influenced the development of this device, as Galileo built a rudimentary model of the machine in 1592 (White, 2020, p. 257).

The thermoscope consists of a glass bulb and a capillary immersed in water. As the air in the bulb expands and contracts, the water rises and falls in the capillary, indicating temperature changes. In a sense, it can be seen as an ancient thermometer using water and air, in which temperatures were marked with string and calipers were used to measure the changes. Over decades of use, the thermoscope evolved into liquid-in-glass thermometers. The instruments were sealed, and the air was replaced with water to eliminate the influence of atmospheric pressure. Brandy was introduced into the system to replace water because it was more sensitive and did not freeze. Furthermore, mercury replaced brandy because it was more reproducible. However, there was no unified scale (White, 2020, p. 257).

The Fahrenheit scale originated in 1724, when physicist Daniel Gabriel Fahrenheit proposed the temperature scale, based on three original fixed points: the temperature of a mixture of ice and salt (0 °F), the temperature of the human body (96 °F) and the boiling point of water (212 °F). In addition to experimental developments, using better materials that allowed for the reproduction of experiments, abstract formulations and concepts emerged that gradually defined temperature. Understanding, however, depends on the construction of a mathematical language that isolated temperature from other physical and mathematical objects. This process was as slow as the development of experimental apparatus for measuring temperature.

Temperature is a physical quantity that expresses the degree of agitation of the particles in a system, directly related to the average kinetic energy of the molecules. Broadly speaking, it is a measure of the thermal state of a body and determines the direction of heat flow between two systems.

In a system, heat flows spontaneously from the body with a higher temperature to the one with a lower temperature. Heat flows from one substance to another through conduction, convection, and radiation. In the development of thermodynamics, the notion of temperature was formalized by several scientists. James Prescott Joule experimentally demonstrated the equivalence between mechanical work and heat, which contributed to the formulation of the principle of conservation of energy and reinforced the idea of temperature as a reflection of a system's internal energy.

Later, Rudolf Clausius established the second law of thermodynamics, introducing the concept of entropy and contributing to the distinction between heat and work. From this point on, temperature began to be understood not only in mechanical terms, but as a fundamental variable in the irreversible behavior of thermal systems. Constantin Carathéodory offered a more abstract mathematical formulation of thermodynamics, based on the state-space structure, in which temperature emerges as an integrable function related to energy and entropy. His approach allowed us to define temperature without directly resorting to empirical notions of heat, reinforcing its nature as a fundamental state variable in the thermodynamic formalism (White, 2020, p. 259).

Temperature can be measured on different scales, such as Celsius (°C), Kelvin (K), and Fahrenheit (°F), with the Kelvin scale being the one used in the International System of Units (SI). This concept is fundamental in thermodynamics and is associated with the average kinetic energy of the constituent particles of matter.

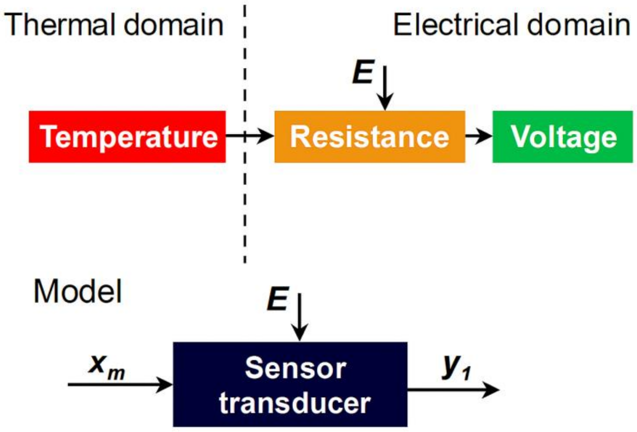
The project presented in this article aims to implement a temperature gauge on a scale of 0°C to 100°C using a Pt100 resistance thermometer, which has a value of 100 ohms at 0°C. The project was developed using an Arduino Uno, an interface with LabView software, and a circuit involving a Wheatstone bridge for sensitive measurement of changes in the resistive element. The practical project provides familiarity with the field of instrumentation and control, and an introductory approach to applied computing.

2 THEORETICAL BACKGROUND

2.1 Resistance variation measurement

Thermal-electric transducer sensors, such as the RTD, convert temperature variations into electrical signals. In the thermal domain, the measured physical quantity is temperature, which causes a change in the electrical resistance of the sensing material. This variable resistance, when subjected to electrical excitation (E), results in an output voltage proportional to the temperature. Thus, transduction occurs between the thermal and electrical domains. In the illustrated model, the input signal (x_m) represents the physical variable (temperature), and the output signal (y_1) corresponds to the sensor's electrical response, allowing for a quantitative interpretation of the measured variable.

Figure 1 - Relationship between the thermal and electrical domains in the resistance thermometer measurement model



Source: the authors (2025)

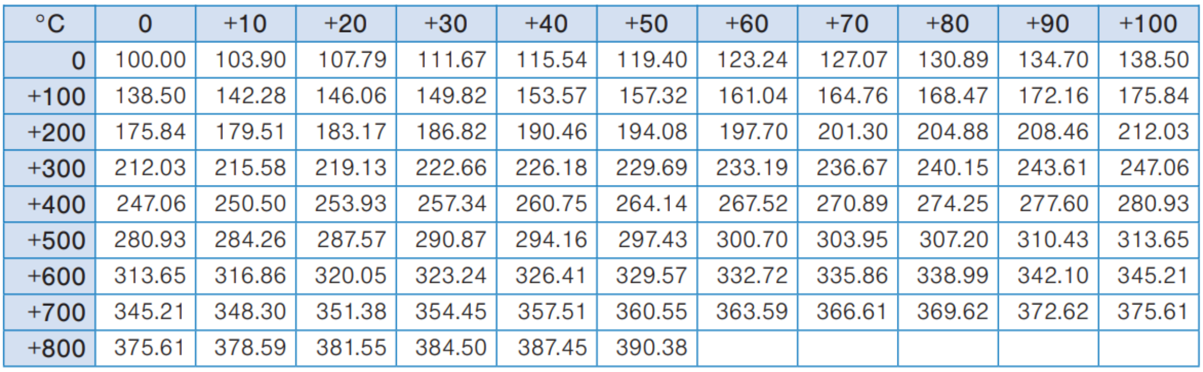
Temperature measurement using resistance sensors, such as the PT100, is associated with the development of thermal instrumentation. The development of electrified designs using conductive materials is also linked to the implementation of temperature measurement systems during the XIX and XX centuries.

In the XIX century, Sir William Siemens observed and demonstrated that the electrical resistance of metals increases linearly with temperature. In 1871, Siemens proposed the use of platinum as a sensing element due to its chemical stability, corrosion resistance, and linear behavior over a wide temperature range. His early experiments were pioneering for the later use of resistance temperature detector (RTD) technology, with platinum quickly establishing itself as a material of significant use.

The development of PT100 as a standard came later, in the XX century, when international norms began standardizing resistance temperature sensors. The acronym “PT” refers to Platinum, and the number 100 indicates that the sensor has 100 ohms of resistance at 0°C. Organizations as the IEC or the International Electrotechnical Commission established calibration curves and tolerances, enabling the integration of PT100 into industrial process control systems. Over time, technological improvements in the manufacturing process, platinum purification, and sensor miniaturization have made PT100 more robust and accurate. Today, they remain widely used because their reliability, stable response and good linearity over certain temperature ranges.

Because platinum resistivity varies with temperature, Pt100 requires electronic signal conditioning circuits for its data to be correctly interpreted by digital systems. The integration of these sensors into supervisory systems or human-machine interfaces represented a significant advance in thermal control engineering, enabling real-time monitoring of industrial thermal processes.

Table 1 - Resistance versus temperature for Pt100



°C	0	+10	+20	+30	+40	+50	+60	+70	+80	+90	+100
0	100.00	103.90	107.79	111.67	115.54	119.40	123.24	127.07	130.89	134.70	138.50
+100	138.50	142.28	146.06	149.82	153.57	157.32	161.04	164.76	168.47	172.16	175.84
+200	175.84	179.51	183.17	186.82	190.46	194.08	197.70	201.30	204.88	208.46	212.03
+300	212.03	215.58	219.13	222.66	226.18	229.69	233.19	236.67	240.15	243.61	247.06
+400	247.06	250.50	253.93	257.34	260.75	264.14	267.52	270.89	274.25	277.60	280.93
+500	280.93	284.26	287.57	290.87	294.16	297.43	300.70	303.95	307.20	310.43	313.65
+600	313.65	316.86	320.05	323.24	326.41	329.57	332.72	335.86	338.99	342.10	345.21
+700	345.21	348.30	351.38	354.45	357.51	360.55	363.59	366.61	369.62	372.62	375.61
+800	375.61	378.59	381.55	384.50	387.45	390.38					

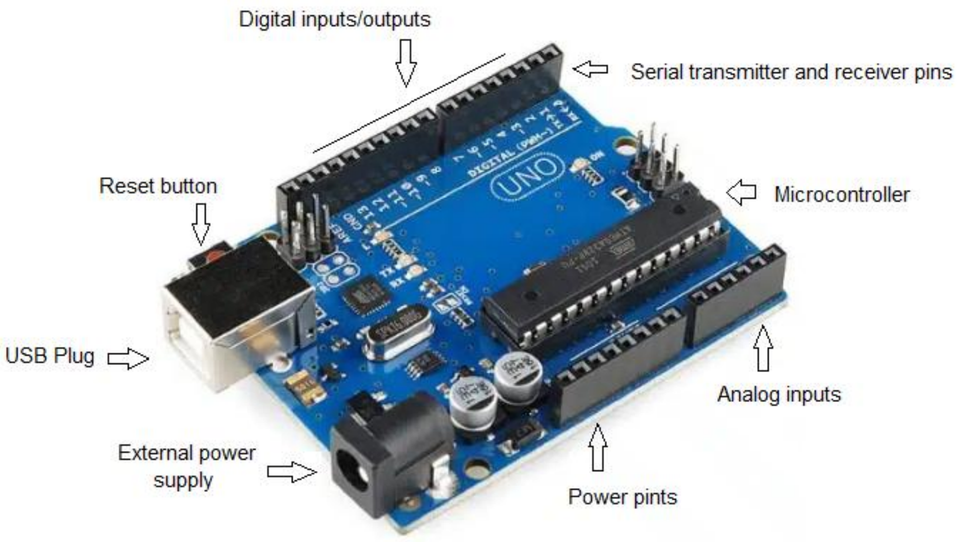
Source: Data sheet TF Pt100-3L from Störk-Tronic (2023)

The development of digital temperature measurement systems is linked to the studies of mathematical and physical studies on thermal conduction. A fundamental formulation in this context was the work of Joseph Fourier, in the early XIX century, whose investigations resulted in the heat diffusion equation. Based on the studies of Fourier, it was possible to understand the propagation of heat in continuous media.

After the historical comments, current teaching technologies that allow the visualization of physics and mathematics concepts can be considered. The Arduino platform, used for automatic data acquisition, is a methodology capable of support the teaching and learning process of Physics.

Arduino is a microcontroller platform based on Atmel microcontrollers, with a wide range of models available for the development of activities. It is a flexible and didactic board, based on C/C++, which can interact with the environment through sensors and actuators, communicating with a computer to perform a task using specific software.

Figure 2 – Arduino structure



Source: the authors (2025)

The Arduino board uses the Atmel microcontroller as its command center. It stores the processes executed by the integrated microcontroller, which executes these commands. Most boards can be powered via the USB port or an external 6 to 12 V DC power supply. Arduino boards have digital ports that can be used as digital inputs or outputs, in addition to analog ports that can receive 0-5V signals.

The number of ports varies depending on the board model. Analog inputs can assume various values within a 0-5V range. However, the board's microcontroller doesn't work with analog signals, only digital ones. Therefore, it's necessary to convert an analog signal to a digital value. This process is performed by the Analog-to-Digital Converter, or A/D Converter. The number of values representable by an A/D converter depends on its bit resolution. The resolution of an A/D converter can be obtained using Equation 1:

$$Resolution = \frac{Vref}{2^n}$$

Where: (Vref) is the reference voltage of the A/D converter. In the case of the Arduino UNO, it is 5 V; (n) is the number of bits of the converter. In the case of the ATmega328, n = 10.

$$Resolution = \frac{5V}{2^{10}} = \frac{5}{1024} = 0{,}00488\,V$$

Each increment in the digital value represents approximately 4.88mV.

Sensors can be analog or digital, with analog sensors being electronic, such as those found in alarms, thermometers, clocks, electronic thermal compensation circuits, heat sinks, and air conditioners. Sensors can be either Negative Temperature Coefficient or Positive Temperature Coefficient thermistors.

Regarding temperature control, several studies based on thermal systems consider the modeling of thermal systems. Martinazzo and Orlando developed a comparative study on temperature measurement using different types of sensors and a circuit based on the Arduino Uno microcontroller. They used LM35, Thermistor, and DS18B20 sensors. They performed 40 measurements for each sensor. The comparison was made using a mercury thermometer as a reference. The LM35 showed greater variation than the other sensors, while the other sensors presented more stable readings (Martinazzo, Orlando, 2016, p. 103).

The authors determined that the best option among the three is the DS18B20 digital sensor. Thermistor and LM35 sensors can also be used in cases where high sensor sensitivity is not required, and they are less expensive (Martinazzo, Orlando, 2016, p. 103). The DS18B20 is a digital sensor and does not require analog-to-digital signal conversion. Although it is expensive, it is best suited for applications requiring greater precision and repeatability. The LM35 and thermistor sensors are analog and require the conversion of their analog readings to digital, considering the resolution of the Arduino system, 10 bits, and the sensors themselves (Martinazzo, Orlando, 2016, p. 104).

The first microcontrollers appeared in the decade of 1980, but they became popular in later years. Microcontrollers are present in everyday devices in several technologies, as cell phones, cars, and televisions. In urban societies, embedded systems are present in applications and fields (Martinazzo, Trentin, Ferrari, and Piaia, 2014).

Currently, there are several low-cost microcontroller options on the market, but the best-known is the Arduino board, which has become popular as a teaching kit for learning basic applied computing concepts. The Arduino module is based on an Atmel AVR microcontroller. Programming is performed on the computer and then transferred to the Arduino via a USB cable. The Arduino board consists of an open-source microcontroller platform and a standard C/C++ language, allowing it to be used for acquiring and processing sensor data from its input ports.

The Arduino software development environment is called an IDE, which stands for "Integrated Development Environment." It's where code is developed and programming concepts are applied for later compilation and testing on breadboards or test simulators like Thinkercad.

In physics learning, computational modeling of phenomena and study through experiments with microcontrollers can be valuable resources for better understanding certain topics. Consequently, the portable "microcomputer" can be used as a science laboratory instrument, allowing students to see in practice what is found in textbooks (Martinazzo, Trentin, Ferrari, & Piaia, 2014).

Various phenomena can be studied in practical projects using an Arduino, whether for displaying data on a connected 16x2 LCD display or for other data acquisition purposes. Some examples include acceleration, uniformly varied motion, oscillation, cooling, evaporation, falling bodies, and heat studies.

It is well known that studies on the heating of liquids and solids, and on heat conduction, were essential to the industrial revolution of the XVIII century and to the improvement of production systems that depended on machines. Consequently, a series of studies by mathematicians and physicists were developed to understand heat, combustion, and the possibilities of instrumentalizing natural forces for practical purposes (White, 2020, p. 258).

Temperature is a fundamental quantity in physics. Various types of sensors can be used to measure temperature values. It can be mentioned: thermistors, integrated circuits like LM35, LM60, PT100 and thermocouples. In this article, it was applied a platinum based sensor, PT100 and a termopar for reference measure.

There is a famous quote by Galileo Galilei that states that the great book of nature was written in mathematical language. According to this quote, the book of the sensible world could only be understood by those who knew the language in which it was written, and that language would be mathematics. Although this statement has sparked debate among mathematicians about its validity, it can be argued that activities that foster mathematical comprehension in students should be valued, as they contribute to a more accurate understanding of the physical world.

Newton's Law of Cooling describes the process by which an object's temperature changes over time when it is exposed to a constant-temperature environment. The law is expressed by the differential equation:

$$\frac{dT}{dt} = -k\,(T - Tamb)$$

Where: (T) is the temperature of the object at a given instant; (Tamb) is the ambient temperature or the medium; (k) is the cooling constant that depends on the thermal and geometric properties of the system; (t) is time.

When Tamb is constant, the solution to the differential equation is:

$$T(t) = Tamb + (T0 - Tamb).\,e^{-kt}$$

Where T0 is the initial temperature of the object at time t = 0.

The derivative represents the rate of change of one quantity in relation to another. In this case, how the temperature of a body varies over time. In Newton's Law of Cooling, the derivative is used to mathematically express the idea that "the rate at which the temperature of an object changes" is proportional to the "difference between the temperature of the object and that of the surroundings." This mathematical language allows us to quantify this continuous change, that is, it describes "how" and how quickly the object cools at each instant. Thus, when using a derivative, the law translates a physical observation that cooling is faster when the temperature difference is greater, which is expressed in the form of an equation.

Newton's Law of Cooling states that the rate at which an object's temperature changes is proportional to the difference between its temperature and its surroundings. The greater the difference, the greater the rate at which the object cools or heats. As the temperature difference decreases, the rate at which the object changes temperature also decreases, approaching the surrounding temperature over time.

Newton's Law of Cooling is used in systems involving heat exchange, such as air conditioning, food preservation, and the study of chemical processes in reactors. It is an approximate model for situations where the temperature difference is not very large and convective and radiative effects are the main heat exchange mechanisms. There are other fundamental laws and principles that describe the behavior of temperature in liquids, especially in the context of heat transfer and phase changes.

Fourier's Law of Thermal Conduction describes heat conduction in solid and liquid materials. It states that the rate of heat transfer (Q) through a substance is directly proportional to the cross-sectional area (A) and the temperature difference (ΔT), and inversely proportional to the thickness (L) of the material. The Fourier Law equation is given by:

$$Q = -k.A.\frac{\Delta T}{L}$$

Where: (Q) is the heat transfer rate (W); (k) is the thermal conductivity of the material; (A) is the heat exchange area; (ΔT) is the temperature difference; (L) is the thickness of the material.

This law applies to both solids and liquids, and is essential for understanding how temperature propagates in liquids when there is a thermal difference.

In turn, Hii’s Law, or the Law of Convective Heat Transfer, is also used by scientists and engineers. In liquids, heat exchange also occurs through convection, which is the process of heat transport due to fluid movement. The convective heat transfer equation can be expressed as:

$$Q = h.A.(Tsurface - Tliquid)$$

Where: (Q) is the rate of convective heat transfer (W); (h) is the convective heat transfer coefficient (W/m^2.K); (A) is the surface area in contact with the fluid (m^2); (Tsurface) is the surface temperature (K or ºC); Tliquid is the fluid temperature (K or ºC).

The equation shows that the rate of heat transfer is proportional to the temperature difference between the surface and the fluid relative to the contact area available for heat exchange. Hii's Law is relevant to the study of processes such as heating liquids in boilers and cooling fluids in heat exchange systems. It can be a suitable approach for studying systems in which a liquid moves, such as in pumps or refrigeration circuits.

The temperature of liquids is closely linked to phase change, the phenomenon that occurs when a liquid reaches its boiling or freezing point. Studying temperature in liquids is crucial to understanding processes such as distillation, freezing, and evaporation, which involve the laws of thermodynamics, such as the Clausius-Clapeyron Law, which relates pressure and temperature variations during phase changes.

The laws governing temperature in liquids are associated with the phenomena of conduction, convection, and phase change, and are studied for the control and analysis of thermal systems. The principles outlined above are applied in various industrial and laboratory processes where temperature control is required.

A temperature measurement activity using Arduino, however simple, can be developed to draw parallels with physics formulas and equations on the topic. This can enhance students' intuition about real-world applications of concepts like derivatives. One consequence of observing that the cooling of a heated liquid can be expressed by a derivative is that mathematical abstraction exists in the real world and can be part of everyday life. By observing that the liquid cools over a given time when in contact with room temperature, the student can imagine that a derivative is present and is part of that reality.

Khaing, Raju, Sinha, and Swe (2018) developed an automated temperature monitoring system using Arduino. They included a 16x2 LCD display in the project, which displayed temperature values. The microcontroller read the signals via the analog input and then converted them from analog to decimal. To display the values in °C and °F, the algorithm converted the data to each scale and then displayed the data. If the value read by the system exceeded the setpoint, the circuit activated a fan to reduce the temperature (Khaing, Raju, Sinha, and Swe, 2018, p. 235). The temperature sensor used by the authors was an LM35, which is an analog sensor, therefore requiring data conversion to digital.

Rosa, Marco, Rosa, and Giacomelli (2016) developed a prototype for measuring temperature and evaluating thermal conduction in a metal structure over time. The authors collected and processed data from an Arduino microcontroller using an LM35 temperature sensor. The heat source consisted of a lamp, and two metal bars of the same length were placed, with three thermometers positioned on each side. The purpose of the experiment was to assess whether there would be any difference between the bars, as one of the bars was made of aluminum and the other of copper. From the measurement table presented by the authors, it was possible to observe that the points marked on the copper bar reached a higher temperature than on the aluminum bar, considering that there was greater thermal conduction in the copper bar (Rosa, Marco, Rosa, Giacomelli, 2016, p. 299).

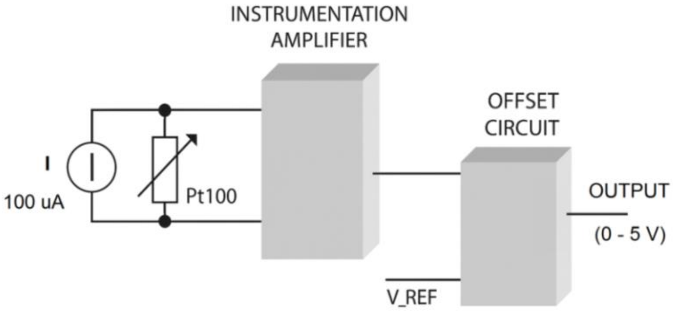
Ojeda-Misses developed a project with the Arduino microcontroller in which he presented a comprehensive analysis of Newton's law of cooling. The project involved a derivative, demonstrating the possibility of inserting a system to adjust the temperature read by the Arduino. The goal is to establish optimal control of the function, adjusted throughout the operation, to stabilize the system and reduce error (Ojeda-Misses, 2022, p. 167). The author presents a proportional derivative (PD) control.

Electrical resistance and its temperature dependence in conductors are included in physics curricula at the secondary, high school, and university levels. Electrical resistance and the factors that affect it, such as cross-sectional area, length, and conductor type, are covered in the 8th and 9th grades of primary school. Temperature-dependent changes in conductor resistance are typically studied in high school. Similar topics are included in physics courses in many university programs. Furthermore, factors that affect resistance, such as conductor length, type, and cross-sectional area, are examined in practical studies.

With hands-on activities, students can easily understand and apply these contents. However, because some schools lack experimental equipment, the understanding of the effect of temperature on resistance may not be sufficiently studied. The reason physics experiments related to the temperature-resistance relationship cannot be performed frequently may be due to the complex structure of the test equipment, such as heating elements, current modules, and resistance measurement modules, as well as the fact that they are not inexpensive.

The project has a 0-5 V voltage output and consists of a Wheatstone bridge connected to a linearization system. The integrated circuits used were LM351 operational amplifiers.

Figure 3 – Amplifier circuit

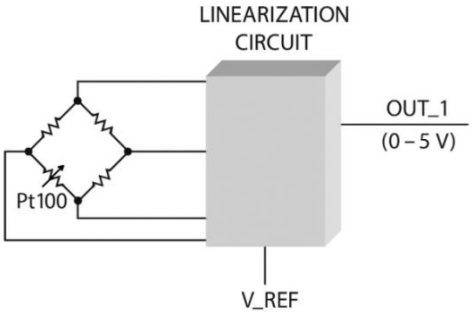


Source: the authors (2025)

The circuit uses a Wheatstone bridge for accurate resistance measurements, coupled with a PT100 temperature sensor. The PT100 is a temperature sensor based on a platinum resistor, which has a resistance that varies with temperature. The most important feature of the PT100 is that its resistance at 0°C is 100Ω and increases linearly with temperature, allowing for accurate measurement of thermal variations.

The Wheatstone bridge consists of an arrangement of four resistors arranged in a "bridge" configuration, with a central voltage point between two pairs of resistors. When the resistance of one of the resistors in the bridge varies, it causes an imbalance, which can be detected as a potential difference between the two central points of the bridge. The bridge is adjusted so that, in a balanced condition, the voltage between the two central points is zero. When the resistance of the PT100, which is one of the resistors in the bridge, varies due to a change in temperature, the bridge becomes unbalanced, generating a small output voltage that is measured by the circuit.

Figure 4 – Wheatstone Bridge

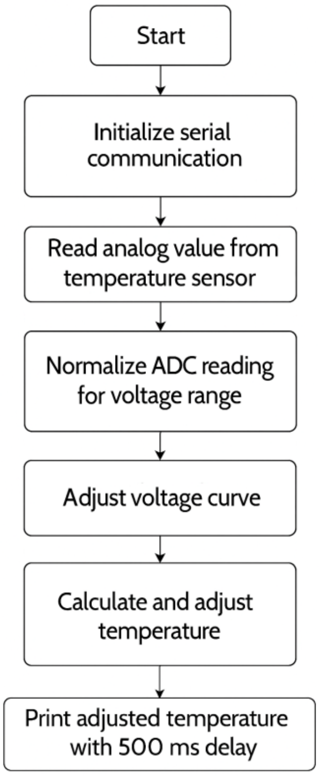


Source: the authors (2025)

3 MATERIALS AND METHODS

The system uses the Arduino platform to acquire the signal and reports the temperature to the computer via the Arduino's own serial interface monitor and also via the interface developed in Linx software. On the computer, the supervisory system responds to temperature variations detected by the sensor. On the breadboard, a circuit is connected to the Arduino microcontroller, which monitors temperature variations from the sensor in real time.

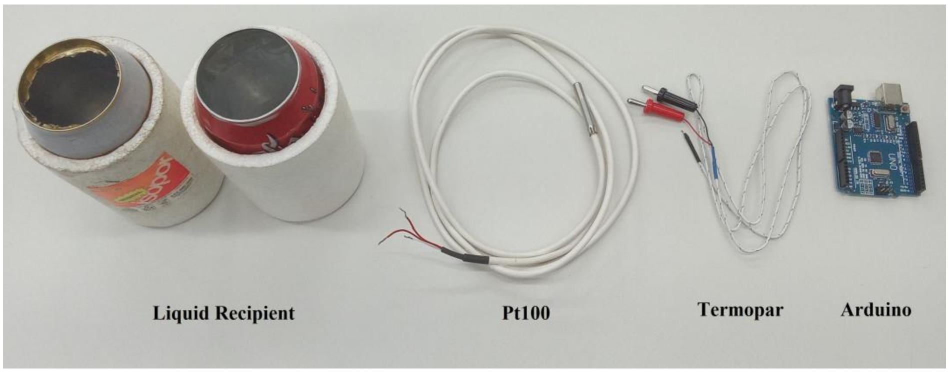
Figure 5 – Code flowchart on Arduino



Source: the authors (2025)

To collect temperature variation data, a liquid medium was used, consisting of two containers. One was filled with cold water, while the other was filled with water heated by a heat source.

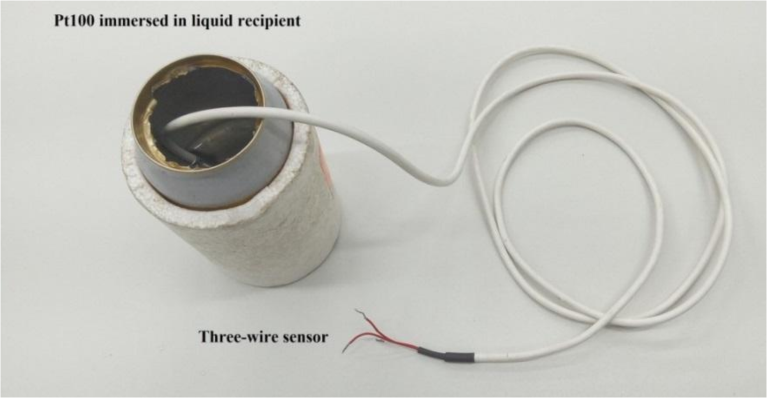
Figure 6 – List of materials



Source: the authors (2025)

During the experiment, both the Pt100 sensor and the thermocouple were immersed in liquid. The thermocouple, connected to a multimeter on the temperature scale, was used as a reference system because its error is low.

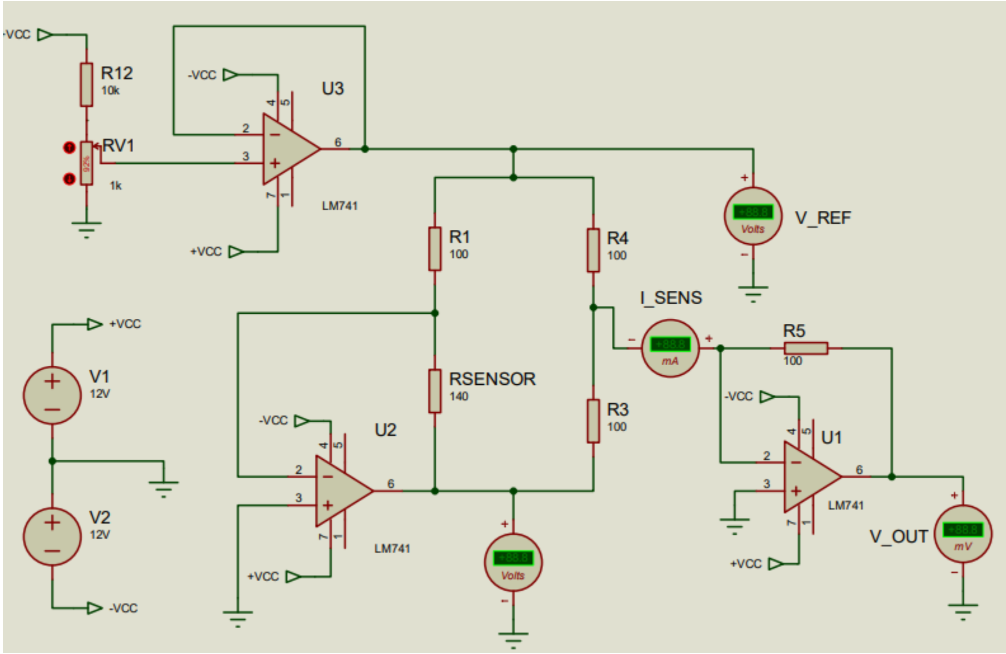
Figure 7 – Apparatus for collecting temperature signals



Source: the authors (2025)

The temperature sensor has a resistance output that varies from 100 to 138 ohms for the temperature range, and is represented as "Rsensor" in the schematic circuit figure.

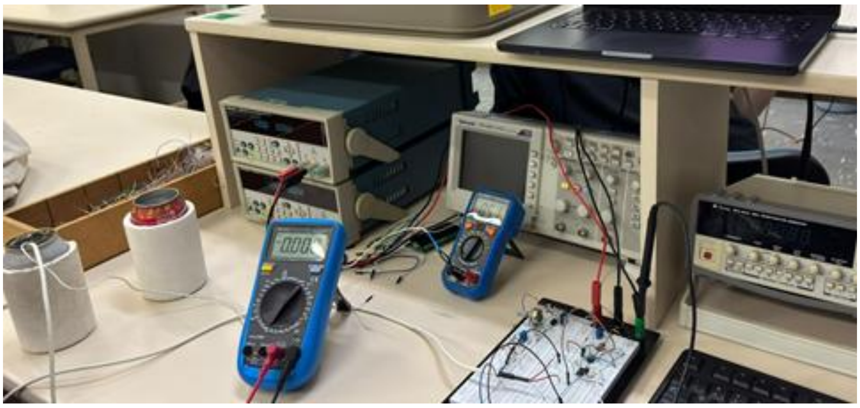
Figure 8 – Data acquisition circuit from the temperature sensor



Source: the authors (2025)

Figure 9 shows an integrated circuit assembly, comprising a breadboard connected to the Arduino and the computer, as well as a container that stores water. The sensor is immersed inside the metal can, and the water temperature is altered by a heated water source.

Figure 9 - Assembly of the temperature measurement circuit

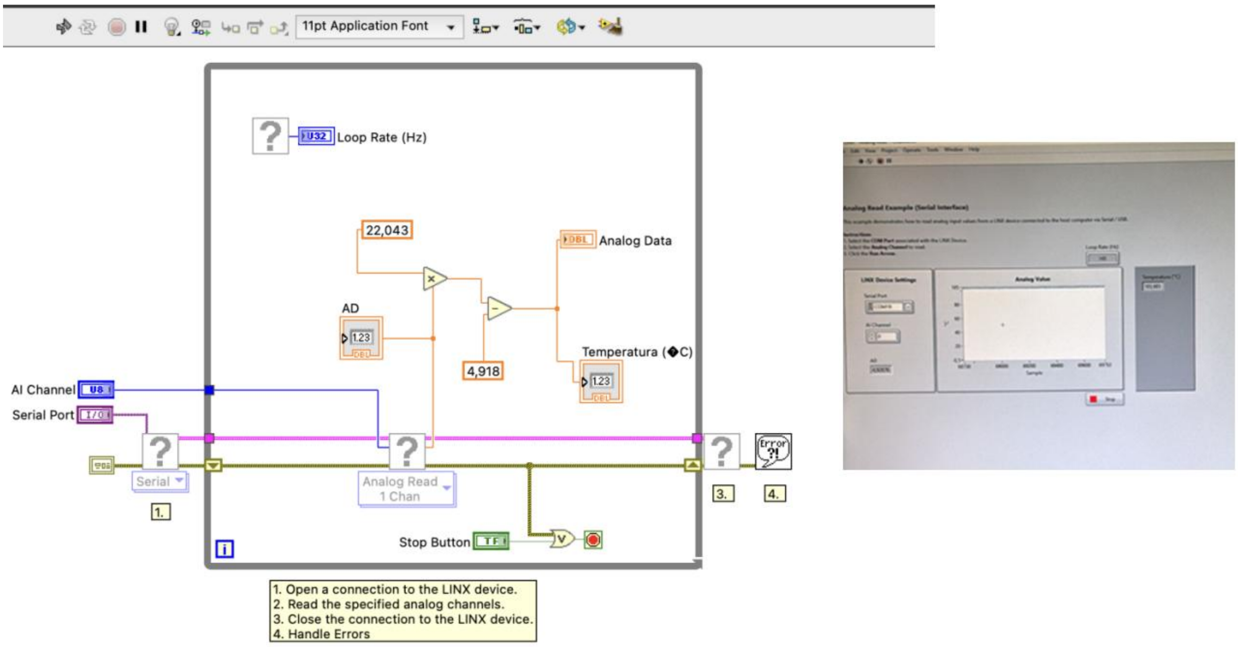


Source: the authors (2025)

On the computer, the supervisor displays a graph of temperature over time, with a temperature indicator on the right side. The value displayed on the screen can be compared with the multimeter's temperature scale reading, which provides a reference value since it is connected to a thermocouple.

Labview is a supervisory and control software that allows integration with various industrial automation systems and measurement devices, such as the PT100 sensor. To achieve this, the control system that captures temperature data from the Wheatstone bridge, typically through a PLC or other data acquisition device, can be configured to send this information in real time to the Labview Supervisory System. In Labview, it is possible to configure dynamic graphs that represent temperature variation over time. Using data collected from the PT100, which is converted into a temperature reading, Labview can display this information in graph form, with the option of including alarms or monitoring LEDs.

Figure 10 – Labview low-code development interface and application screen in operation



1. Open a connection to the LINX device.
2. Read the specified analog channels.
3. Close the connection to the LINX device.
4. Handle Errors

Source: the authors (2025)

The code developed for Arduino can be seen below:

```
#include <Arduino.h>
const int sensorPin = A0; // Temperature sensor pin (analog)
float temperatura = 0.0;
// --- Arduino Setup ---
void setup() {
Serial.begin(9600);
}
// --- Main Loop ---
void loop() {
int valorADC = analogRead(sensorPin);
float tensao = valorADC * (5.0 / 1023.0); // ADC reading normalization
float tensaoAj = -0.1453 + 1.0382*tensao; // Voltage Curve Adjustment (0 - 5V)
temperatura = 21.585*tensao - 3.2239;
// Temperature Calculation Based on Voltage: Range 0V–5V →0–100°C
float temperaturaAj = 0.9731*temperatura - 2.8867;
// Temperature curve adjustment based on Pt100 readings
 Serial.println(temperaturaAj);
delay(500);
}
```

The "Reference System" consists of a multimeter connected to a thermocouple immersed in the liquid container. Two aluminum cans lined with Styrofoam, a type of thermal insulation, were used to maintain the liquid's temperature. In Figure 10, the multimeter measures 51°C, while the Arduino serial monitor displays a value ranging from 50°C to 51°C. This indicates that the system's response range is adequate, considering the error found was less than 2°C.

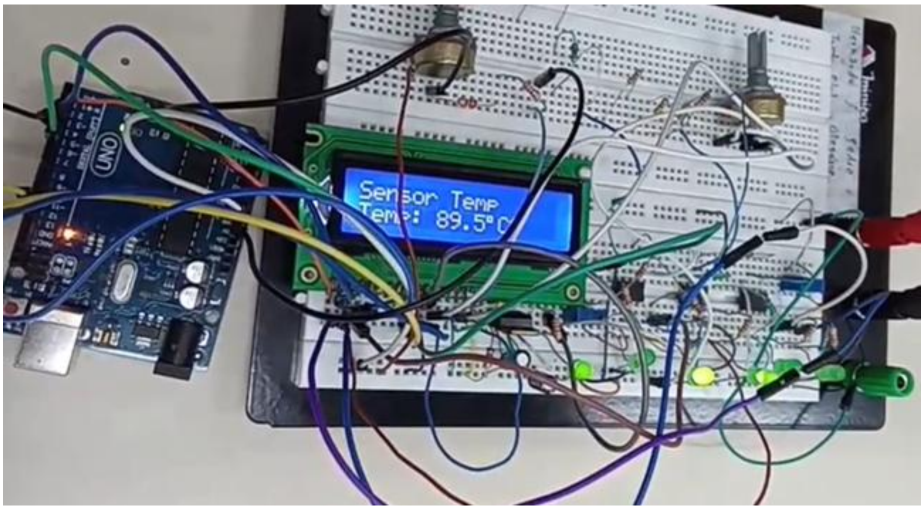
Figure 11 – Comparison of the measurement by Arduino and the “Reference System”

Source: the authors (2025)

4 RESULTS AND DISCUSSION

Initially, a 16x2 LCD display was used to display the measured temperature values. The LCD system was able to receive signals and display the measurement on the breadboard itself.

Figure 12 – Temperature measurement with 16x2 LCD



Source: the authors (2025)

When executed, the algorithm running on the computer receives data from the camera. When a human face is located, it calibrates the system for a few seconds and then displays green text and numeric indications on the left and right sides of the screen. Figure 13 shows the face detection result after automatic calibration, which occurs within 8 seconds. It provides a panoramic view of the complete project. Temperature readings were presented for the range of values from 20°C to values close to 90°C during the practical test with a container and liquid.

Figure 13 – Tests with Pt100

Source: the authors (2025)

Measurements were taken with the circuit to test its operation. The collected data were systematized into two tables.

Table 2 – Response to different resistance values

Pt100 Resistance (Ω)	Temperature (°C)	Output Output voltage (V)
100	0	0,14
110	25,7	1,34
120	51,8	2,55
130	77,7	3,76
138.5	100,98	4,95

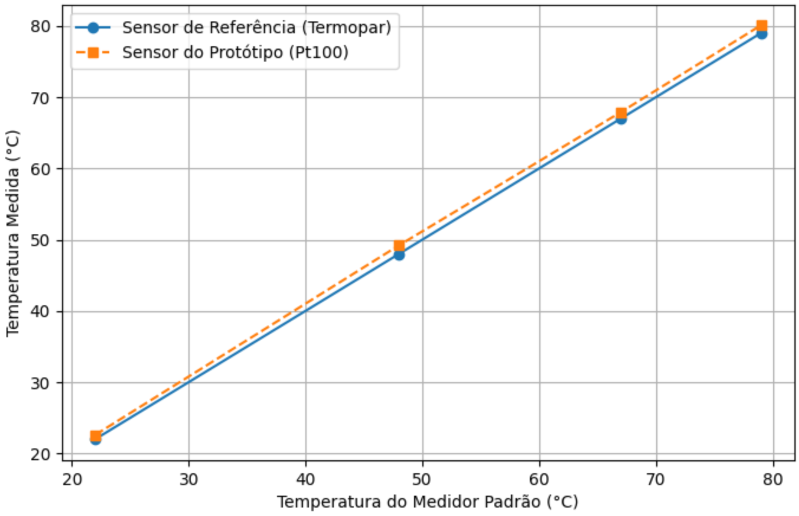
Source: the authors (2025)

Table 3 – Prototype response for temperature measurement compared to standard meter via thermocouple/multimeter

Standard gauge temperature (°C)	Prototype Temperature (°C)	Output - Output voltage (V)
22	22,6	1,22
48	49,2	2,47
67	67,9	3,26
79	80,1	4,02

Source: the authors (2025)

Figure 14 – Comparison between reference measurement and prototype measurement



Source: the authors (2025)

5 FINAL CONSIDERATIONS

The project successfully measured temperature using an Arduino microcontroller and can be developed as a teaching resource for engineering. In addition to applying basic C++ programming concepts using Arduino hardware, the project also applies electronics knowledge, such as building a Wheatstone Bridge for precise measurement of resistance variations.

A temperature measurement activity using Arduino, however simple, can be developed to draw parallels with physics formulas and equations on the topic. This can enhance students' intuition about real-world applications of concepts like derivatives. One consequence of observing that the cooling of a heated liquid can be expressed by a derivative is that mathematical abstraction exists in the real world and can be part of everyday life. By observing that the liquid cools over a given time when in contact with room temperature, the student can imagine that a derivative is present and is part of that reality.

The activity can be adapted to different sensors, allowing for a comparison of sensor responses. This strategy was adopted by some of the studies identified in the literature review. On the other hand, the practice can also be adapted to monitor temperature variation in different liquid media, as the review indicated that one study evaluated the differences in solid aluminum or copper media. However, for liquid media, no educational article comparing the variation in different solutions was found.

The algorithm was corrected using an optimization method applied based on adjustments to the function, resulting from a set of points. The modification occurred in a single line of code, which inserted the result of a correction implemented using an optimization method. In Microsoft Excel, it is possible to obtain a corrected function from points (x, y) for two variables. The code line was adjusted in the software implemented in the Arduino IDE to reduce errors, what reduced the error for less than 2 ºC in comparison to termopar of reference.

In conclusion, the project met the requirements, as the measurement table presented satisfactory values. Although the project is preliminary, it can be viewed in terms of its educational nature in the field of instrumentation. The practice was instructive because it simulated a concrete need in many industrial environments. It can be thought of as a simulation of the type of project expected of engineers working in industries that require precise temperature control. Furthermore, it can be used as a resource for discussing mathematical formulas and equations related to temperature, such as Newton's law of cooling, which contains a derivative.

One limitation of the project is that the results were not evaluated to present error percentages relative to a calibrated standard meter. The reference meter used was a thermocouple connected to a multimeter, which also presents an error percentage. As a possibility for improvement, the project could include a comparison with a precision digital thermometer, creating a comparative graph with a larger plot of points.

As a future step, the algorithm could be enhanced to include a closed-loop control system to optimize its behavior based on data collected throughout the operation, without the need for manual optimization. Additionally, an equation visualization in Labview could be implemented, which could help with learning concepts in the exact sciences.

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