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Development of Arduino-Based Temperature Control Teaching Aids with Matlab Interface as a Tool for Newton Cooling Practicum

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Abstract - *Physics practicums require accurate, efficient, and traceable measurement systems, particularly in thermodynamic experiments involving continuous temperature changes. In the Newtonian Cooling practicum, conventional measurements with thermometers and stopwatches often lead to recording errors, inaccurate synchronization of temperature and time, limited data density, and reduced student focus on physical interpretation. This study aimed to develop, validate, and assess the practicality of an Arduino-based temperature control teaching aid integrated with a MATLAB graphical user interface (GUI) to support real-time data acquisition in the Newtonian Cooling practicum. The research employed a Research and Development (R&D) approach using the 4D model, consisting of the Define, Design, Develop, and Disseminate stages, with product development limited to expert validation and minimal practical testing. The tool was developed using an Arduino Uno microcontroller, a DS18B20 temperature sensor, and a MATLAB GUI that displays temperature-time graphs and automatically stores measurement data in Excel. The study involved two expert validators and 10 Physics Education students who participated in the Thermodynamics practicum. The validation results showed that all assessed indicators, including tool recognition, user control, application display, application assistance, and application output, obtained the highest score of 4, indicating very high validity. The practicality assessment also showed excellent results, with an average score of 4.0 and 98% of students reporting positive responses, indicating that the tool was highly practical for practicum use. The novelty of this study lies in integrating real-time temperature measurement, automatic temperature-time data synchronization, graphical visualization, and direct data storage into a single practicum-oriented system. The findings indicate that the developed teaching aid improves the efficiency and accuracy of temperature measurement, reduces manual recording errors, and helps students focus on analyzing cooling phenomena. This study contributes to physics education by providing an affordable, valid, and practical microcontroller-based teaching aid that strengthens laboratory-based learning and promotes data-driven scientific reasoning.*

Keywords: *arduino teaching; MATLAB interface; Newton cooling; physics practicum; temperature control*

I. INTRODUCTION

Education is a strategic process that shapes civilization by transforming knowledge, attitudes, and behavior into useful competencies. Science and technology play an important role in supporting this process, particularly in improving the quality of learning. The rapid development of technology and knowledge requires educational institutions, including higher education, to adapt their learning tools, methods, and ecosystems to contemporary needs (Rafiqah et al., 2020; Anggereni, 2021). In physics education, this demand extends beyond theoretical mastery to include practical competence and measurement skills, which are essential foundations of scientific experimentation. When laboratory instruments are limited, practicum activities may become administrative routines rather than scientific processes that produce meaningful data. Therefore, innovations in learning media and practicum tools should be directed toward improving the accuracy, efficiency, and traceability of data, enabling practicum activities to train evidence-based scientific thinking (Sirait & Lubis, 2020).

Laboratory practicum is a primary means of verifying theories and developing conceptual understanding through direct observation. Through practicum activities, students are trained to solve problems, think critically, and apply scientific procedures systematically (Rohayani et al., 2021). A curriculum that emphasizes a scientific approach also requires prospective teachers to develop strong science process skills, because these skills will later support their ability to guide students in experiment-based learning (Richardo et al., 2023). The success of practicum-based learning depends on the quality of the learning process and the availability of supporting infrastructure, including accurate, easy-to-use measurement instruments (Rafiqah et al., 2022). From a value-based perspective, efforts to improve measurement accuracy can also be understood as an effort to reflect the principle of regularity in measurement, as stated in the Qur'an, Surah Al-Furqan, verse 2, which, according to Tafsir Ibn Kathir, refers to the determination of measure and orderly arrangement. This principle strengthens the present study's orientation toward more precise and standardized measurement.

The main problem in the thermodynamics practicum, particularly in the Newtonian Cooling unit, is the need to measure temperature changes over time in real time. In the Basic Physics and Electronics Laboratory, thermometers capable of automatically recording temperature changes over time remain limited. As a result, temperature changes are commonly observed manually. In a typical procedure, students heat a fluid to a specified initial temperature, stop heating, and then observe the temperature decrease over time. In laboratory conditions that still depend on conventional thermometers and stopwatches, students must manually synchronize temperature readings with time records and then enter the data into worksheets before creating graphs. This process is time-consuming and shifts students' attention away from physical reasoning toward repetitive, error-prone data recording and processing. Manual measurement may also lead to repeated errors, such as parallax errors, inaccurate time-temperature synchronization, and inconsistencies among practitioners. In addition, the data obtained are often sparse, for example, when students record data only for every 5°C decrease, so the cooling dynamics are not fully represented, and further analysis becomes less reliable.

These problems require an automated real-time temperature-time data acquisition system integrated with graphical visualization. Such a system can reduce the burden of manual recording and allow students to focus on interpreting physical phenomena. Technologically, a common approach is to use microcontrollers and digital temperature sensors to acquire data, which is then transmitted to a computer for systematic display and storage. Arduino Uno, an open-source microcontroller board based on the AtMega328p, is widely used for developing instrumentation systems because it is relatively low-cost and technically accessible (Pujiant et al., 2022). Its open-source characteristics and ease of programming make it suitable for integrating various sensors in academic activities (Efendi & Narji, 2020). On the interface side, MATLAB provides a scientific computing environment for data processing, visualization, and programming. It also supports graphical user interface facilities that allow users to operate button-based applications, panels, tables, and graphs without directly interacting with low-level code (Gao et al., 2021; Herve et al., 2021).

Previous studies on educational media and practicum tools show that digital temperature measurement can improve the quality of practicum activities, especially in relation to science process skills. Muchlisa et al. (2021) reported the effective use of digitally based temperature-measurement teaching aids for physics education students, with students' science process skills reaching the high and very high categories. These findings indicate that digital measurement tools not only replace analog instruments but also enrich the learning experience by making data easier to access, observe, and analyze. In addition, Qaddafi et al. (2026) developed an Arduino Uno-based temperature measurement teaching aid using LM35 sensors and LEDs to support data collection in a physics practicum, showing the potential of teaching aids to connect temperature concepts with measurement practice (Qaddafi et al., 2026). Conceptually, this approach aligns with the demands of physics learning, which positions experimentation and measurement as essential means for constructing scientific understanding (Sulayman et al., 2024).

Studies in systems engineering also provide a technical basis for integrating Arduino with MATLAB GUI to display sensor data in real time. Gao et al. (2021) developed an Arduino-based control and monitoring system using a MATLAB GUI and showed that parameter changes could be observed through graphical displays and output values (Gao et al., 2021). Other monitoring designs based on MATLAB GUI have combined voltage and temperature sensors with Arduino to display numerical values and graphs on computers. Herve et al. (2021) used an Arduino integrated with MATLAB GUI to monitor wind power plants and reported compatibility between interface readings and measurement instruments (Herve et al., 2021). From the sensor perspective, the DS18B20 has a measurement range of -55°C to 125°C and an accuracy of ±0.5°C within this range, and it can be integrated via the 1-wire protocol. Therefore, the combination of a microcontroller, digital temperature sensor, and MATLAB GUI is a rational configuration for developing a teaching aid that emphasizes ease of use, data readability, and processing speed.

However, the existing literature still shows a gap when the context is narrowed to the needs of Newtonian Cooling practicum in physics education. Newtonian cooling emphasizes the relationship between the cooling rate and the temperature difference between an object and its environment. Therefore, accurate, consistent, and minimally biased temperature-time data are needed to derive graphs and cooling constants more responsibly. Sardjito and Yuningsih (2020) emphasized the importance of assessing temperature changes over time because linear assumptions are often less accurate than expected; consequently, the quality of experimental data is crucial for supporting scientific arguments. Previous studies on Arduino–MATLAB GUI integration have generally focused on engineering monitoring systems, such as converters, accumulators, and wind turbines, and have not specifically addressed the typical obstacles encountered in the Newtonian Cooling practicum. These obstacles include automatic temperature-time synchronization, direct storage to worksheets, ready-to-use graphical displays for reports, and operational procedures that fit the practicum workflow. At the institutional level, the absence of an integrated real-time thermometer for this practicum further strengthens the need to develop contextual teaching aids that are tested through expert assessment and user feedback.

Based on these gaps, this study aims to develop an Arduino-based temperature-control teaching aid with a MATLAB interface as a tool for the Newtonian Cooling practicum in the Physics Education Program, Faculty of Tarbiyah and Teacher Training, UIN Alauddin Makassar. The novelty of this study lies in the design of a system that integrates real-time temperature readings, temperature-time graph visualization, and automatic data storage for practicum reports. The system uses Arduino Uno (AtMega328p), a DS18B20 temperature sensor, and a user-friendly MATLAB GUI. The scope of this study is limited to product development up to the development stage, expert validity assessment, and practicality assessment by students. The study focuses on the use of the tool in Newtonian Cooling practicum and on the outputs in the form of temperature-time data and graphs that support thermodynamic analysis.

II. METHODS

This study employed a research and development (R&D) approach using the 4D development model, which consists of Define, Design, Develop, and Disseminate stages. This model was selected because it provides a systematic framework for producing educational products that meet the criteria of validity and practicality. The product developed in this study was an Arduino-based temperature control teaching aid integrated with a MATLAB GUI. The tool was designed to support the Newtonian Cooling practicum in the Basic Physics course at the Faculty of Tarbiyah and Teacher Training, UIN Alauddin Makassar.

The research was conducted at the Basic Physics Laboratory, Faculty of Tarbiyah and Teacher Training, UIN Alauddin Makassar. The research subjects were 10 students of the Physics Education Study Program from the 2021 cohort who participated in the Newtonian Cooling practicum in the Thermodynamics course. These students were selected because they had studied the basic concepts of temperature and thermodynamics and had experience conducting practicums requiring temperature measurements over time. In addition, two expert lecturers were involved as validators to assess the validity of the developed teaching aid. Their assessment was used to ensure that the product was scientifically appropriate and feasible for students' use in practicum activities.

This development research followed the 4D model proposed by Thiagarajan, as cited in Rizki et al. (2016). The stages of the model are illustrated in Figure 1. The model was used as a guide for designing and developing educational teaching aids. The purpose of the development process was to produce a tool that could improve the quality of the thermodynamics practicum, particularly the Newtonian Cooling practicum, which requires real-time temperature measurement.

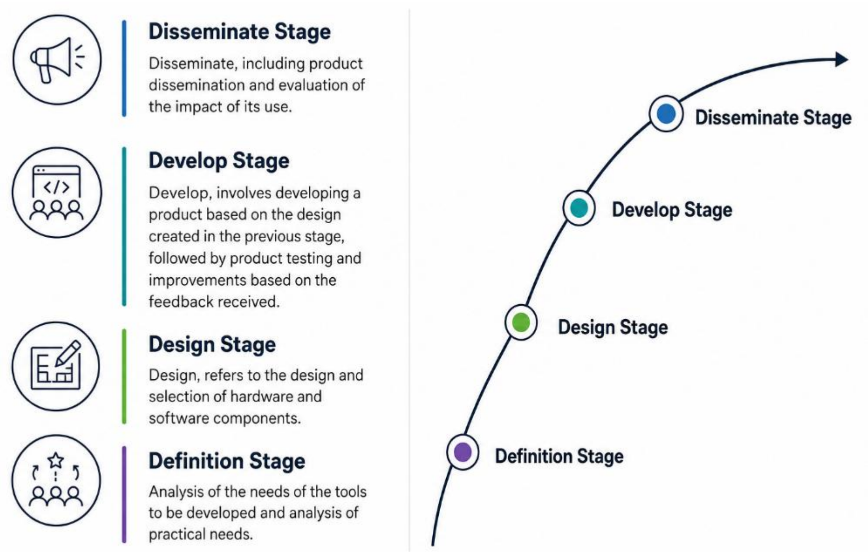


Figure 1. 4D development model

The Define stage involved analyzing the need for the teaching aid and the practicum requirements. This stage also included preliminary studies to determine the validity and practicality criteria to be used in product testing and evaluation. The Design stage focused on designing the hardware and software components of the tool. The hardware design included the selection and arrangement of an Arduino Uno, a DS18B20 temperature sensor, jumper cables, a breadboard, and other supporting components. The software design included developing a MATLAB GUI to display temperature data and time-series graphs. The Develop stage involved assembling the tool, integrating the hardware with the MATLAB interface, testing the product, and improving it based on expert and user feedback. Although the 4D model includes a Disseminate stage, development in this study was limited to the Develop stage because the product was evaluated through expert validation and limited user-practical testing in the Basic Physics Laboratory.

The instruments used in this study consisted of an Arduino-based temperature-control teaching aid and a practicality questionnaire. The teaching aid was used to measure temperature changes over time during the Newtonian Cooling practicum. The data obtained from the sensor were processed and displayed in MATLAB as a temperature-time graph. The practicality questionnaire was used to collect students' responses after they used the tool in the practicum.

The teaching aid developed in this study was an Arduino Uno-based temperature control device equipped with a MATLAB GUI. Arduino Uno was selected as the main microcontroller because it can process temperature sensor data and support real-time device control. The temperature sensor used was the DS18B20, which has a measurement range of -55°C to 125°C and an accuracy of ±0.5°C within this range. This sensor was selected for its reliable temperature measurement, ease of integration with Arduino, and relatively low cost. The MATLAB GUI was designed to provide a visual, interactive interface that allows practitioners to observe the temperature-time graph in real time during the experiment. MATLAB was used because it can support data processing, visualization, and graphical display effectively. Overall, the tool was designed to improve ease of use, increase practicum efficiency, and reduce human error in data recording and processing.

The validity of the teaching aid was assessed by two expert lecturers using a validation instrument. The assessment criteria included tool recognition, user controls, application display, application assistance, and application output. The validation scores were analyzed using the Gregory content validity coefficient (Gregory, 1995). This analysis produced a validity score indicating the extent to which the teaching aid met the expected validity criteria.

The Gregory content validity coefficient was calculated using the following equation:

$$\frac{D}{A+B+C+D} \quad (1)$$

The practicality of the teaching aid was assessed using a questionnaire distributed to students after they used the tool. This assessment aimed to determine the extent to which the teaching aid facilitated practicum data collection and how easily students could use it. The practicality data were analyzed using the percentage formula developed by Nurdin and Hartati (2019):

$$P = \frac{F}{n} \times 100\ \% \qquad (2)$$

Description:

P = percentage of practicality

f = the number of positive student responses from each aspect that arises

n = total number of students

The practicality criteria for the teaching aid are presented in Table 1.

Table 1. Table of practical criteria for teaching aids

Range	Level of practicality
P ≥ 90%	Very practical
80% ≤ P < 90%	Practical
70% ≤ P < 80%	Quite practical
60% ≤ P < 70%	Less practical
P < 60%	Impractical

Source: (Nurdin & Hartati, 2019)

III. RESULTS

The development of the Arduino-based temperature control teaching aid with a MATLAB interface for the Newtonian Cooling practicum was carried out using the 4D development model. This section presents the results of the development process, beginning with the identification of practicum needs and continuing with the design of the hardware and software components.

3.1 Define stage

The efine stage was conducted to identify the main problems in the Newtonian Cooling practicum and to determine the requirements for developing the teaching aid. This stage included a literature review on the use of Arduino in physics practicum tools and an analysis of hardware and software capable of supporting real-time temperature measurement, computer-based data visualization, and automatic data storage.

The front-end analysis showed that the main problem in the thermodynamics practicum, particularly in the Newtonian Cooling unit, was the manual measurement of temperature changes over time. Based on the researcher's observation, students were required to record temperature and time simultaneously during the cooling process. In the practicum procedure, a fluid, such as water with a predetermined mass and volume, was heated to an initial temperature of 80°C. After the heating process was stopped, students observed the temperature decrease over time.

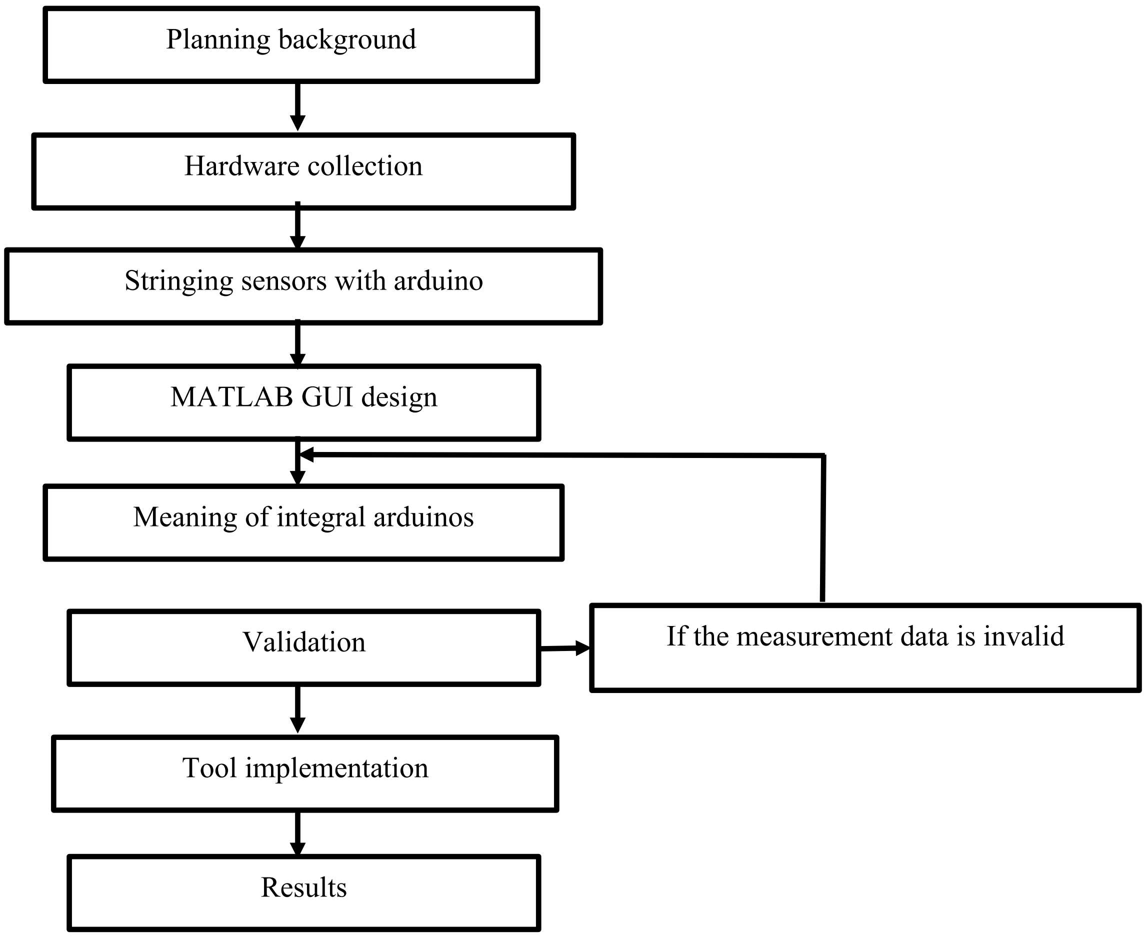


Figure 2. Schematic of the flow of prop manufacturing

In the conventional procedure, students used a thermometer to monitor the temperature decrease and a stopwatch to record the corresponding time. The measurement was usually recorded for every 5°C decrease in temperature. This procedure required students to observe two instruments simultaneously and manually synchronize the temperature and time data. As a result, the data collection process was time-consuming and prone to errors, such as inaccurate time recording, parallax errors, and inconsistencies among practitioners.

After the data collection process was completed, students manually entered the practicum data into Microsoft Excel to generate a temperature-time graph. The graph was then printed and attached to the complete Newtonian Cooling practicum report. This workflow showed that students spent considerable time on technical recording and data processing activities. Therefore, an automated tool was needed to acquire temperature-time data in real time, display the data graphically, and store it automatically.

The learner analysis indicated that the teaching aid was intended for Physics Education students enrolled in the Thermodynamics practicum. Although the initial observation involved Physics Education students from the 2020 cohort, the product testing in this study targeted students from the 2021 cohort, who served as practitioners during data collection. The concept analysis confirmed that the practicum unit selected for the development of the teaching aid was Newtonian Cooling because this topic requires continuous, accurate temperature measurements over time.

3.2 Design stage

The design stage involved preparing the tools, components, and system design required to develop the Arduino-based temperature control teaching aid with a MATLAB interface. This stage focused on designing both the hardware and software components so that the tool could be operated easily, including by users who were not yet familiar with Arduino-based measurement systems.

The hardware design involved constructing an electronic circuit that connected the Arduino Uno with the DS18B20 temperature sensor and other supporting components. The supporting components included jumper cables, a breadboard, and a power source. The circuit design was arranged to ensure that the sensor could read temperature changes and transmit the data to the Arduino for further processing. The hardware design also considered ease of assembly, stability of sensor connection, and suitability for use in the Newtonian Cooling practicum.

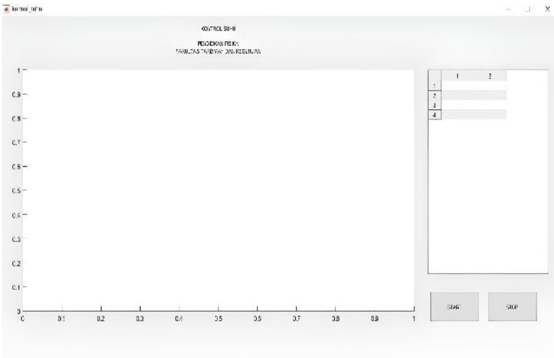


Figure 3a. Initial design of the Matlab GUI for props

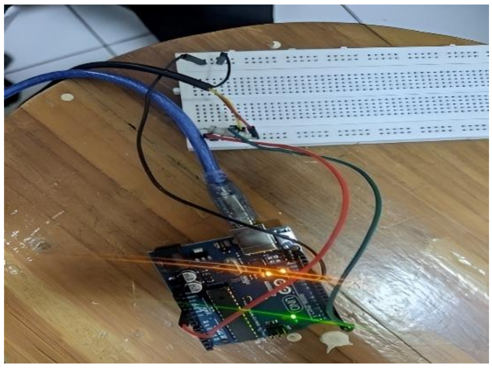


Figure 3b. Preliminary design of the temperature control props

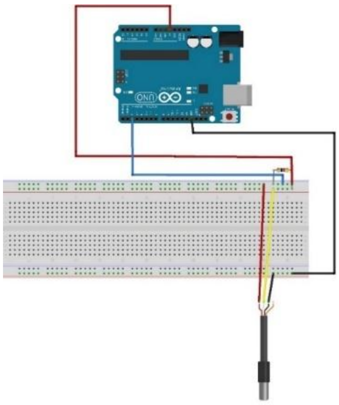


Figure 3c. Schematics of the prop range

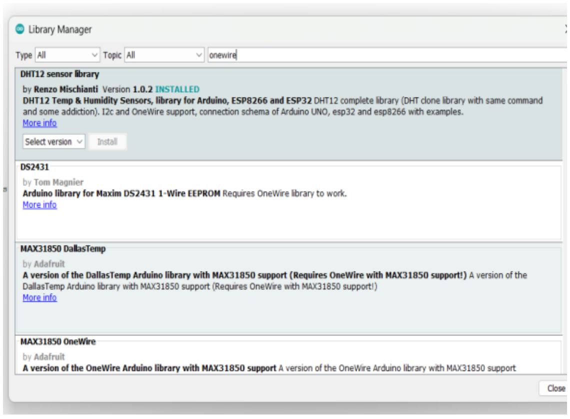


Figure 3d. Install library

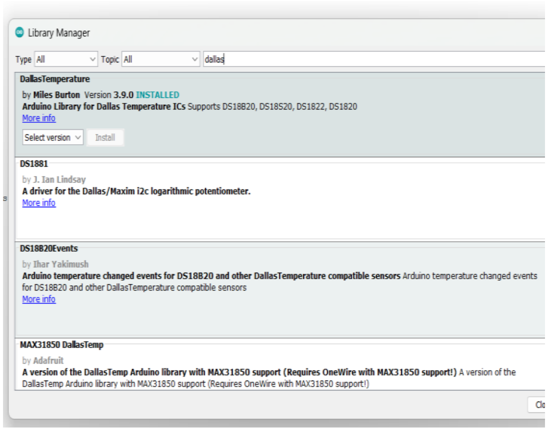


Figure 3e. Install dallas temprature

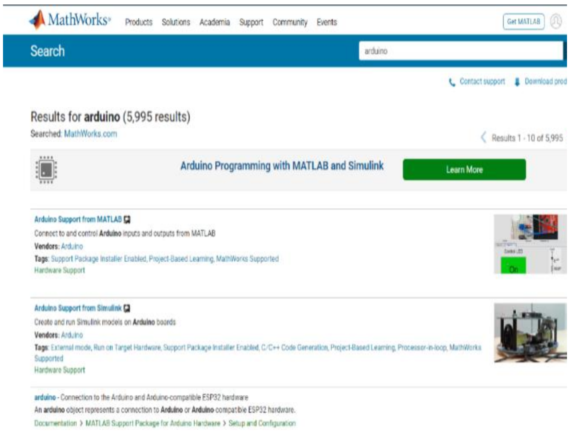


Figure 3f. Install library arduino di Matlab

Figure 3. Product design stages

The software design involved developing a graphical user interface (GUI) using MATLAB. The GUI was designed to display temperature data as a graph of temperature versus time during the cooling process. The interface also provided buttons to start and stop data acquisition. This design enabled users to operate the tool more easily without interacting directly with the program code.

All data obtained during the practicum were designed to be saved automatically in Excel format. This feature was included to support further data analysis and to help students prepare practicum reports more efficiently. With this design, the developed tool was expected to reduce manual recording errors, accelerate data collection, and provide more accurate temperature-time graphs for analyzing the Newtonian Cooling phenomenon.

3.3 Development stage

In the Development stage, the teaching aid was produced based on the design prepared in the previous stage. Hardware development included assembling the electronic circuit, connecting the DS18B20 temperature sensor to the Arduino Uno, and testing each component's functionality. After the hardware assembly was completed, the system was integrated with the software interface developed using MATLAB.

After the teaching aid was assembled and the MATLAB program was implemented, functional testing was conducted to ensure the system operated correctly. The test was carried out by measuring the temperature of an object or fluid as it cooled. The temperature and time data were then displayed as a graph on a computer connected to the Arduino. This process confirmed that the developed tool could acquire temperature-time data and present them visually through the MATLAB GUI.

The development results consisted of the physical teaching aid, the MATLAB-based user interface, the output data, the graphical display, the expert validation results, and the students' practicality responses. These results indicate the extent to which the Arduino-based temperature control teaching aid with a MATLAB interface met the expected validity and practicality criteria for supporting the Newtonian Cooling practicum in the Physics Education Program, Faculty of Tarbiyah and Teacher Training, UIN Alauddin Makassar.

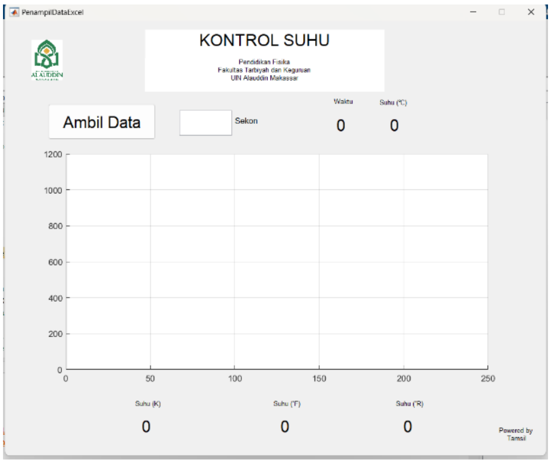
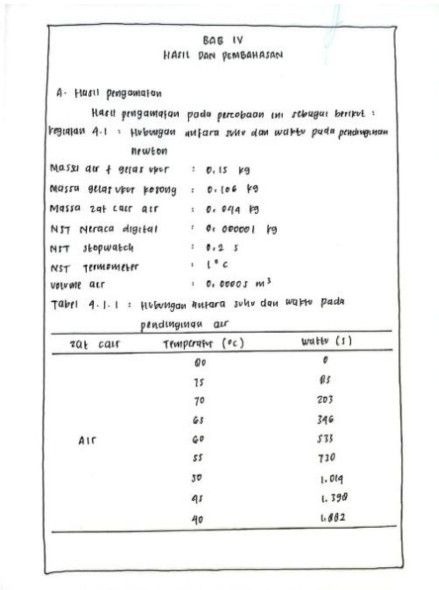


Figure 4a. UI of temperature control props

Figure 4b. Physical shape of temperature control props



BAB IV
HASIL DAN PEMBAHASAN

A. Hasil pengamatan

Hasil pengamatan pada percobaan ini sebagai berikut :
Kegiatan 4.1 : Hubungan antara suhu dan waktu pada pendinginan newton

Massa air + gelas ukur : 0,15 kg
Massa gelas ukur kosong : 0,106 kg
Massa zat cair air : 0,044 kg
NST Neraca digital : 0,000001 kg
NST stopwatch : 0,2 s
NST termometer : 1 °C
Volume air : 0,00005 m³

Tabel 4.1.1 : Hubungan antara suhu dan waktu pada pendinginan air

Zat cair	Temperatur (°C)	Waktu (s)
Air	80	0
	75	85
	70	203
	65	346
	60	533
	55	730
	50	1.019
	45	1.390
	40	1.882

Figure 4c. Practical data without the use of props

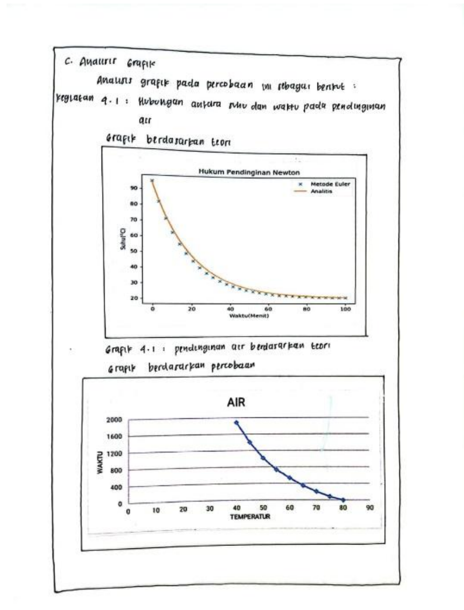


Figure 4d. Graph using data without props

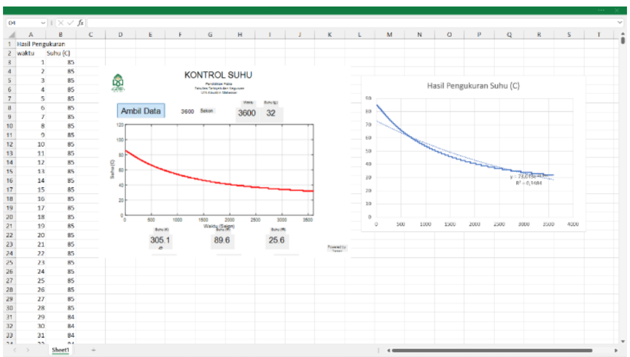


Figure 4e. Data and graphs in one Excel file using temperature control props

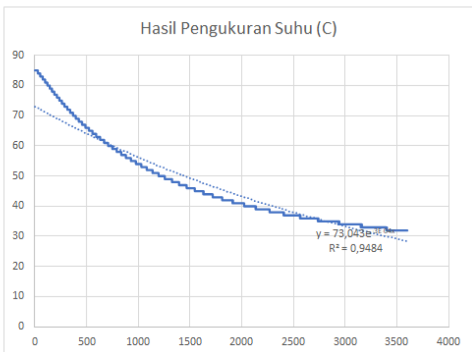


Figure 4f. Graph of measurement results using props

Figure 4. Product development results

The temperature control teaching aid developed in this study used an Arduino Uno as the main microcontroller, integrated with a DS18B20 temperature sensor. The DS18B20 sensor was selected because it has an accuracy of ±0.5°C over the range of -10°C to 85°C, which is suitable for the precision required in the Newtonian Cooling practicum. The sensor is also relatively easy to install because it uses the 1-wire protocol, which enables communication through a simple connection.

The MATLAB-based graphical user interface was designed to display measured temperature data as a temperature-time graph during the cooling experiment. The interface also included start and stop buttons for data acquisition and a display panel for temperature readings. This design made the tool easier to operate and allowed students to observe the cooling process directly through numerical and graphical outputs. The data obtained during the practicum were automatically saved in an Excel file, which could then be used for further analysis and practicum report preparation. The developed tool measures changes in fluid temperature over time and displays the data in real time on a computer connected to the Arduino. In addition to graphical output, the tool also provides numerical temperature data at each observed time point. These outputs allow students to observe the pattern of temperature decrease more clearly and to analyze the Newtonian Cooling phenomenon using more systematic data.

The validity of the developed teaching aid was assessed by two expert validators: a Physics lecturer and a Physics Education lecturer. The assessment criteria included tool recognition, user controls, application display, application assistance, and application output. The validation process used a scale from 1 to 4, where 1 indicated "very inappropriate," 2 "inappropriate," 3 "appropriate," and 4 "very appropriate." The scores from the two validators were analyzed using the Gregory validity coefficient (Gregory, 1995) to determine whether the teaching aid met the required validity standard.

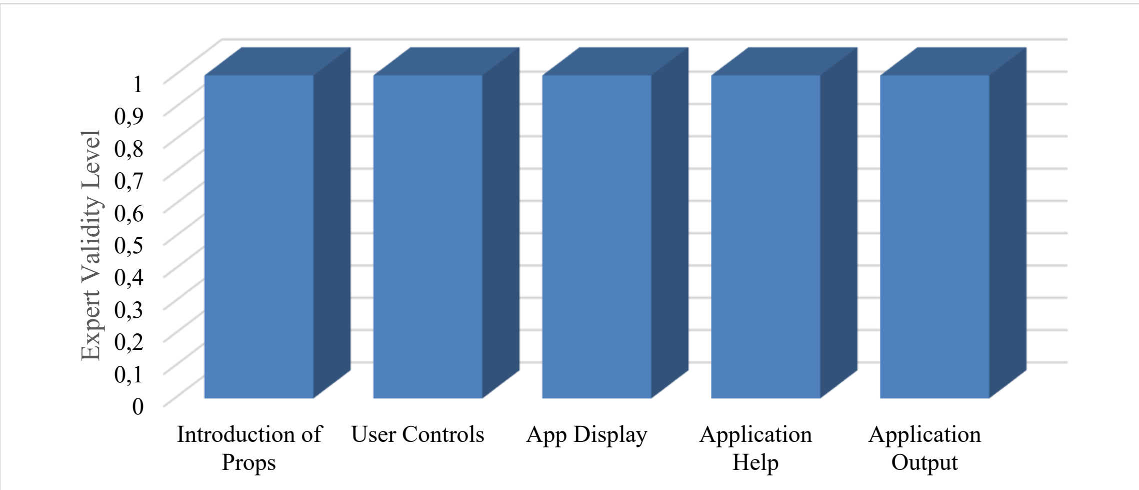


Figure 5. Expert validity results

The validation results showed that all assessed indicators scored 4. This result indicates that the Arduino-based temperature control teaching aid with the MATLAB interface met the very high validity criteria. The expert assessment also shows that the tool was appropriate in terms of recognition, user control, display, assistance features, and output. Therefore, the developed teaching aid can be considered valid for use in the Newtonian Cooling practicum.

In addition to validity, the practicality of the teaching aid was evaluated to determine whether the tool could be used easily and effectively by students. Practicality was assessed using a questionnaire distributed to students after they used the tool in the practicum. The questionnaire included statements related to ease of use, ease of understanding, speed of data collection, usefulness of the graphical display, automatic data storage, and improvement of temperature measurement accuracy. The questionnaire used a Likert scale, with a score of 1 for "strongly disagree," 2 for "disagree," 3 for "agree," and 4 for "strongly agree." The practicality assessment involved 10 student respondents.

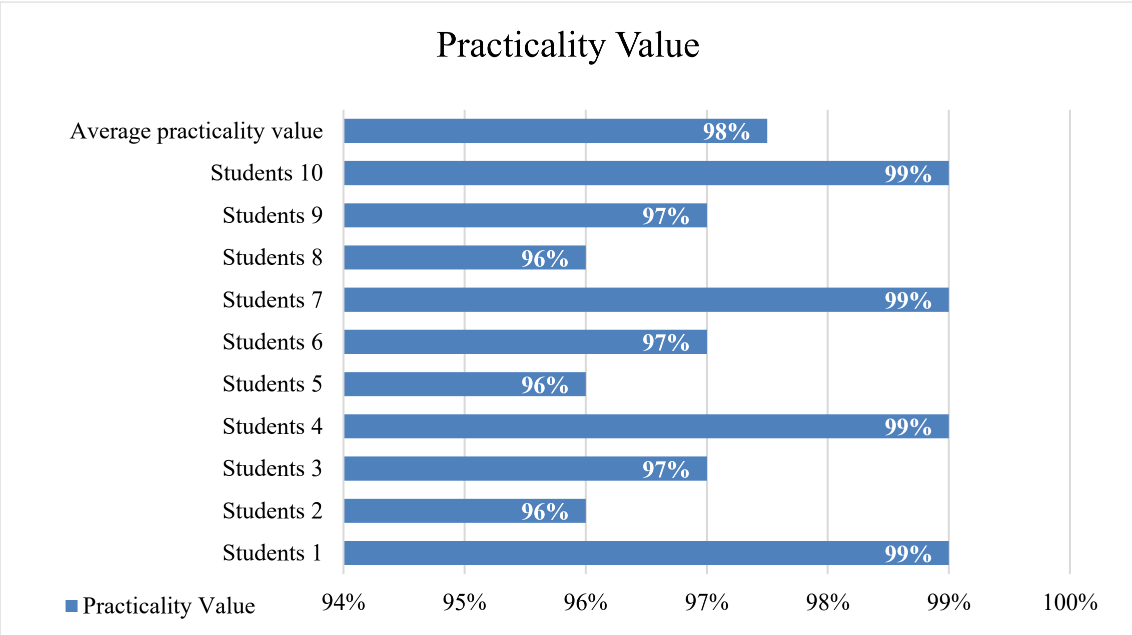


Figure 6. Practical results

The questionnaire results showed that the average practicality score reached 4.0. This result indicates that the developed teaching aid was very practical for use in the Newtonian Cooling practicum. The practicality of the tool was reflected in its ease of operation, faster data acquisition, clearer graphical display, automatic data storage, and reduced potential for human error in recording temperature-time data. These findings show that the tool can help students conduct practicum activities more efficiently and accurately.

3.4 Disseminate stage

After completing the development stage, the final product was used on a limited basis by Physics Education students at UIN Alauddin Makassar. The product met the very high validity criteria based on expert assessment and elicited very practical responses from students. This limited dissemination was conducted to introduce the Arduino-based temperature control teaching aid with a MATLAB interface to users in the Basic Physics Laboratory environment.

The results of this development were also presented in dissemination activities involving lecturers, laboratory staff, and laboratory assistants in the Physics Education Laboratory. In addition, the results were prepared for publication in an accredited journal. This dissemination stage aimed to communicate the results of product development and to provide opportunities for further use and improvement of the teaching aid in physics practicum activities.

IV. DISCUSSION

The findings of this study indicate that the Arduino-based temperature control teaching aid with a MATLAB interface met the criteria of high validity for use in the Newtonian Cooling practicum. The Gregory validity results showed that each assessment indicator was in the very valid category. This finding confirms that the developed teaching aid was appropriate for the practicum's needs, particularly in enabling more precise temperature measurement and easier operation for practitioners. The very high validity score also indicates that the developed GUI can provide clear information, simple operation, and accessible data display for users.

The assessment by two validators, who represented expertise in microcontroller applications and physics education, strengthens the feasibility of the developed tool for educational use. Their evaluation shows that the teaching aid is not only technically valid in terms of sensor function and Arduino integration but also pedagogically appropriate for supporting practicum-based learning. This means that the tool can be used in the learning process without reducing the intended learning objectives.

These results are consistent with previous studies showing that expert validation is an important stage in the development of learning materials and teaching aids, especially to ensure the accuracy and relevance of the information presented (Ojeda-Misses & Chavero, 2023). The high validation score also reflects the maturity of the design and the suitability of the implemented technology for students' needs, which may support the long-term sustainability of the platform in educational contexts (Nurjannah et al., 2025).

Another important finding of this study is the high practicality of the Arduino- and MATLAB-based temperature control teaching aid. Based on student responses, the practicality score reached an average of 4.0, and 98% of students considered the tool very practical. No student categorized the tool as "quite practical" or "less practical". These results indicate that the developed tool helps practitioners operate the system more easily, reduces the time required for data collection, and yields more accurate, systematic data.

The practicality of the tool is particularly important in physics laboratory learning, where students are often required to complete several experimental procedures within a limited time. By using an efficient, automated measurement system, students can spend less time on manual data recording and more time analyzing the physical phenomena under investigation. This finding is consistent with previous research indicating that technology-based teaching aids, including digital temperature-measuring devices, can improve students' science process skills (Ahzari & Akmam, 2025).

The practicality results also support previous studies reporting that Arduino-based technology can improve the efficiency of practicum learning and provide a low-cost alternative to expensive industrial or laboratory instruments (Hamzah et al., 2021). In addition, digital platforms can support better collaboration between students and laboratory assistants. This is consistent with Richardo et al. (2023), who reported that the use of digital platforms in education can encourage more effective interaction in project-based learning and increase student motivation (Ojeda-Misses & Chavero, 2023; Richardo et al., 2023).

The findings are also relevant to the study by Hamzah et al. (2021), which developed a digital temperature measuring instrument using an LM35 sensor based on Arduino Uno as a valid, practical, and effective physics learning medium for blackbody radiation material. That study showed that low-cost, accurate, self-developed instruments can improve students' conceptual understanding through practicum activities (Hamzah et al., 2021). Similarly, Pujiant et al. (2022) demonstrated that an Arduino Uno can be used to design a work-area noise-hazard detection system that provides real-time warnings via visual indicators such as LEDs and LCDs. Furthermore, Nethravathi et al. (2019) reported that Arduino-based systems are cheaper, more portable, and more energy-efficient than more complex PC-based systems.

The use of low-cost microcontrollers such as Arduino is also effective in bridging abstract academic theory and practical real-world applications in educational settings (Herceg & Herceg, 2020). In control and monitoring systems, Arduino-based devices can be integrated with scientific software interfaces to support numerical data processing and real-time data visualization through USB or wireless communication (Goldenberg, 2025; Hercog et al., 2023). Previous studies have shown that physical sensors, including DS18B20 temperature sensors for fermentation monitoring and environmental sensors for room-condition prediction, can be connected to microcontroller boards to enable precise monitoring of physical conditions (Chidean et al., 2025;

Hercog et al., 2023; Pajpach et al., 2022). The ability of such systems to transmit data to external devices supports the development of practicum tools that can automatically respond to changes in physical variables with high accuracy (Goldenberg, 2025; Oyebode et al., 2025).

Despite its high practicality, the tool still requires further refinement. Some practitioners suggested improving the interface design to make it more attractive and adding features such as initial temperature setting and more flexible data acquisition timing. These suggestions indicate that although the tool functions well, further development is still needed to improve the interface quality and feature customization to meet practitioners' needs.

One important contribution of this study is the comparison between the Arduino-based temperature-control teaching aid and conventional temperature measurement with a thermometer and stopwatch. In conventional measurement, practitioners must manually observe temperature and record time simultaneously. This process may cause data recording errors, parallax errors, and inaccurate time recording. It also limits the amount of data that can be collected, because practitioners usually record temperature only at certain intervals, such as every 5°C decrease. This condition reduces the rigor of the analysis and may limit students' understanding of the cooling process.

In contrast, the Arduino- and MATLAB-based teaching aid allows practitioners to measure temperature at tighter intervals, for example, every 0.5°C, and to observe the temperature-time graph in real time. This improves measurement accuracy and provides a more complete representation of the cooling phenomenon. The data can also be stored directly in Excel format, making it easier for students to process the data further, including calculating the Newtonian cooling constant (Irawan et al., 2025; Anggereni, 2021; Gelu, 2026; Sulayman et al., 2024). In addition, automatic data acquisition reduces the likelihood of human error and accelerates data collection. As a result, students can focus more on analyzing physical phenomena rather than spending excessive time on manual recording. This finding is consistent with previous research indicating that digital teaching aids can improve students' understanding of physics concepts by enabling them to focus more on the experimental process itself (Gelu et al., 2026).

The implementation of the Arduino-based temperature control teaching aid with a MATLAB interface in the Newtonian Cooling practicum has positive implications for physics learning. The tool not only facilitates temperature measurement but also increases students' engagement in understanding thermodynamic concepts and Newton's law of cooling. In physics learning, science process skills are essential because they allow students to observe, measure, interpret, and analyze physical phenomena systematically. With real-time, automatic temperature data, students can directly interpret it graphically and better understand the relationship between temperature and time. This process can strengthen students' practical understanding of theoretical concepts and support their analytical skills in solving physics problems. The developed tool can also be adapted for other physics practicums that require temperature measurement or other physical parameters. Its ability to integrate measurement devices with computer-based data visualization opens opportunities to develop other microcontroller-based practicum tools at different levels of physics education.

The implementation of Arduino-based teaching aids in practicum learning can also positively affect students' motivation, engagement, and learning outcomes compared with purely theoretical learning methods (Herceg & Herceg, 2020; Panskyi et al., 2021). Through a Project-Based Learning (PrBL) approach, students can progressively develop electronic design and programming skills, including those from non-STEM backgrounds (Chidean et al., 2025). The use of physical devices in practicum activities can increase students' emotional satisfaction and interest because they can interact directly with hardware and observe the real effects of the code they write (Ciungan et al., 2025; Panskyi et al., 2021). Therefore, the integration of interactive digital interfaces not only facilitates complex data analysis but also supports students' computational thinking skills in the Industry 4.0 era (Chuang & Lee, 2021; Jeong & Samuel, 2022; Pajpach et al., 2022; Pantos et al., 2023; Servi et al., 2025).

Although the teaching aid developed in this study met the criteria of high validity and practicality, several limitations should be considered for further development. One limitation concerns the accuracy of temperature measurement (Gao et al., 2021). Although the DS18B20 sensor has good accuracy, the use of a sensor with higher precision or a smaller measurement resolution, for example, with two decimal places, may further improve the accuracy of the tool (Sakti & Napsawati, 2021; Usman et al., 2025). In addition, practitioners' suggestions regarding a more attractive interface and additional features, such as flexible data acquisition timing and initial temperature setting, should be considered in future development. Improving the interface may make the tool more user-friendly and flexible for different practicum situations (Herve et al., 2021). Another limitation is that this study tested the tool only in the Newtonian Cooling practicum. Therefore, future studies should test the tool in other physics practicums to determine its broader applicability in physics learning

V. CONCLUSION AND SUGGESTION

This study successfully developed an Arduino-based temperature control teaching aid with a MATLAB interface to support the Newtonian Cooling practicum. The tool integrates an Arduino Uno microcontroller, a DS18B20 temperature sensor, and a MATLAB GUI to measure temperature in real time, display temperature-time graphs, and automatically store measurement data. The validation results showed that the teaching aid met the very high validity criteria, while the practicality assessment indicated that the tool was very practical for student use. These findings demonstrate that the developed teaching aid can improve practicum efficiency, reduce human error in recording temperature-time data, and help students focus more on analyzing physical phenomena during the Newtonian Cooling practicum.

This study has several limitations. The product was tested only in the Newtonian Cooling practicum, and the interface features still need further refinement, particularly in terms of more flexible initial temperature settings and data acquisition timing. Future research should test the tool in other physics practicums, improve sensor accuracy and measurement resolution, and examine the teaching aid's effectiveness with a broader group of users. The contribution of this study is a valid, practical microcontroller-based practicum tool that supports real-time data acquisition, graphical visualization, and automatic data storage. Therefore, this study strengthens the integration of affordable digital instrumentation into physics education and offers a model for developing similar teaching aids to improve the quality of laboratory-based learning.

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