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Development of Arduino-Based Learning Materials in Heat and Temperature

Lope D. Labayandoy Jr.[1] and Susan S. Janer[2]
[1,2]Sorsogon State University, Graduate School, Sorsogon City, Philippines
Email: [1]lope.labayandoy@deped.gov.ph and [2]sihjaner@sorsu.edu.ph

***Abstract*—** The lack of effective learning materials remains a persistent challenge for students and often contributes to poor academic performance. This study aimed to develop Arduino-based Learning Materials (ALMs) focused on the topics of heat and temperature to enhance the teaching and learning process for Grade 12 students. A developmental research design was employed, utilizing a revised ADDIE model for the design and evaluation of the ALMs. The developed materials included experiment guides and complementary practicum tools. The study recommends the full implementation of these learning materials, as well as the continued development and integration of diverse, innovative teaching strategies and instructional tools across various disciplines and subject areas.

***Keywords*—** Arduino Technology, Development, Heat and Temperature, Learning Materials.

I. INTRODUCTION

In today's fast-paced world, marked by technological breakthroughs and global challenges, the ability to understand and apply scientific concepts is more important than ever. Science education, particularly in STEM (Science, Technology, Engineering, and Mathematics) disciplines, must evolve to equip students not only with knowledge but also with the skills to drive societal transformation (Tasquier et al., 2022).

However, the latest results from the Programme for International Student Assessment (PISA) revealed that Philippines recorded significantly lower than most participating countries especially in science ($\bar{x}$ = 356). This score was also statistically below the OECD average, implying that majority of the students were not yet able to handle basic science tasks and concepts confidently (OECD, 2023).

Low proficiency rates suggest overreliance on memorization rather than deep, transferable understanding, as students struggle with critical thinking, problem-solving, and knowledge transfer. One of the key reasons for this underperformance is the inadequacy and inappropriateness of learning materials in the Philippines compared to those in OECD countries (Public Hearing of the Committee on Basic Education, 2024; Trinidad, 2020).

The PISA 2022 results highlighted the educational disparity between Filipino students and their international counterparts, revealing significant gaps in access to quality educational resources, learning facilities, and innovative instruction. These findings underscored the urgent need for educational practices that provide appropriate materials and laboratory infrastructure to support hands-on, critical-thinking-based learning experiences (Tupas & Matsuura, 2019).

Heat and temperature are inherently abstract concepts, as they lack tangible representations that students can easily visualize or manipulate. This makes them particularly challenging for students to fully comprehend. Yeo and Zadnik (2001) argued that misconceptions in these topics often stem from interactions within social and physical environments, especially when imprecise language is used. Similarly, Kotsis et al. (2023) found that many students struggled to distinguish between heat and temperature.

Alwan (2011) also observed that students often rely on personal experiences to understand these concepts, which can lead to alternative conceptions. For instance, difficulty in grasping thermal equilibrium may arise from its misalignment with everyday sensory experiences.

The abstract nature of these concepts frequently results in poor conceptual understanding and persistent misconceptions that hinder effective learning. To address this, the adoption of modern and interactive teaching strategies—particularly for complex physics topics—is essential (Oseo et al., 2023), including approaches such as demonstration and laboratory methods (Frago & Janer, 2020).

Integrating tools like Arduino enables students to visualize abstract ideas through hands-on experiments and real-time data, fostering deeper understanding, critical thinking, and more meaningful engagement with scientific content.

Arduino bridges the gap between abstract science concepts, fostering an interactive and hands-on learning experience. Its ability to integrate sensors and actuators offers students opportunities to explore, experiment, and engage in problem-solving.

The Arduino platform is an accessible open-source system for electronics development, widely recognized for its intuitive design (Gibb, 2010) and ability to connect digital programming with real-world physical systems through actuators and sensor integration (O'Sullivan & Igoe, 2004).

This technology serves as an avenue to develop critical thinking skills, problem solving skills, improves motivation, develops computational skills (García-Tudela & Marín-Marín, 2023; Marín-Marín et al., 2024), and provides a sense of accomplishment among the student (Kim & Lee, 2017).

The cited studies collectively affirm the efficacy Arduino, as a versatile tool that offers practical ways to make science lessons more engaging, interactive and factual. With the use of sensors, actuators, and real-time data collection, students can explore scientific concepts through direct experimentation.

The hands-on nature of Arduino and its ability to yield accurate data show great potential for improving conceptual understanding, as they encourage problem-solving and collaboration, prompting students to design, test, and refine their experiments. This approach helps connect abstract ideas to real-world applications, making science more relatable and easier to grasp.

To address gaps in the existing literature and in line with the Department of Education's (DepEd) call for research and innovation to enhance the quality of education in the country (Department of Education, 2016), this study explored the potential of Arduino in developing high-quality, technology-driven learning resources.

Specifically, the research sought to provide opportunities for students to develop essential skills, promote innovation in science education, and help elevate the overall quality of education in the Philippines.

The Arduino-based learning materials are significant to students, teachers, school administrators, the Department of Education, and future researchers. This study may enhance students' conceptual understanding; increase teachers' awareness of Arduino technology as an instructional tool; support school administrators in making informed decisions about resource allocation for STEM education; provide the Department of Education with valuable data on the effectiveness of Arduino-based instruction; and offer future researchers additional evidence to support educational theories by examining the impact of Arduino technology on various aspects of science education.

This study aimed to develop Arduino-based Learning Materials (ALMs) in heat and temperature for Grade 12 STEM students, academic year 2024-2025. Specifically, it sought to develop Arduino-based learning materials in thermal equilibrium, thermometer and temperature scales, thermal expansion, specific heat capacity, and heat transfer.

II. METHODOLOGY

This study focused on developing learning materials in heat and temperature using Arduino technology. It employed a developmental approach as it was deemed appropriate to the scope of the study.

This approach involves constructing, refining, and evaluating instructional procedures, programs, and materials to achieve desired outcomes (Richey, 1994). The study design involved the development of Arduino-based learning materials in heat and temperature, guided by the revised ADDIE model.

III. RESULTS

The experiment guide template used in this study was adapted from internationally recognized science education standards, including the Next Generation Science Standards (NGSS), and UNESCO Science Education Standards.

These frameworks emphasize hypothesis formulation, data analysis, and critical evaluation of results, which align with the objectives of this study.

The template was modified to suit the specific context of the current study, with adjustments made to the structure, language, and level of detail to ensure appropriateness for the target audience. The parts of the experiment worksheets are the following:

Cover. It is designed in a unique and visually appealing manner to fit the students' level, as shown in figure 1.

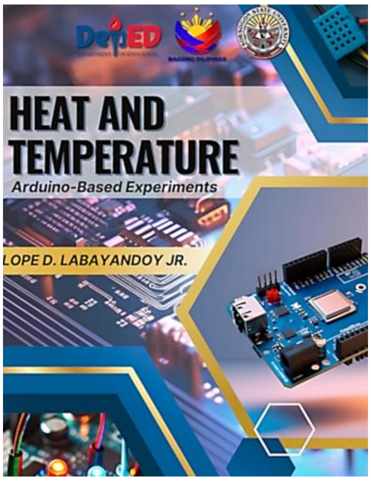


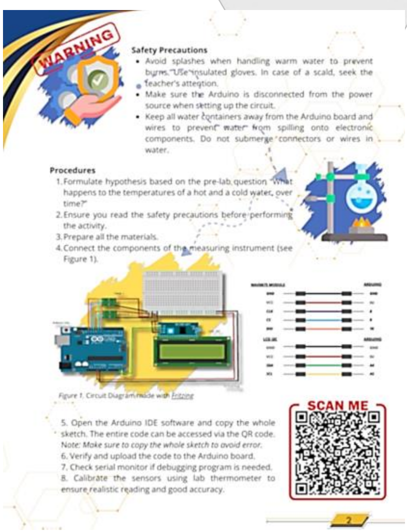
Figure 1. *ALMs Cover Page*

Header. This section includes the activity sheet number, student's name, grade level, date, and the title of the worksheet. It serves as the identification of the group or students and maintains essential data in an organized and systematic manner.

Objectives. This section outlines the goals for both content knowledge and skills that students should achieve. The experiment objectives clearly describe the expected behaviors or performances that demonstrate students' competence.

Materials. This section enumerated all the tools, equipment, and resources required to complete the activity or experiment, including the specific quantities or units of each material.

Key Concepts. This part explains the main ideas of the topic. It gives a short and clear explanation of the most essential points. This helps students focus on what they need to know to understand and finish the activity.



WARNING

Safety Precautions

- Avoid splashes when handling warm water to prevent burns. Use insulated gloves. In case of a scald, seek the teacher's attention.
- Make sure the Arduino is disconnected from the power source when setting up the circuit.
- Keep all water containers away from the Arduino board and wires to prevent water from spilling onto electronic components. Do not submerge connectors or wires in water.

Procedures

1. Formulate hypothesis based on the pre-lab question "What happens to the temperatures of a hot and a cold water, over time?"
2. Ensure you read the safety precautions before performing the activity.
3. Prepare all the materials.
4. Connect the components of the measuring instrument (see Figure 1).

Figure 1. Circuit Diagram made with Fritzing

5. Open the Arduino IDE software and copy the whole sketch. The entire code can be accessed via the QR code. Note: *Make sure to copy the whole sketch to avoid error.*
6. Verify and upload the code to the Arduino board.
7. Check serial monitor if debugging program is needed.
8. Calibrate the sensors using lab thermometer to ensure realistic reading and good accuracy.

SCAN ME

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Procedures. This part gives step-by-step instructions for doing the experiment. It includes formulating hypothesis, utilization of circuit diagram and expected design of the experimental setup. These guides make it easy for students to follow the steps, understand the ideas, and get the right results. Moreover, after setting-up the experimental setup, students are prompted to conduct the experiment and record observations thoroughly (see figure 2).

Data analysis. This part helps students write down what they see and measure during the experiment. It has tables, charts, or spaces to record data and observations. This keeps everything organized so students can use the information later for analysis.

Guide questions. This part helps students understand the data gathered and interpret its meaning. It includes guide questions to help them look for patterns, make conclusions, and analyze its significance to the main ideas and goals of the experiment.

Attachments. This section includes important materials related to the experiment. Primarily, it contains sketches, codes, or other essential resources needed to set up and execute the experiment effectively.

IV. DISCUSSION

T The ALMs followed the scientific method, prompting students to properly formulate hypotheses, conduct experiments, record results, analyze and interpret data, and generate conclusions—similar to the studies conducted by (Astra & Suganda, 2024; Sari et al., 2024). Students developed hypotheses based on a given problem or situation, which are then tested through hands-on experiments. Afterward, they analyzed the recorded results, including both numerical and descriptive data, and ultimately draw conclusions.

To facilitate this process, the experimental setup utilized a microcontroller and a temperature sensor, specifically an Arduino Uno and a MAX6675 module with a Type-K thermocouple (see figure 3). The MAX6675 module is primarily used to measure temperature, while the Arduino Uno processes and interprets the acquired data based on the code uploaded via Arduino IDE. For instance, users can modify the code to enable the Arduino to interpret sensor data and generate results in three different temperature scales. Additionally, the serial monitor can be used to display real-time data along with graphical representations.

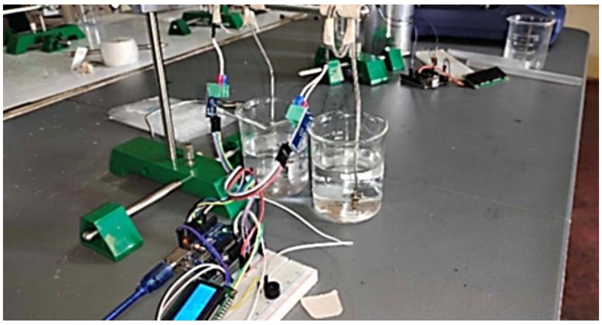

Figure 3. *Sample setup in experiment 1*

In the context of this study, the serial monitor functioned as both an input and output system, allowing users to input parameters while simultaneously displaying the output data during the duration of the experiment. This method was chosen by the researcher because it enables students to visualize data in real time. While integrating Internet of Things (IoT) would have been the ideal approach, resource limitations prevented its implementation in this study.

V. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the study, the developed Arduino-based learning materials (ALMs) on the topic of heat and temperature covered key concepts such as thermal equilibrium, thermometers and temperature scales, thermal expansion, specific heat capacity, and mechanisms of heat transfer. These materials included experiment guides and complementary practicum tools. The study recommends the full implementation of these learning materials, along with the development and use of diverse, innovative teaching strategies and instructional tools across various disciplines and subject areas. Additionally, teachers are encouraged to create similar learning resources for abstract topics in Physics and other fields of science.

REFERENCES

[14] Alwan, A. A. (2011). Misconception of heat and temperature Among physics students. Procedia - Social and Behavioral Sciences, 12, 600–614. https://doi.org/https://doi.org/10.1016/j.sbspro.2011.02.074

[15] Astra, M., & Suganda, Y. (2024). The Effect of Using Worksheet Based on a Scientific Approach Assisted by Scaffolding on High School Student's Cognitive Learning Outcomes on Temperature and Heat Material. Journal of Physics: Conference Series, 2866(1). https://doi.org/10.1088/1742-6596/2866/1/012103

[16] Department of Education. (2016). Adoption of the Basic Education Research Agenda. https://www.deped.gov.ph/wp-content/uploads/2016/06/DO_s2016_039.pdf

[17] Frago, R. L., & Janer, S. S. (2020). Effect of Demonstration Method and Laboratory Method in Enhancing the Conceptual Understanding of Grade Ten (10) Students in Chemistry. In IJESC. http://ijesc.org/

[18] García-Tudela, P. A., & Marín-Marín, J. A. (2023). Use of Arduino in Primary Education: A Systematic Review. In Education Sciences (Vol. 13, Issue 2). MDPI. https://doi.org/10.3390/educsci13020134

[19] Gibb, A. M. (2010). NEW MEDIA ART, DESIGN, AND THE ARDUINO MICROCONTROLLER: A MALLEABLE TOOL. https://api.semanticscholar.org/CorpusID:61743518

[20] Kim, S.-W., & Lee, Y. (2017). Development and application of arduino-based education program for high school students'. Journal of Theoretical and Applied Information Technology, 95. Retrieved from: https://www.jatit.org/volumes/Vol95No18/4Vol95No18.pdf

[21] Kotsis, K. T., Stylos, G., Pinelopi Houssou, & Kamaratos, M. (2023). Students' Perceptions of the Heat and Temperature Concepts: A Comparative Study between Primary, Secondary, and University Levels. European Journal of Education and Pedagogy, 4(1), 136–144. https://doi.org/10.24018/ejedu.2023.4.1.577

[22] Marín-Marín, J. A., García-Tudela, P. A., & Duo-Terrón, P. (2024). Computational thinking and programming with Arduino in education: A systematic review for secondary education. Heliyon, 10(8). https://doi.org/10.1016/j.heliyon.2024.e29177

[23] OECD. (2023). PISA 2022 Results (Volume I). OECD. https://doi.org/10.1787/53f23881-en

[24] Oseo, M. R. G., Janer, S. S., & Ricafort, J. D. (2023). Performance and Conceptual Understanding of Grade 11 Students in Physical Science. https://uijrt.com/articles/v4/i6/UIJRTV4I60005.pdf

[25] O'Sullivan, Dan., & Igoe, Tom. (2004). Physical computing : sensing and controlling the physical world with computers. Cengage Learning.

http://www.nomads.usp.br/pesquisas/design/objetos_interativos/arquivos/restrito/Thomson,.Physical.Computing.Sensing.and.Controlling.(2004).LinG.LotB.pdf

[26] Public Hearing of the Committee on Basic Education. (2024). Analysis of the Programme for International Student Assessment (PISA) 2022 Results for the Philippines" Background 1. https://legacy.senate.gov.ph/publications/LRS/Quick%20Notes/Comm%20on%20Basic%20Ed-PISA-14Feb2024.pdf

[27] Richey, R. C. (1994). Developmental Research: The Definition and Scope. https://eric.ed.gov/?id=ED373753

[28] Sari, I. N., Angraeni, L., Kurniasih, D., & Nurussaniah, N. (2024). Effectiveness of Guided Inquiry-Based Worksheets in Improving Science Process Skills on Vibrations and Waves Material. KAPPA JOURNAL Physics & Physics Education How to Cite, 8(3), 534–540. https://doi.org/10.29408/kpj.v8i3.28525

[29] Tasquier, G., Knain, E., & Jornet, A. (2022). Scientific Literacies for Change Making: Equipping the Young to Tackle Current Societal Challenges. Frontiers in Education, 7. https://doi.org/10.3389/feduc.2022.689329

[30] Trinidad, J. E. (2020). Material resources, school climate, and achievement variations in the Philippines: Insights from PISA 2018. International Journal of Educational Development, 75, 102174. https://doi.org/https://doi.org/10.1016/j.ijedudev.2020.102174

[31] Tupas, F. P., & Matsuura, T. (2019). Moving forward in stem education, challenges and innovations in senior high school in the Philippines: The case of Northern Iloilo polytechnic state college. Jurnal Pendidikan IPA Indonesia, 8(3), 407–416. https://doi.org/10.15294/jpii.v8i3.19707

[32] Yeo, S., & Zadnik, M. (2001). Introductory thermal concept evaluation: assessing students' understanding. The Physics Teacher, 39(8), 496–504. https://doi.org/10.1119/1.1424603