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Development of IoT-Based Physics Teaching Aids for Basic Physics Practicum

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Abstract: This study aims to develop an Internet of Things (IoT)-based physics teaching aid for basic physics laboratory practice, focusing on temperature and heat experiments. The research employed a modified Borg & Gall research and development (R&D) model, consisting of six stages: research and information collecting, planning, preliminary product development, preliminary field testing, product revision, and main field testing. The subjects involved were physics education students and expert lecturers as validators. The developed prototype integrated a DS18B20 temperature sensor and ESP8266 microcontroller, enabling real-time data transmission and visualization through a web-based application. Expert validation results showed an average score of 89.38%, categorized as very valid. Student responses reached an average score of 89.92%, indicating the tool was very well received. The feasibility test produced a score of 90.76%, confirming that the product is highly feasible for use in laboratory learning. The findings demonstrate that IoT-based teaching aids can enhance the accuracy of experimental data, increase interactivity, and improve student motivation and conceptual understanding in basic physics. Despite limitations such as WiFi range dependency and the need for sensor calibration, the prototype offers significant potential as a modern instructional medium. In conclusion, the IoT-based teaching aid developed in this study is valid, practical, and feasible, making it a promising innovation for modernizing laboratory practices in higher education and supporting the integration of digital technology into physics education.

Keywords: Borg & Gall R&D; Higher education; Instructional media; Internet of things (IoT); Physics practicum; Temperature and heat experiments

Introduction

Science education plays a crucial role in fostering critical thinking, problem-solving skills, and technological literacy among students, especially in preparing them to face global challenges in the era of the Fourth Industrial Revolution (McGrath et al., 2019; Susilawati et al., 2022; Verawati et al., 2025). According to constructivist learning theory, meaningful learning occurs when students actively construct knowledge through direct experience and interaction with phenomena (Bruner, 2020; Egerton, 2025; Piaget, 1972; Rigopouli et al., 2025). In this context, the integration of digital technology into education is no longer optional but essential. The Internet of Things (IoT), as one of the emerging technologies, provides opportunities to modernize science learning by enabling real-time data acquisition, interactive experimentation, and

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visualization of abstract concepts (Abdullah et al., 2024; Dudhat et al., 2023; Meylani, 2024, 2025; Rasyid et al., 2024).

Physics, as a fundamental branch of science, often requires students to bridge abstract theories with observable phenomena. Laboratory activities serve as a vital medium to strengthen this connection (Hoftein et al., 2003; Miller et al., 2023; Muliyadi et al., 2023; Munandar et al., 2024; Pratiwi et al., 2025). However, conventional laboratory instruments such as manual thermometers, stopwatches, and simple multimeters are limited in accuracy, efficiency, and interactivity. These limitations hinder students' ability to fully grasp essential concepts such as temperature and heat, which are foundational for advanced physics topics (Abrahams et al., 2008; Ruf et al., 2023). Cognitive load theory emphasizes that when tools are inefficient, students' working memory is overloaded, reducing their ability to process and internalize scientific concepts (Egerton, 2025; Mayer, 2009). Previous studies have demonstrated that technology-based media can enhance conceptual understanding, reduce cognitive barriers, and increase student engagement in science learning (Abdullah et al., 2024; Hake, 1998; Pratiwi et al., 2025; Prince, 2004).

Despite the growing adoption of IoT in various educational contexts—such as weather monitoring or environmental data collection—its direct application in basic physics laboratory experiments remains scarce (Islamiah et al., 2022; Matsun et al., 2022). Specifically, the measurement and visualization of temperature and heat using IoT-based tools have not been widely implemented, even though these topics are critical for building deeper knowledge in thermodynamics and related fields (Aprilia et al., 2025; Nugroho et al., 2023). This gap highlights the need for innovative instructional media that can overcome the limitations of conventional tools and provide students with accurate, real-time, and interactive learning experiences (Kolb, 2024; Zhang et al., 2025).

This study introduces the development of an IoT-based physics teaching aid designed for basic physics practicum, focusing on temperature and heat experiments. The novelty of this research lies in integrating IoT technology with laboratory practice to provide real-time data visualization through a web-based application, thereby enhancing both accuracy and interactivity (Abdullah et al., 2024; Rasyid et al., 2024). The urgency of this innovation is underscored by the demand for modern laboratory tools that align with 21st-century learning competencies, digital transformation in higher education, and the need to strengthen students' scientific literacy (UNESCO, 2021; Ulfah et al., 2025; Widyastuti et al., 2024).

Method

This study employed a Research and Development (R&D) method using the Borg and Gall model, which was modified into six stages: (a) Research & Information Collecting – Conducted through literature review and interviews with lecturers and students of basic physics laboratory courses to identify the need for modern IoT-based learning media. (b) Planning – System design planning, including the use of the DS18B20 sensor, ESP8266/ESP32 microcontroller, and an IoT-based web application. (c) Develop Preliminary Product – Development of an initial prototype consisting of hardware and software to visualize temperature and heat data in real time. (d) Preliminary Field Testing – A small-scale trial involving 10 students to obtain initial feedback regarding practicality and data readability. (e) Main Product Revision – Prototype revision based on validator input, such as interface simplification, sensor accuracy improvement, and addition of connection indicators. (f) Main Field Testing – The main trial conducted with 25 students using instruments such as expert validation questionnaires, student response questionnaires, and observation sheets.

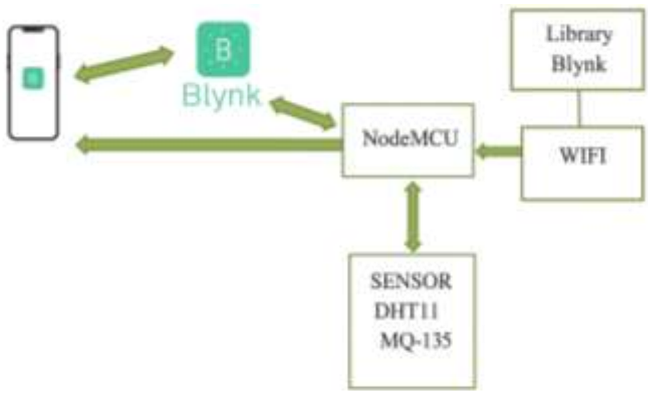

Figure 1. IoT software design

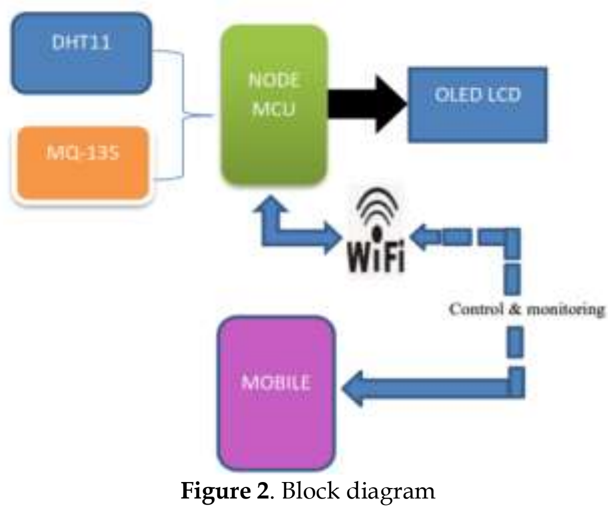

Figure 2. Block diagram

Population and Sample

The research subjects consisted of 25 Physics Education students participating in Basic Physics laboratory activities and 4 lecturers as expert validators.

Research Instruments

- Expert validation questionnaire (to assess construct validity, functionality, and alignment with learning objectives).
- Student response questionnaire (to evaluate ease of use, data readability, and usefulness).
- Observation sheet (to observe student interaction with the device).

Data Analysis Technique

Quantitative data obtained from questionnaires were analyzed by calculating percentage scores. The validation results were categorized as highly valid if the score was ≥ 85%. Student responses were classified as very good if the score was ≥ 85%.

Result and Discussion

Results

Prototype Development

The IoT-based physics teaching aid was successfully developed using a DS18B20 temperature sensor and an ESP8266 microcontroller. Data were transmitted via WiFi to a web application and visualized in the form of a temperature-versus-time graph. This system enabled students to observe heat changes in real time, making the learning process more interactive. Similar approaches have been reported in previous studies, where IoT-based sensors improved the accuracy and immediacy of laboratory data collection (Matsun et al., 2022; Zhang et al., 2021).

Expert Validation Results

Validation was conducted by four expert lecturers and yielded an average score of 89.38%. The highest-rated aspects were the clarity of feasibility indicators (100%) and the clarity of instrument language (100%). Minor weaknesses were identified in the application interface, which was considered not yet simple enough. These findings are consistent with other validation studies of IoT-based instructional media, which emphasize the importance of user-friendly interfaces for effective adoption (Hartini et al., 2017; Widodo et al., 2021).

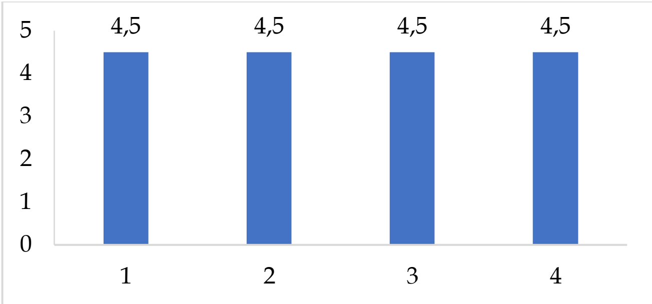

Figure 3. Validation

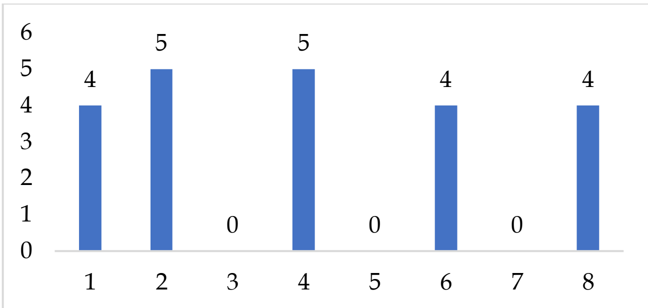

Figure 4. Result validators

Student Responses

Trials involving 25 students produced an average response score of 89.92%, categorized as very good. Students reported that the tool was easy to use, the data were clearly readable, and the practicum became more engaging. These results are consistent more engaging. These results are consistent with Reinanda et al. (2024), who demonstrated that demonstrated that IoT-based sensors IoT-based sensors enhance student motivation and participation enhance student in laboratory activities motivation and participation in laboratory activities.

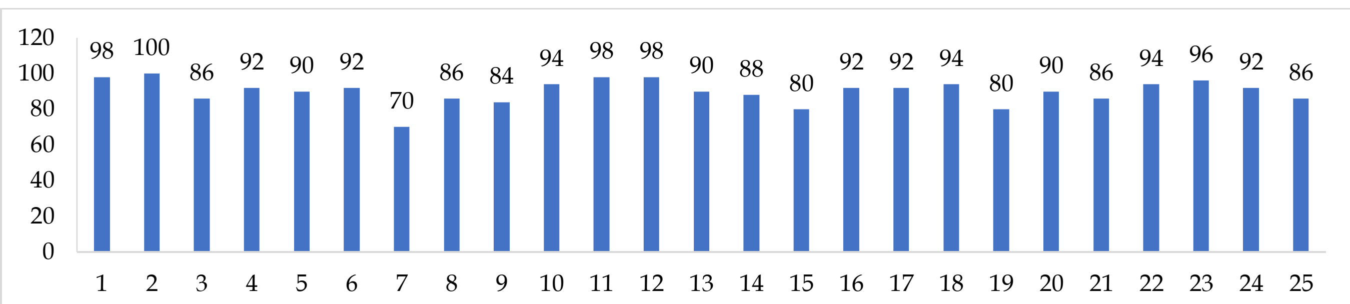

Figure 5. Student grades

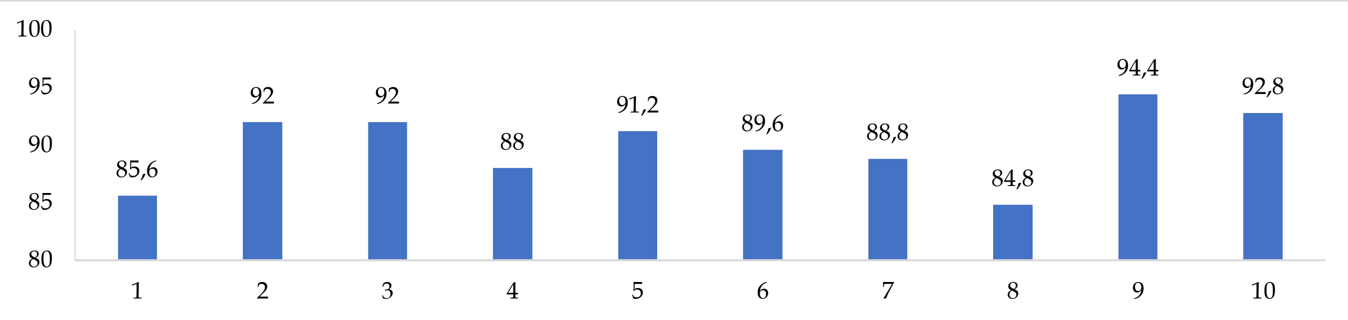

Figure 6. Student responses

Product Feasibility Testing

The overall feasibility score, combining expert validation and student responses, was 90.76%, indicating that the product is highly feasible for use in Basic Physics laboratory activities. This is consistent with feasibility studies of IoT-based laboratory tools in physics and engineering education, which report similar acceptance levels above 85% (Putra et al., 2025; Rasyid et al., 2024).

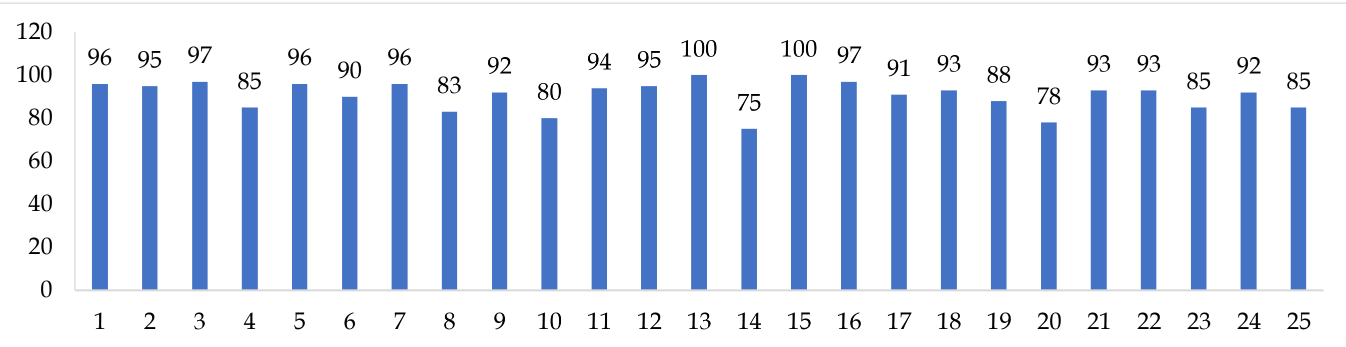

Figure 7. Feasibility of IoT-based learning media

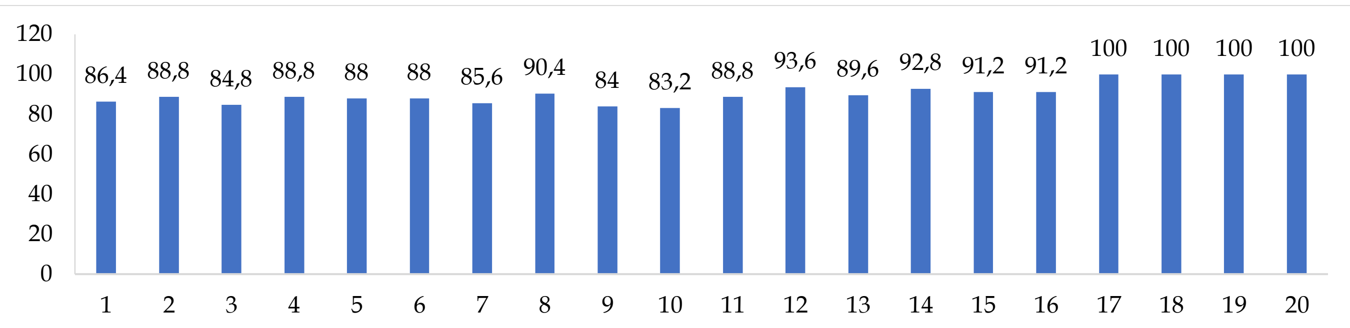

Figure 8. Percentage

Discussion

The findings of this study confirm that IoT-based teaching aids can enhance learning motivation, accuracy of experimental data, and interactivity in laboratory practice. This is in line with previous studies that highlight IoT's role in bridging abstract physics concepts with real-world applications (Zhang, 2025; Rustami et al., 2022; Meylani, 2024).

Advantages of the developed tool: (a) Provision of accurate real-time experimental data, consistent with Chen et al. (2024), Sya'bandari et al. (2022) and Rahman et al. (2023). (b) Increased student engagement and interactivity, as supported by Romero et al. (2024). (c) Alignment with 21st-century learning competencies, as emphasized by UNESCO (2021) and Aydin et al. (2023).

Limitations identified: (a) WiFi range restricted to laboratory areas, similar to constraints noted by Widodo et al. (2021). (b) Sensor calibration required for accuracy, consistent with findings by Suryani et al. (2022). (c) Application interface needs simplification, echoing usability concerns in IoT-based educational systems (Novak et al., 2024; Ruf et al., 2023).

Implications: This innovation demonstrates that IoT-based teaching aids can modernize laboratory learning in higher education. Furthermore, the approach can be expanded to other physics topics such as electricity, mechanics, and fluid dynamics, as suggested by recent studies on IoT integration in STEM education (Kumar et al., 2020; Lestari et al., 2022; Zhang et al., 2025).

Feasibility evaluation of the teaching aid: (a) The teaching aid was evaluated based on aspects of functionality, reliability, and ease of use, with a minimum feasibility standard of 80% based on expert and student validation results. (b) The system was able to operate continuously for at least 3 hours without significant technical issues.

Scientific output and intellectual property; (a) IoT system prototype. (b) Scientific article submitted to a Sinta 2–accredited national journal. (c) ISBN-registered book. (d) Intellectual Property Rights (IPR) submission.

Application in learning: (a) Adoption of this teaching aid in the Basic Physics laboratory curriculum at universities. (b) Students and lecturers can access experimental data through a web-based platform or mobile application, improving the effectiveness of technology-integrated learning. With these results, the study is expected to make a significant contribution to improving the quality of basic physics learning and serve as an innovation in the development of IoT-based instructional media in education.

Conclusion

This study developed an IoT-based instructional prototype for Basic Physics laboratory activities on temperature and heat using a DS18B20 temperature sensor, an ESP8266 microcontroller, and a web-based real-time data visualization system through a modified six-stage Borg & Gall R&D model. The results demonstrate that the developed prototype is highly valid, with an expert validation score of 89.38%, and is well received by students, as indicated by a very good response score of 89.92% during main field testing. The overall feasibility score of 90.76% confirms that the teaching aid is suitable for use in physics learning. The integration of IoT technology enables accurate, real-time data acquisition, enhancing student engagement, motivation, and conceptual understanding in laboratory activities. Despite limitations related to WiFi connectivity, sensor calibration, and interface optimization, the prototype shows strong potential for modernizing physics laboratory practices and supporting 21st-century digital learning, with opportunities for further development and application to other physics topics.

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Author Contributions

Conceptualization, Sari Wahyuni Rozi Nasution and Thofik Hidayat; methodology, Lia Purnama Sari; software, Sari Wahyuni Rozi Nasution, Hanifah Nur Nasution, and Dwi Anindita Siregar; formal analysis, Thofik Hidayat; investigation, Lia Purnama Sari; resources, Unita Sukma Zuliani; data curation, Hanifah Nur Nasution; writing—original draft preparation, Sari Wahyuni Rozi Nasution; writing—review and editing, Thofik Hidayat; visualization, Dwi Anindita Siregar; project administration, Sari Wahyuni Rozi Nasution; funding acquisition, Sari Wahyuni Rozi Nasution.

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Conflicts of Interest

The authors declare no conflict of interest. This research was funded by KEMDIKTISAINTEK through the BIMA Grant Scheme. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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