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Developing an ESP32-Based Temperature Laboratory Instrument to Enhance Undergraduate Students' Science Process Skills

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Abstract: This study aims to develop an ESP32 microcontroller-based temperature laboratory instrument that is valid, practical, and effective in enhancing students' Science Process Skills (SPS). This study employed the Research and Development (R&D) method with the ADDIE instructional design model (Analyze, Design, Development, Implementation, Evaluation). A large-scale pilot test involved 130 undergraduate students enrolled in the Basic Physics course. Data collection was conducted using expert validation sheets, a practicality questionnaire, and a Science Process Skills (SPS) essay test instrument (pre-test and post-test). The test results showed that the developed instrument is highly suitable for use, with an Aiken's V value of 0.86 (Highly Valid) and a Percentage of Agreement of 92.49% (Reliable). This tool also received a practicality rating of 91.41% from lab assistants and 81.98% from undergraduate students (Highly Practical). Effectiveness testing demonstrated that this tool's intervention significantly improved SPS, with an average N-Gain of 0.40 (Moderate category). The highest improvements were achieved in the domains of data interpretation (0.49) and observation (0.47), accompanied by a reduction in cognitive load due to the minimization of parallax error. Meanwhile, the low gain in the "hypothesis" domain (0.23) was solely due to the ceiling effect. It can be concluded that this ESP32-based laboratory instrument innovation is highly feasible and robust in accelerating students' scientific investigation skills in the laboratory.

Keywords: ESP32 Microcontroller; Laboratory Instrument; Research and Development; Science Process Skills; Temperature and Heat.

Introduction

Physics is a fundamental science that examines the workings of the universe and its constituent components, from macroscopic to microscopic scales (Kiswanto, 2022). An essential concept studied at the higher education level is thermodynamics, particularly temperature and heat (Addaini & Alvina, 2020; Fatiatun et al., 2022). Learning this material consistently requires the execution of experiments or practicums to bridge abstract theories with real-world phenomena (Ningsi et al., 2021). Ideally, laboratory practicums should facilitate undergraduate students in mastering Science Process Skills (SPS). SPS are fundamental investigative competencies required to train scientific argumentation, guiding undergraduate students through the stages of formulating hypotheses, controlling experimental variables, observing, interpreting data, and drawing logical conclusions (Arsyad & Sartika, 2021; Moi & Masing, 2023; Triani et al., 2023). The mastery of SPS is not merely passive theoretical memorization, but rather an integration of reasoning skills and empirical logic to explore knowledge meaningfully (Turiman et al., 2012).

Universally in science education literature, the mastery of SPS is classified into two interconnected hierarchical levels: basic SPS and integrated SPS (Rahmani et al., 2013). In the context of thermophysics experiments, basic SPS focuses on mastering the skills of observing, measuring thermal precision, predicting, and communicating phenomena in a structured manner (Ismunayah et al., 2025; Turiman et al., 2012). Meanwhile, integrated SPS demands a much more complex cognitive load, encompassing the ability of undergraduate students to identify variables, formulate hypotheses, and analytically interpret the fluctuations in experimental data graphs (Lati et al., 2012; Marwan et al., 2025). The synthesis of these six essential indicators is an absolute prerequisite for undergraduate students

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to independently construct scientific understanding in the laboratory.

However, the reality in the field reveals a stark gap between curriculum demands and the actual SPS achievements of undergraduate students. Based on a documentation study of the Basic Physics practicum grade records of undergraduate students across study programs, it was found that the average individual final evaluation score was highly concerning, dropping to 51.55 on a 100-point scale. This disparity confirms a fundamental constraint in the laboratory: undergraduate students still experience significant difficulties in operating, determining uncertainties, and accurately reading the scales of conventional thermal measuring instruments (thermometers) (Tarigan & Budiastuti, 2020). Furthermore, when compiling practicum reports, undergraduate students tend to merely transfer numerical data mechanically without reconstructing the physical meaning of heat transfer phenomena (Sulistiany & Darmawan, 2020; Taqwa et al., 2019). The high cognitive load placed on undergraduate students when they must carefully avoid parallax errors on analog measuring devices causes them to lose focus, thereby preventing the essential stages of SPS, such as interpreting and synthesizing data, from developing optimally.

Therefore, it is highly urgent to develop technology-based instruments to reduce this conventional technical load. This aligns with the findings of Saputra, Isnaini et al. (2025) which assert that physics laboratories strongly rely on the stability and accuracy of digital devices (Internet of Things) to ensure the validity of instrument data and prevent operational losses caused by manual measurements. One proposed innovative solution is the integration of an ESP32 microcontroller paired with a high-precision DS18B20 temperature sensor. This hardware combination has been proven to perform with high stability for use as a wireless laboratory temperature gauge (Baehaqi et al., 2023). The ESP32 microcontroller offers rapid computational processing, efficient power consumption, and flexible wireless connectivity features (Arrahma & Mukhaiyar, 2023; Hercog et al., 2023). Through this smart instrument, the thermal data acquisition process can occur automatically and be represented in the form of graphs and digital numbers in real-time. The digitalization of these experiments is crucial for lowering the mechanical workload of undergraduate students, ensuring that their remaining cognitive capacity can be entirely focused on practicing high-level SPS stage.

Innovations in laboratory equipment and digital media have proven to play a crucial role in physics education. In general, various types of technology, including website-based learning media, have been shown to be capable of visualizing physics concepts and facilitating the interactive engagement of undergraduate students (Isnaini et al., 2026). In the realm of hardware instrumentation, the track record of previous research also demonstrates a positive trend. Saputra et al. (2025) successfully developed an Arduino Nano-based digital viscometer with an inductive sensor that proved effective in streamlining the practicum time for undergraduate students. In a similar vein, Isnaini et al. (2025) also successfully integrated a load cell sensor and an Arduino microcontroller into fluid buoyancy experiments to replace conventional measuring devices (spring scales) that often produced high parallax errors. Building upon the successful track record of such digital instrumentation, this study seeks to synthesize and update laboratory instruments using more advanced ESP32 technology and DS18B20 temperature sensors.

Based on the aforementioned urgency, this study is specifically designed to introduce instrumentation innovation in the laboratory. This research aims to develop a temperature laboratory instrument based on the ESP32 microcontroller that meets the criteria of validity, practicality, and effectiveness in enhancing the Science Process Skills (SPS) of undergraduate students.

Method

This study applied the Research and Development (R&D) method. Principally, developmental research is a systematic process to design, develop, and validate educational products to ensure their empirical feasibility (Setyosari, 2016). The adopted development model was the ADDIE instructional design, which consists of the Analyze, Design, Development, Implementation, and Evaluation phases (Branch, 2009). The selection of this model was based on its highly structured and revolutionary framework in bridging technological innovation with instructional design (Adeoye et al., 2024; Hidayat & Nizar, 2021).

During the empirical implementation phase in the laboratory, this study utilized a pre-experimental One-Group Pre-test-Post-test Design. The large-scale trial involved undergraduate students from the Mathematics Education Study Program at the University of Mataram who were taking the Basic Physics Practicum course. Participants were selected using a purposive sampling technique, with inclusion criteria comprising a uniformity of academic background and no prior experience in using the ESP32 microcontroller device (Aini et al., 2020).

Data collection in this study utilized three main instruments: expert validation sheets, practicality response questionnaires, and an essay test instrument. The theoretical product quality was evaluated through a content validity test using the Aiken's V index (Utami et

al., 2024). The formula for calculating validity is formulated in Equation (1) as follows.

$$V = \frac{\sum s}{n(c-1)} \quad (1)$$

Description:

V = Aiken's V validity index

$\sum s$ = The difference between the score assigned by the validator and the lowest rating score $(r - l_o)$

n = Number of expert validators

c = Number of rating scale categories

Based on the aforementioned formulation, the level of product validity was interpreted referring to Retnawati's (2016) stipulations, namely the "Highly Valid" category ($V > 0.8$), "Moderate Validity" ($0.4 < V \leq 0.8$), and "Less Valid" ($V \leq 0.4$). Furthermore, to ensure that the agreement among the experts was consistent and free from bias, a reliability test of the Percentage of Agreement (PA) was conducted using Equation (2) (Emmer & Millett, 1970).

$$PA = \left(1 - \frac{A-B}{A+B}\right) \times 100\% \quad (2)$$

Description:

PA = Percentage of Agreement (Instrument reliability)

A = Higher rating score from the validator

B = Lower rating score from the validator

An instrument is declared to have good dependability and reliability if the percentage of agreement among validators reaches a minimum threshold of 75% (Borich, 2011). On the other hand, the extent to which the product's ease of application in the field was measured using the practicality percentage through Equation (3) below (Akbar, 2013; Irawan & Hakim, 2021).

$$\%\text{Practicality} = \frac{\text{Total score from raters}}{\text{Maximum total scor}} \times 100\% \quad (3)$$

The practicality evaluation criteria were interpreted into five ranges, where the product is declared to meet the "Highly Practical" requirements if the obtained percentage breaks through the 81% to 100% mark (Akbar, 2013).

Finally, to measure the effectiveness of the product on the investigative skill variables of undergraduate students, a practicum scenario-based essay test focusing purely on Science Process Skills (SPS) was employed. The SPS indicators measured included the ability to observe, predict, formulate hypotheses, identify variables, interpret data, and draw conclusions (Ismunayah et al., 2025; Marwan et al., 2025). The evaluation scoring was based on the accuracy, completeness, and precision of the undergraduate students' scientific steps using a 0 to 4 scale rubric. After the score for each item was obtained, the final SPS score was converted into a 100-point scale using Equation (4) (Arikunto, 2021).

$$\text{SPS Score} = \left(\frac{\text{Total obtained score}}{\text{Maximum total score}}\right) \times 100 \quad (4)$$

The significance of the improvement in undergraduate students' SPS post-intervention was then objectively calculated using the Normalized Gain (N-Gain) test in Equation (5) (Hake, 1998; Wahab et al., 2021)

$$N - Gain = \frac{(\text{posttest score} - \text{pretest score})}{(\text{maximum score} - \text{pretest score})} \quad (5)$$

The results of the N-Gain calculation were subsequently classified into three achievement levels, namely the "High" category ($g > 0.7$), the "Medium" category ($0.3 \leq g \leq 0.7$), and the "Low" category ($g < 0.3$) (Hake, 1998).

Result and Discussion

Product Feasibility (Validity and Reliability)

Before the instrument is implemented to measure learning effectiveness, the ESP32 microcontroller-based hardware and its accessories must be ensured to meet laboratory feasibility standards. Physically, the developed final product has been packaged into a compact (portable) smart instrument, equipped with a DS18B20 precision temperature sensor and an interactive LCD screen for data reading, as presented in Figure 1.



Figure 1. The developed ESP32-based temperature practicum tool

Based on the expert judgment test by subject matter and media experts using the Aiken's V index for the instrument, an average score of 0.86 was obtained, falling into the "Highly Valid" category. Furthermore, the inter-validator assessment consistency test using the Percentage of Agreement (PA) method showed a

percentage of 92.49% (Reliable). This figure confirms that structurally and functionally, this laboratory instrument is free from theoretical defects and is ready for field use.

Product Practicality

The operational quality of the ESP32-based temperature measuring device was also proven through a practicality test. The assessment from the practicum assistants as expert users showed a very high practicality score of 91.41%. In line with this, the large-scale trial involving 130 undergraduate students yielded a practicality percentage of 81.98% (Highly Practical). These findings confirm the research of Saputra, Gunada, and Wahyudi (2025) and Isnaini et al. (2025) , which state that the digitalization of measuring instruments using digital interfaces is highly effective in cutting down the complexity of physical experimental procedures, thereby proving the device to be user-friendly and efficient for undergraduate students mechanically.

Instrument Effectiveness on Science Process Skills

The primary focus of developing the laboratory instrument in this study was to evaluate the extent to which technological intervention could improve the Science Process Skills (SPS) of undergraduate students. The implementation of the instrument was carried out directly in the laboratory, where undergraduate students operated the ESP32 device to acquire thermal data automatically and in real-time. The atmosphere of the experimental execution and the interaction of undergraduate students with the digital device can be seen in Figure 2.



Figure 2. Implementation of the ESP32-based tool during the practicum

The effectiveness analysis of this intervention was then conducted quantitatively by comparing the pre-test and post-test scores using the Normalized Gain (N-Gain) test. A summary of the N-Gain achievement for each SPS indicator is presented in Table 1.

Table 1. Science Process Skills Achievement Results per Indicator

SPS Indicators	Average pre-test	Average post-test	N-Gain	Category
Observing and Measuring	1.97	2.92	0.47	Medium
Predicting	1.32	2.52	0.45	Medium
Formulating Hypotheses	3.08	3.29	0.23	Low
Identifying Variables	1.50	2.49	0.40	Medium
Interpreting Data	1.04	2.49	0.49	Medium
Drawing Conclusions / Communicating	0.45	1.65	0.34	Medium
Overall Average	1.56	2.56	0.40	Medium

Based on Table 1, the overall average N-Gain for the undergraduate students' SPS is at 0.40, which falls into the "Medium" category. This improvement proves that the use of the ESP32 smart instrument with the DS18B20 precision temperature sensor provides a tangible positive impact on the scientific investigative abilities of undergraduate students. The trend of score spikes per indicator is visualized more comprehensively through Figure 3.

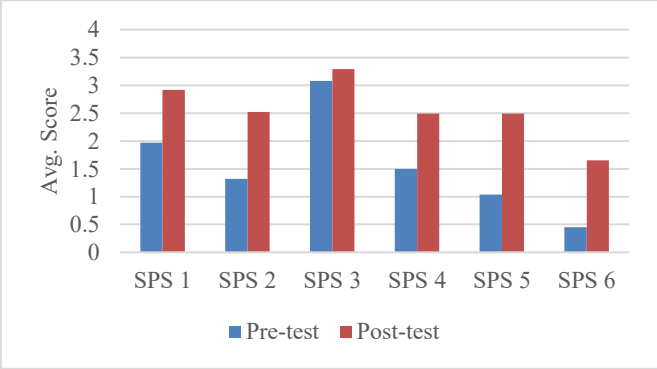


Figure 3. The improvement graph of Science Process Skills

If dissected more specifically based on Table 1 and Figure 3, the highest surge in improvement margin was facilitated by the instrument in the Interpreting Data (0.49) and Observing and Measuring (0.47) indicators. The high achievement in these two domains is highly rational. In conventional practicums, the working memory of undergraduate students is generally drained merely to avoid parallax errors when reading analog thermometer scales. With the ESP32 instrument, thermal data acquisition is represented in the form of precise decimal numbers and graphs in real-time. This convenience takes over the operational technical load, allowing the remaining cognitive capacity of undergraduate students to be devoted to analyzing and interpreting data trends. This is in line with Wahyuni et al. (2022) , who assert that interactive experimental data representation is crucial in stimulating learners to

transform abstract phenomena into meaningful quantitative analysis.

On the other hand, the least significant improvement was detected in the Formulating Hypotheses indicator, with an N-Gain achievement of 0.23 (Low Category). Although the gain appears low, an in-depth analysis of the raw scores reveals that undergraduate students had actually achieved a very high pre-test score for this indicator (3.08 out of a maximum scale of 4.00). This exceedingly high initial achievement triggered a ceiling effect phenomenon. The empirical reviews by Halimah and Fathurrohman (2025) and Habibi *et al.* (2026) confirm that when the target group already possesses a high baseline mastery of a measured variable, the remaining cognitive margin that can be statistically improved post-intervention becomes very narrow. Furthermore, the ability to formulate hypotheses fundamentally relies on the wealth of prior knowledge that undergraduate students have before entering the laboratory, rather than being a direct kinetic output of operating the instrument during the experiment (Darmaji et al., 2019).

Based on this analysis, the ESP32 microcontroller-based temperature laboratory instrument is proven capable of accelerating the essential skills of undergraduate students. This instrumentation innovation has successfully shifted the practicum paradigm from merely "assembling and recording" to "thinking and synthesizing" activities, which is the true essence of university-level Science Process Skills.

Conclusion

Based on the trial results and data analysis from this developmental research, it can be concluded that the ESP32 microcontroller-based temperature laboratory instrument is proven to be highly feasible, practical, and effective for implementation in the laboratory. Structurally and functionally, this instrument is declared highly valid with an average Aiken's V index of 0.86 and highly consistent with a Percentage of Agreement (PA) of 92.49% (Reliable). In terms of its usability, the interface of this digital instrument is proven to be highly practical and user-friendly in reducing the mechanical technical barriers of the experiment, as evidenced by the high ratings from the practicum assistants (91.41%) and the responses of the target undergraduate students (81.98%).

Furthermore, the intervention using this automated instrument has proven effective in significantly accelerating the Science Process Skills (SPS) of undergraduate students, with an overall average N-Gain of 0.40, which falls into the Medium category. The convenience of real-time thermal data acquisition successfully reduces the cognitive load of undergraduate students from the routine of avoiding parallax errors on analog devices, enabling their reasoning portion to be optimally focused on higher-order skills. This is evidenced by the highest surge in SPS improvement occurring in the domains of Interpreting Data (N-Gain 0.49) and Observing and Measuring (N-Gain 0.47). As for the relatively low improvement margin in the Formulating Hypotheses domain (0.23), empirically, it is not an instrument failure, but rather purely caused by the ceiling effect phenomenon because the undergraduate students already possessed a very high baseline mastery (pre-test score) before the practicum began.

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Author Contributions

Conceptualization, H.A.S., A.D., and K.; methodology, H.A.S. and A.D.; software, H.A.S.; validation, A.D. and K.; formal analysis, H.A.S.; investigation, H.A.S.; resources, H.A.S. and K.; data curation, H.A.S.; writing—original draft preparation, H.A.S.; writing—review and editing, A.D. and K.; visualization, H.A.S.; supervision, A.D. and K.; project administration, H.A.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. 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.

References

Addaini, A., & Alvina, S. (2020). Pengaruh Model Pembelajaran Contextual Teaching Learning (CTL) Terhadap Hasil Belajar Siswa pada Materi Suhu dan Kalor. *Relativitas: Jurnal Riset Inovasi Pembelajaran Fisika*, *2*(2), 16–22. https://doi.org/10.29103/relativitas.v3i1.2536

Adeoye, M. A., Wirawan, K. A. S. I., Pradnyani, M. S. S., & Septiarini, N. I. (2024). Revolutionizing Education: Unleashing the Power of the ADDIE Model for Effective Teaching and Learning. *JPI (Jurnal Pendidikan Indonesia)*, *13*(1), 202–209.

https://doi.org/10.23887/jpiundiksha.v13i1.68624

Aini, H., Sutrio, S., & Doyan, A. (2020). Pengaruh Model Pembelajaran Perolehan Konsep Berbasis Masalah Terhadap Kemampuan Pemecahan Masalah dan Pemahaman Konsep Fisika Peserta Didik Kelas XI MIA MAN 1 Mataram. *ORBITA: Jurnal Kajian, Inovasi dan Aplikasi Pendidikan Fisika*, *6*(1), 188. https://doi.org/10.31764/orbita.v6i1.1629

Akbar, S. (2013). *Instrumen Perangkat Pembelajaran*. Remaja Rosdakarya.

Arikunto, S. (2021). *Dasar-Dasar Evaluasi Pendidikan* (Edisi 3). Bumi Aksara.

Arrahma, S. A., & Mukhaiyar, R. (2023). Pengujian ESP32-Cam Berbasis Mikrokontroler ESP32. *JTEIN Jurnal Teknik Elektro Indonesia*, *4*(1), 60–66. https://doi.org/10.24036/jtein.v4i1.347

Arsyad, A. A., & Sartika, D. (2021). Analisis Keterampilan Proses Sains Mahasiswa Calon Guru Fisika pada Praktikum Fisika Dasar. *Indonesian Journal of Educational Science (IJES)*, *3*(1), 69–74. https://doi.org/10.31605/ijes.v3i1.1012

Baehaqi, M., Rosyid, A., Siswanto, A., & Subiyanta, E. (2023). Performance Testing of DHT11 and DS18B20 Sensors as Server Room Temperature Sensors. *Mestro: Jurnal Teknik Mesin Dan Elektro*, *2*(02), 6–11. https://doi.org/10.47685/mestro.v5i02.466

Branch, R. M. (2009). *Instructional Design: the ADDIE approach*. Springer.

Darmaji, D., Kurniawan, D. A., Astalini, A., & Samosir, S. C. (2019). Persepsi Mahasiswa Pendidikan Biologi dan Pendidikan Kimia Terhadap Penggunaan Buku Panduan Praktikum Fisika Dasar Berbasis Mobile Learning. *Edusains*, *11*(2), 213–220. https://doi.org/10.15408/es.v11i2.11185

Emmer, E. T., & Millett, G. B. (1970). *Improving Teaching Through Experimentation: a laboratory approach*. Prentice-Hall, Inc.

Fatiatun, F., Pratiwi, A. D., Wirdati, A. C., & Avifatun, N. (2022). Penerapan Termodinamika Heating Dan Colling Pada Dispenser. *Jurnal Penelitian dan Pengabdian Kepada Masyarakat UNSIQ*, *9*(2), 146–150. https://doi.org/10.32699/ppkm.v9i2.2658

Habibi, R. Z., Oktavia, B. V., Alqorina, A. Z., Pufindrayana, E. Y. P., & Ulhaq, M. A. D. (2026). Pengaruh Green Product Trust dan Green Product Value terhadap Green Behavioral Intention pada Mahasiswa Universitas Negeri Semarang. *Jurnal Multidisiplin Ilmu Akademik (JMIA)*, *3*(3), 1326–1338. https://doi.org/10.61722/jmia.v3i3.10725

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. https://doi.org/10.1119/1.18809

Halimah, I. N., & Fathurrohman, M. (2025). Pengaruh Media E-Modul terhadap Hasil Belajar Siswa Kelas VII pada Mata Pelajaran Islamic Faith Education di Sekolah Menengah Pertama Al Abidin Bilingual Boarding School Surakarta Tahun Pelajaran 2024/2025. *Jurnal Manajemen Pendidikan*, *10*(3), 1608–1617. https://doi.org/10.34125/jmp.v10i3.858

Hercog, D., Lerher, T., Truntič, M., & Težak, O. (2023). Design and Implementation of ESP32-Based IoT Devices. *Sensors*, *23*(15), 6739. https://doi.org/10.3390/s23156739

Hidayat, F., & Nizar, M. (2021). Model ADDIE (Analysis, Design, Development, Implementation and Evaluation) dalam Pembelajaran Pendidikan Agama Islam. *Jurnal Inovasi Pendidikan Agama Islam (JIPAI)*, *1*(1), 28–38. https://doi.org/10.15575/jipai.v1i1.11042

Irawan, A., & Hakim, M. A. R. (2021). Kepraktisan Media Pembelajaran Komik Matematika pada Materi Himpunan Kelas VII SMP/MTs. *PYTHAGORAS Jurnal Program Studi Pendidikan Matematika*, *10*(1), 91–100. https://doi.org/10.33373/pythagoras.v10i1.2934

Ismunayah, R., Uswatun, D. A., Nurasiah, I., & Sutisnawati, A. (2025). Peningkatan Keterampilan Proses IPA Melalui Pendekatan Science, Environment, Technology, and Society (SETS) di Sekolah Dasar. *ELSE (Elementary School Education)*, *9*(1), 85–96. https://doi.org/10.30651/else.v9i1.21975

Isnaini, A. H., Muliadi, I., Amrullah, L. A., & Saputra, H. A. (2026). The Role of Website-Based Learning Media in Enhancing Students' Conceptual Understanding: a Literature Review. *Indonesian Journal of Teacher Education*, *7*(1), 41–50.

Isnaini, A. H., Rifaldy, R., Ansori, A., Saputra, H. A., Zuhri, L. M. N., Sutrio, S., & Fuadi, H. (2025). Penerapan Sensor Load Cell dan Mikrokontroler Arduino dalam Eksperimen Gaya Apung Fluida. *Jurnal Ilmu Terapan dan Pendidikan*, *1*(1), 16–23.

Kiswanto, H. (2022). *Fisika Dasar 1*. Syiah Kuala University Press.

Lati, W., Supasorn, S., & Promarak, V. (2012). Enhancement of Learning Achievement and Integrated Science Process Skills Using Science Inquiry Learning Activities of Chemical Reaction Rates. *Procedia - Social and Behavioral Sciences*, *46*, 4471–4475. https://doi.org/10.1016/j.sbspro.2012.06.279

Marwan, A., Wahidin, W., Mustofa, R. F., Badriah, L., & Hernawati, D. (2025). Profil Keterampilan Proses Sains Siswa dalam Mata Pelajaran Projek IPAS di SMKN Bantarkalong Kabupaten Tasikmalaya. *SCIENCE : Jurnal Inovasi Pendidikan Matematika dan*

IPA, *5*(1), 113–122.

Moi, M. Y., & Masing, F. A. (2023). Pengembangan E-Modul Praktikum Mikrobiologi Menggunakan Aplikasi Kvisoft Flipbook Maker bagi Mahasiswa Pendidikan Biologi. *Jurnal Basicedu*, *7*(6), 3683–3691. https://doi.org/10.31004/basicedu.v7i6.6508

Ningsi, A. P., Purwaningsi, S., & Darmaji. (2021). Pengembangan Penuntun Praktikum Elektronik Berbasis Keterampilan Proses Sains Materi Suhu dan Kalor untuk SMP/Mts. *Emasains : Jurnal Edukasi Matematika dan Sains*, *10*(1), 198–209. https://doi.org/10.5281/zenodo.4734431

Rahmani, R., Abbas, M., & Alahyarizadeh, G. (2013). The Effects of Peer Scaffolding in Problem-based Gaming on the Frequency of Double-loop Learning and Performance in Integrated Science Process Skills. *Procedia - Social and Behavioral Sciences*, *93*, 1994–1999. https://doi.org/10.1016/j.sbspro.2013.10.154

Retnawati, H. (2016). *Analisis Kuantitatif Instrumen Penelitian*. Parama Publishing.

Saputra, H. A., Gunada, I. W., & Wahyudi, W. (2025). Development of an Arduino Nano-Based Viscometer to Enhance Students' Physics Concept Understanding. *Jurnal Pendidikan Fisika dan Teknologi*, *11*(2), 360–366. https://doi.org/10.29303/jpft.v11i2.10141

Saputra, H. A., Isnaini, A. H., Rifaldy, R., & Fathoni, J. W. (2025). Implementation of an IoT-based Temperature and Humidity Monitoring System in the Physics Education Laboratory. *Indonesian Journal of Educational Innovation*, *1*(2), 54–60.

Setyosari, P. (2016). *Metode Penelitian Pendidikan & Pengembangan*. Penerbit KENCANA.

Sulistiany, H., & Darmawan, H. (2020). Pengembangan Modul Praktikum Biokimia Untuk Meningkatkan Keterampilan Proses Sains Mahasiswa Pendidikan Biologi. *Bioma : Jurnal Ilmiah Biologi*, *9*(2), 172–188. https://doi.org/10.26877/bioma.v9i2.7057

Taqwa, M. R. A., Priyadi, R., & Rivaldo, L. (2019). Pemahaman Konsep Suhu dan Kalor Mahasiswa Calon Guru. *Jurnal Pendidikan Fisika*, *7*(1), 56. https://doi.org/10.24127/jpf.v7i1.1547

Tarigan, C. U., & Budiastuti, E. (2020). Evaluasi Pemanfaatan Laboratorium Dalam Meningkatkan Kompetensi Tata Kecantikan Kulit Mahasiswa Prodi Tata Rias Universitas Negeri Medan. *Home Economics Journal*, *4*(1), 28–36. https://doi.org/10.21831/hej.v4i1.28681

Triani, E., Darmaji, D., & Astalini, A. (2023). IDENTIFIKASI KETERAMPILAN PROSES SAINS DAN KEMAMPUAN BERARGUMENTASI. *Jurnal Pendidikan dan Pembelajaran IPA Indonesia*, *13*(1), 9–16. https://doi.org/10.23887/jppii.v13i1.56996

Turiman, P., Omar, J., Daud, A. M., & Osman, K. (2012). Fostering the 21st Century Skills through Scientific Literacy and Science Process Skills. *Procedia - Social and Behavioral Sciences*, *59*, 110–116. https://doi.org/10.1016/j.sbspro.2012.09.253

Utami, L., Festiyed, F., Ilahi, D. P., Ratih, A., & Yenti, E. (2024). Analisis Indeks Aiken Untuk Mengetahui Validitas Isi Instrumen Scinetific Habbits of Mind. *Journal of Research and Education Chemistry*, *6*(1), 59. https://doi.org/10.25299/jrec.2024.vol6(1).17430

Wahab, A., Junaedi, J., & Azhar, M. (2021). Efektivitas Pembelajaran Statistika Pendidikan Menggunakan Uji Peningkatan N-Gain di PGMI. *Jurnal Basicedu*, *5*(2), 1039–1045. https://doi.org/10.31004/basicedu.v5i2.845

Wahyuni, S. A., 'Ardhuha, J., Gunada, I. W., & Gunawan, G. (2022). Pengembangan Perangkat Pembelajaran Fisika Berbasis Model Problem Based Learning Berbantuan Simulai PhET untuk Meningkatkan Pemahaman Konsep Peserta Didik. *Kappa Journal*, *6*(2), 220–229. https://doi.org/10.29408/kpj.v6i2.6509