Indonesian Journal of Elearning and Multimedia
Volume 5, Issue 2, 113-130
e_ISSN: 2830-2885
https://ejournal.1001tutorial.com/ijoem/index
DOI: 10.58723/ijoem.v5i2.662

Development of Arduino-Based Elevator Learning Media to Enhance Scientific Reasoning Skills in Mechanical Energy

Wika Aryani Sinulingga*
Universitas Bengkulu,
INDONESIA

Dedy Hamdani
Universitas Bengkulu,
INDONESIA

Tiara Hardyanti Utama
Universitas Bengkulu,
INDONESIA

Article Info

Article history:

Received: April 23, 2026
Revised: May 12, 2026
Accepted: May 24, 2026

Keywords:

Arduino-Based Learning Media;
Elevator System;
Mechanical Energy Learning;
Scientific Reasoning Skills.

Abstract

Background: Physics education, particularly in mechanical energy topics, often faces challenges such as low conceptual understanding and limited scientific reasoning skills. These issues are frequently associated with the lack of interactive and technology-enhanced learning media that enable students to engage with real-time data and experimental visualization.
Aims: The aim of this study is to provide interactive learning media based on the Arduino Uno using an elevator system, evaluate its feasibility, and examine its effectiveness in enhancing students' scientific reasoning skills, particularly control of variables, hypothetical–deductive reasoning, and learning engagement.
Method: This study used the ADDIE process (analysis, design, development, implementation, and evaluation) to conduct research and development (R&D). Data were gathered using needs analysis questionnaires, expert validation sheets, two-tier multiple-choice tests (pretest–posttest), and student response questionnaires. The N-Gain approach was used to examine how students' scientific reasoning abilities improved.
Results: The implementation of the developed learning media was followed by a significant increase in students' scientific reasoning scores, with the average score increasing from 32 on the pretest to 88 on the posttest, resulting in an N-Gain score of 0.82 (high category). Additionally, the developed learning media received very positive student responses (94.6%), indicating high usability and engagement.
Conclusion: The implementation of the Arduino-based interactive learning media using an elevator system was associated with improvements in students' understanding of mechanical energy concepts and scientific reasoning skills, particularly in controlling variables and drawing evidence-based conclusions, while also providing an engaging and technology-supported learning experience.

To cite this article: Sinulingga, W. A., Hamdani, D., & Utama, T. H. (2026). Development of Arduino-Based Elevator Learning Media to Enhance Scientific Reasoning Skills in Mechanical Energy. *IJOEM: Indonesian Journal of Elearning and Multimedia*, *5*(2), 113–130. https://doi.org/10.58723/ijoem.v5i2.662

INTRODUCTION

Physics education plays a vital role in helping students develop higher-order cognitive abilities, such as critical thinking, problem-solving, and scientific reasoning. In the context of 21st-century learning, students are expected not only to comprehend scientific ideas but also to use them to analyze real-world phenomena (Ainia, 2020). However, international assessments such as PISA and TIMSS indicate that students' scientific reasoning and conceptual understanding remain relatively low, particularly in developing countries (Hadi & Novaliyosi, 2019). This condition emphasizes the need for more effective teaching approaches that promote deeper conceptual understanding and higher-order thinking skills (Tasrif, 2023).

One of the fundamental topics in physics learning is mechanical energy, which includes kinetic energy, potential energy, and the energy conservation concept. Despite its importance, students often experience conceptual difficulties in understanding the relationships between these forms of energy, particularly in connecting theoretical equations with real physical phenomena (Saputra et al., 2024). Learning practices that are still dominated by lecture-based instruction and procedural problem-

---

*** Corresponding author:**
Wika Aryani Sinulingga, Universitas Bengkulu, Indonesia. ✉ wikaaryani8@gmail.com

solving further limit students' ability to develop meaningful understanding and scientific reasoning skills.

Understanding mechanical energy concepts requires not only symbolic and mathematical reasoning but also physical interaction with real-world phenomena. According to the embodied cognition perspective, conceptual understanding develops more effectively when students physically interact with objects and directly experience changes in motion, force, and energy (Desutter & Stieff, 2017). Hands-on interaction enables students to connect abstract physics equations with observable phenomena, thereby strengthening conceptual meaning and reducing misconceptions (Kotsis, 2026). In contrast, screen-based simulations may simplify physical processes and reduce students' opportunities to engage in authentic experimental activities and direct manipulation of physical variables during learning. Therefore, physical experimental systems such as the Arduino-based elevator model can provide richer cognitive experiences that support deeper scientific understanding.

Previous studies have highlighted the value of inquiry-based and experimental learning in improving students' conceptual understanding and scientific reasoning skills. Learning environments that involve direct experimentation allow students to observe, analyze, and interpret physical phenomena, thereby strengthening their understanding of abstract concepts (Muchoyimah et al., 2020). In this context, the use of teaching aids and interactive media has been demonstrated to increase student involvement and facilitate meaningful learning experiences.

The integration of technology, particularly microcontroller-based systems such as Arduino Uno, provides new opportunities for developing interactive learning media. Arduino-based systems enable real-time data acquisition and visualization, allowing students to connect theoretical concepts with empirical data obtained during experiments (Jafar et al., 2024). Such technology-supported learning environments align with the principles of multimedia learning, where user interaction, real-time feedback, and usability play essential roles in enhancing learning effectiveness.

Scientific reasoning skills are essential in physics learning as they enable students to analyze data, interpret relationships between variables, and draw evidence-based conclusions. According to Antika et al. (2022), scientific reasoning consists of several indicators. However, this study focuses on two key indicators: control of variables (CV) and hypothetical–deductive reasoning (HDR). The control of variables (CV) indicator reflects students' ability to design fair experiments by manipulating one variable while keeping others constant. Meanwhile, hypothetical–deductive reasoning (HDR) refers to the ability to formulate hypotheses, test them through experimentation, and draw conclusions based on empirical data. These indicators are widely used to assess students' scientific reasoning in experimental learning contexts (Fawaiz et al., 2020).

Despite the growing integration of technology in physics education, existing studies primarily focus on improving conceptual understanding or general learning outcomes, while the explicit development of specific scientific reasoning indicators is often overlooked (Bao & Koenig, 2019). In particular, there is still limited research that effectively integrates interactive learning media with real-time data visualization to support control of variables and hypothetical–deductive reasoning in physics learning, as many existing simulation-based environments tend to promote oversimplified and algorithmic reasoning processes.

Therefore, the use of a physical elevator system in this study was intended to provide students with opportunities to directly manipulate experimental variables such as mass and height while observing real-time changes in motion and energy (Jian, 2022). This hands-on interaction supports the control of variables (CV) process more effectively than screen-based simulations because students can directly manipulate variables, obtain first-hand experimental data, and experience authentic physical feedback during experimentation (Shao et al., 2024). Furthermore, direct experimentation encourages students to formulate hypotheses, test predictions through observation and experimentation, and evaluate empirical outcomes during the learning process (Rodrigues & Gomes, 2020).

Consequently, there is still limited research that effectively integrates interactive learning media with real-time data visualization to support control of variables and hypothetical–deductive reasoning in physics learning, although interactive simulations and video analysis have been shown to enhance students' understanding and engagement in data-driven learning (Hockicko et al., 2015). This circumstance emphasizes the necessity of interactive learning media that integrate experimental activities with real-time data visualization and user interaction, as technology-based tools enable students to observe and analyze experimental data in real time and enhance engagement (Hendri et al., 2025). Arduino-based systems offer a practical and accessible solution for creating such learning environments, as they enable real-time data acquisition, sensor-based measurement, and interactive control, while also supporting visualization and hands-on learning (Rodriguez & Cuesta, 2021).

To ensure the quality of the developed media, feasibility evaluation is required, particularly in terms of content, media design, technical aspects, and learning support, as validation by content and media experts is essential to guarantee both pedagogical and technical quality (Hingmane & Rahmadonna, 2025). In addition, students' responses to the developed learning media are also important to evaluate its usability and effectiveness, as user experience has been found to be a crucial element affecting both learning outcomes and the intention to use digital educational tools (Rohles et al., 2022). These responses reflect key aspects of user experience, including attractiveness, ease of use, usefulness, and learning motivation, which are essential determinants of students' engagement and interaction with technology-based learning environments (Badr et al., 2024). Specifically, attractiveness plays a role in capturing students' attention and interest, ease of use is closely related to usability and determines how efficiently learners can interact with the system, usefulness reflects students' perceptions of the benefits of the media in supporting their learning, and motivation indicates the extent to which the media encourages active participation and sustained engagement in the learning process.

Therefore, this study aims to develop an Arduino-based interactive learning media using a physical elevator system for mechanical energy learning. Unlike conventional simulation-based learning environments, the developed system allows students to directly manipulate experimental variables such as mass and height while observing real-time changes in motion and energy. The integration of hands-on experimentation and real-time data visualization is expected to support students' scientific reasoning skills, particularly in terms of control of variables (CV) and hypothetical–deductive reasoning (HDR), as suggested in previous studies on experimental-based science learning (Asrizal et al., 2023). In addition, this study evaluates the feasibility, reliability, and effectiveness of the developed learning media, as well as students' responses toward its implementation in physics learning.

METHODS

Research Design

This study employed a Research and Development (R&D) method to develop an Arduino-based interactive learning media using an elevator system for mechanical energy learning, as R&D is widely used to develop and validate educational products (Sugiyono, 2013). As a methodical approach to instructional design, the development process adhered to the ADDIE model proposed by Branch (2009), which consists of analysis, design, development, implementation, and evaluation. Figure 1 shows the steps of the ADDIE model utilized in this investigation.

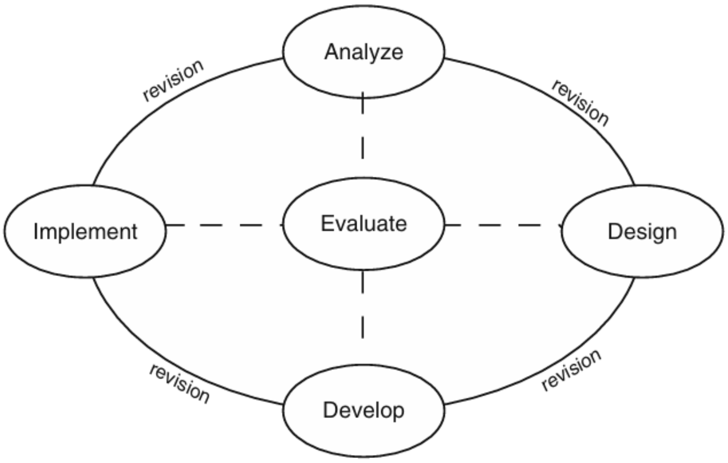

Figure 1. ADDIE Model

Participants

The participants of this study consisted of 26 tenth-grade students from SMAN 11 Kota Bengkulu who were selected using purposive sampling. The selected class had not yet formally studied mechanical energy concepts; however, the students had previously learned prerequisite concepts such as measurement, units, and unit conversion, which were considered essential for conducting experimental activities and interpreting physical variables during learning. These prerequisite skills were particularly important in supporting the development of scientific reasoning indicators, namely control of variables (CV) and hypothetical–deductive reasoning (HDR). The implementation was conducted in one meeting consisting of three instructional periods (3 × 45 minutes) during the second semester of the 2026/2027 academic year using an inquiry-based learning approach. During the learning process, students were engaged in inquiry activities such as formulating predictions, manipulating variables, conducting experiments, observing real-time data, and drawing conclusions based on empirical findings.

Instrumentation

The instruments used in this study consisted of a scientific reasoning test, validation sheets, and student response questionnaires. The scientific reasoning test was designed in a two-tier multiple-choice format, which allows for the assessment of both students' answers and their underlying reasoning, making it more effective in identifying students' scientific reasoning skills (Rahmaniasan et al., 2022).

The scientific reasoning test was developed based on control of variables (CV) and hypothetical–deductive reasoning (HDR), as presented in Table 1.

Table 1. Scientific Reasoning Indicator

Indicator	Description
Control of Variables (CV)	Ability to design fair experiments by controlling variables
Hypothetical–Deductive Reasoning (HDR)	Ability to formulate hypotheses, test them, and draw conclusions

Each item in the two-tier multiple-choice test was scored based on both the correctness of the answer and the appropriateness of the reasoning, with the following criteria: score 2 for correct answer and correct reasoning, score 1 for correct answer but incorrect reasoning, and score 0 for incorrect answer.

The student response surveys and validation sheets were developed using a four-point Likert scale to ensure clear and decisive responses without a neutral option (Zahro et al., 2017). All instruments were validated through expert judgment to ensure content validity. In addition, the reliability of the scientific reasoning test was analyzed using Cronbach's alpha coefficient to determine its internal consistency (Ghazali, 2018).

Procedures and time frame

The study followed the ADDIE stages:

1. Analysis: Identification of learning problems and students' needs through literature review, classroom observations, and needs analysis questionnaires. The analysis focused on students' difficulties in understanding mechanical energy concepts, the availability of experimental tools, and the need for interactive media to support data-driven learning.
2. Design: Development of the system design, including hardware and software architecture of the Arduino-based elevator system, experimental procedures, and learning activities. At this stage, research instruments were also designed, including validation sheets, student response questionnaires, and two-tier multiple-choice tests to measure scientific reasoning skills.
3. Development: Construction of the Arduino-based interactive learning media through component assembly, system programming, and functional testing. Experts validated the developed product in terms of content, media design, and technical aspects, followed by revisions based on expert feedback to ensure its feasibility.
4. Implementation: The developed media was implemented in classroom learning through a pretest–posttest design. Students conducted experiments using the elevator system in groups, observed changes in mechanical energy, and recorded data. The implementation included pretest, learning activities, and posttest to measure improvements in scientific reasoning skills.
5. Evaluation: Evaluation was conducted through both formative and summative approaches. Formative evaluation involved expert validation during the development stage, while summative evaluation included analysis of students' learning outcomes and responses to evaluate the developed learning media's usefulness and effectiveness.

Analysis plan

Feasibility Analysis

To evaluate the feasibility of the developed educational materials. The feasibility of the Arduino-based interactive learning media was analyzed using expert validation data. The validation scores obtained from experts were calculated using percentage analysis:

$$\text{Validation Score Percentage} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100\%$$

Since the instrument used a four-point Likert scale with 16 items, the minimum possible percentage corresponds to 25% and the maximum to 100%. The results were interpreted using the standards listed in Table 2.

Table 2. Validation Results Criteria (Sahlan, 2022)

Criteria	Percentage
Not Feasible	25%–43.75%
Less Feasible	43.76%–62.50%
Feasible	62.51%–81.25%
Very Feasible	81.26%–100%

Effectiveness Analysis

To examine the effectiveness of the developed learning media in improving students' scientific reasoning skills, pretest and posttest data were analyzed using results obtained from a two-tier multiple-choice test. The test measured two indicators of scientific reasoning, namely control of variables (CV) and hypothetical–deductive reasoning (HDR). Students' responses were scored based on both the correctness of the answer and the appropriateness of the reasoning, with the following criteria: score 2 for correct answer and correct reasoning, score 1 for correct answer but incorrect reasoning, and score 0 for incorrect answer. The enhancement of students' scientific reasoning skills was calculated using the N-Gain formula:

$$N_{Gain} = \frac{(Post - Pre)}{(S.Maks - Pre)}$$

The N-Gain values were classified into different levels of improvement based on the criteria presented in Table 3.

Table 3. N-Gain Interpretation Criteria (Saadah et al., 2025)

N-Gain (g)	Interpretation
g ≥ 0.7	High
0.3 ≤ g < 0.7	Medium
g < 0.3	Low

Student Response Analysis

To analyze students' responses toward the developed learning media, the data were obtained from a student response survey using a four-point Likert scale. The questionnaire measured several aspects, including attractiveness, usability, usefulness, learning support, scientific reasoning support, and learning motivation. Each item was scored using the following criteria: Strongly agree receives a score of 4, agree receives a score of 3, disagree receives a score of 2, and strongly disagree receives a score of 1. The students' response scores were calculated using percentage analysis:

$$\text{Validation Score Percentage} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times 100\%$$

The percentage results were interpreted based on predefined criteria, as presented in Table 4. Although the interpretation uses a 0–100% scale, the minimum possible percentage in this study is 25% due to the use of a four-point Likert scale with 12 items.

Table 4. Student Response Interpretation Criteria (Sahlan, 2022)

Percentage	Interpretation
25%–43.75%	Very Poor
43.76%–62.50%	Poor
62.51%–81.25%	Good
81.26%–100%	Very Good

This analysis was used to determine students' perceptions of the developed learning media in terms of usability, attractiveness, and how well it supports the process of learning.

Scope and limitations of the methodology

This study focused on the development and implementation of an Arduino-based interactive learning media for mechanical energy learning. The measurement of learning outcomes was limited to students' scientific reasoning skills, particularly control of variables (CV) and hypothetical–deductive reasoning (HDR). The investigation was carried out in a single class using a purposive sampling technique, which may limit the generalizability of the findings. In addition, the implementation was carried out in a limited time frame, which may not fully capture long-term learning effects. Furthermore, the effectiveness of the learning media was measured using a two-tier multiple-choice test, focusing on cognitive aspects and not fully representing affective and psychomotor domains.

RESULTS AND DISCUSSION

Results

Needs Analysis Results

The results of the needs analysis were obtained using a four-point Likert scale and converted into percentage values based on the ratio between the obtained score and the maximum possible score. The interpretation was carried out using percentage criteria to determine the level of each aspect.

The findings show that the learning condition reached 73.91%, categorized as moderate, reflecting that instruction is still relatively conventional. The availability of learning media reached 77.17% (high), suggesting that learning facilities are available but not yet optimally utilized.

Students' difficulties in understanding mechanical energy were reflected in a score of 70.11% (moderate), while data literacy reached 63.04% (moderate), indicating limited ability in interpreting experimental data.

In addition, students' experience in scientific reasoning activities reached 75.00% (moderate), suggesting limited engagement in inquiry-based learning. The highest score was observed in the need for interactive learning media (87.68%), categorized as high, highlighting a strong demand for more interactive and experiment-based learning tools.

Product Development Results

The design stage involves selecting and specifying the hardware components required to develop the learning media. The list of tools and materials used in this study is presented in Table 5.

Table 5. Hardware Components and Specifications

No.	Components and Materials	Quantity	Specifications
1	Arduino	1	Arduino Uno R3
2	LCD + I2C Module	1	20 × 4
3	Load Cell Sensor	1	5 kg capacity
4	Acrylic (Elevator Frame)	1	Elevator frame set
5	NEMA 17 Stepper Motor	1	12 V
6	Push Button	2	Normally Open (NO) type
7	Switch	1	Normally Open (NO) type
8	Jumper Wires	As needed	Male to Female
9	Mini Breadboard	1	400 tie-points
10	Power Adapter	1	12 V

In the development stage, the design that had been prepared was realized into a functional product. This stage focused on assembling the hardware components, developing the system program, and conducting testing and refinement until the learning media operated properly and was ready for classroom use. To support the assembly process, the specifications of the components used are presented in Table 5.

The Arduino-based interactive learning media using an elevator system was successfully developed to support the learning of mechanical energy concepts. The system is designed to provide an interactive and experiment-based learning experience by allowing students to directly observe physical quantities such as mass and height.

The developed system consists of integrated hardware and software components. The hardware includes a load cell sensor for measuring mass, a stepper motor for controlling vertical motion, and an LCD for displaying real-time data. Meanwhile, the software was designed to process sensor data, control the movement of the elevator system, and display relevant information, enabling real-time communication between the system and the user. The operational flow of the system is illustrated in Figure 2.

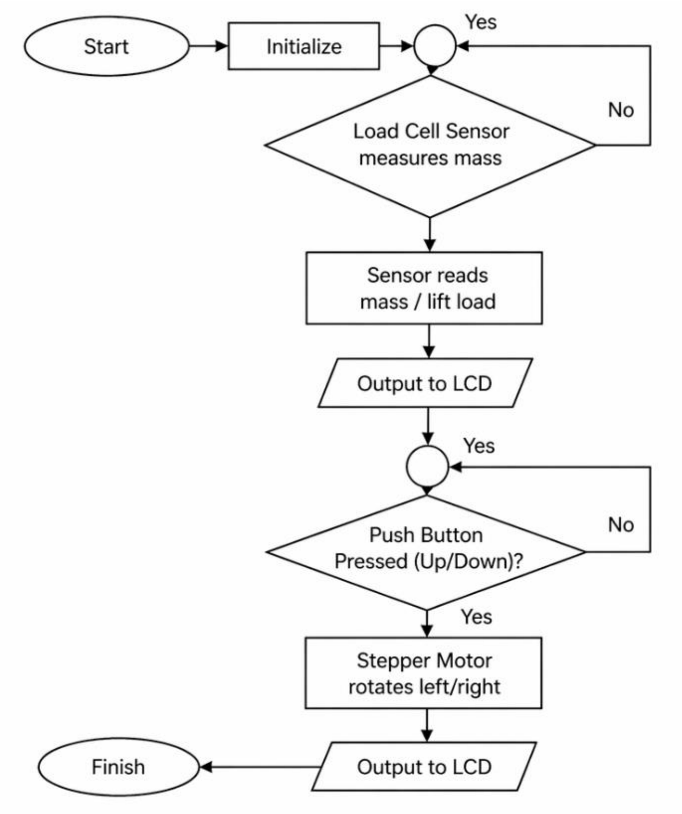

Figure 2. System Operation Flowchart

In the design stage, the Arduino Uno-based elevator learning media was designed to visualize concepts in mechanical energy. The development process began with constructing the elevator frame using acrylic material. The main components used in this design include a NEMA 17 stepper motor, a 5 kg load cell sensor, an Arduino Uno, and a 20×4 I2C LCD. These components were arranged and integrated into the elevator structure according to the planned system design.

The electronic circuit was developed by connecting the load cell sensor to an HX711 module for mass data acquisition. In addition, the stepper motor was connected to an A4988 motor driver, which was controlled by the Arduino to enable vertical movement of the elevator. The 20×4 I2C LCD was installed to display real-time experimental data, such as mass and system status.

After the hardware assembly, the software was developed using the Arduino IDE. The program was designed to read data from the load cell sensor, control the stepper motor movement based on user input from the Up and Down buttons, and display real-time measurement results on the LCD.

An elevator-based learning system was developed using a NEMA 17 stepper motor to move the elevator cabin vertically through four experimental height levels. The total elevator height was designed to be 1 meter, consisting of four observation levels with 20 cm intervals, while the remaining lower section was allocated for load cell placement. Elevator movement was controlled through push buttons, where each button press corresponded to a specific height level. During the experiment, students could directly observe the elevator position, object mass, and travel time displayed in real time through the LCD interface.

To support system operation, the Arduino Uno program controlled the stepper motor movement, processed load cell sensor data, calculated displacement based on motor steps, and continuously updated experimental information on the LCD interface. Mass measurements were obtained using a load cell sensor connected to the HX711 module, while height displacement was generated through the calibrated rotation of the stepper motor system. However, variations in pulley diameter caused by rope winding could produce slight inconsistencies in the automatic height displacement system. Therefore, a measurement scale attached to the elevator frame was used as the primary reference for students when recording experimental height data, allowing more accurate observations during learning activities.

Through this system, students were able to obtain the physical variables required to calculate mechanical energy, namely mass, height, and travel time. Potential energy was calculated using the equation:

$$E_p = mgh$$

while kinetic energy was determined using:

$$E_k = \frac{1}{2} mv^2$$

(Aliaslafti et al., 2019)

where the velocity value was obtained from the ratio between vertical displacement and travel time. Mechanical energy was then determined by summing the potential and kinetic energy values. Since the system utilized gram and centimeter units, students were required to perform unit conversion into kilograms and meters before calculating the energy values.

Real-time visualization of mass, height, and travel time through the LCD interface enabled students to immediately observe how changes in variables influenced the resulting mechanical energy calculations during the experiment. This immediate feedback supported students in controlling variables, interpreting measurements, testing predictions, and evaluating empirical results during inquiry-based learning activities (Hsiao et al., 2017).

Based on the flowchart in Figure 2, the system begins with the initialization of all components. The load cell sensor measures the mass of the load, and the measured value is processed and displayed on the LCD. When the user presses the Up or Down button, the system responds by activating the stepper motor to move the elevator accordingly. After the movement, the system updates and displays the new measurement value on the LCD, indicating continuous interaction between the sensor, control system, and output display. The physical appearance of the developed learning media is presented in Figure 3.

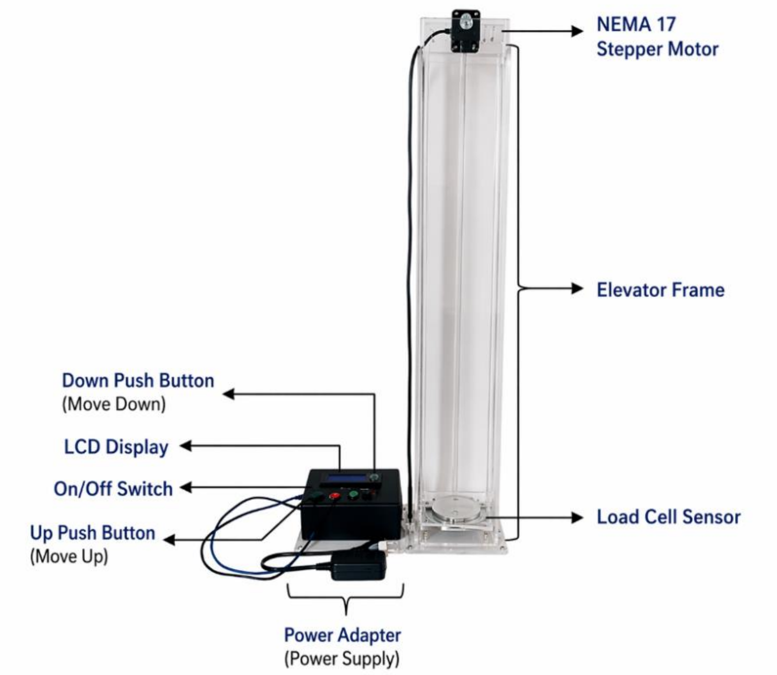

Figure 3. Arduino Based Elevator Learning Media

To evaluate the performance of the measurement system, load cell testing was conducted using several variations of mass. The results are presented in Table 6.

Table 6. Load Cell Accuracy Test Results

No	Mass (g)	Trials			Average	Error (%)
		1	2	3		
1	147	149	149	149	149	1.361
2	295	298	298	298	298	1.017
3	443	447	447	447	447	0.903

The results show that the load cell sensor produced consistent measurements across all trials, indicating good precision. A slight deviation was observed between the measured and actual values, with differences ranging from 2 to 4 g. The measurement error ranged from 0.90% to 1.36%, indicating a low level of deviation. Since potential energy is determined by mass, gravitational acceleration, and height ($E_p = mgh$) small deviations in mass produced only minor differences in the calculated energy values. Considering that the maximum deviation was only 2–4 g, the resulting effect on students' mechanical energy calculations was relatively small and did not significantly alter the interpretation of experimental results. Therefore, the load cell measurements were considered sufficiently accurate for educational purposes, particularly in helping students observe trends in potential energy and mechanical energy changes during experimentation. These findings suggest that the developed system provides sufficient measurement accuracy to support experimental-based learning activities, although minor deviations may still occur due to calibration limitations and mechanical factors within the system.

Implementation Results

The developed learning media was implemented in classroom learning activities to support students' understanding of mechanical energy concepts. The learning process was conducted using a guided inquiry approach, where students were actively involved in observing the system, conducting experiments by varying mass and height, recording data, and analyzing the relationships between variables.

These activities allowed students to directly explore the concepts of potential energy, kinetic energy, and mechanical energy through hands-on experience. The implementation of the developed media in the learning process is presented in Figure 4.

Figure 4. Student Activities Using the Elevator Learning Media

Feasibility Results

Three knowledgeable validators assessed the developed learning media's feasibility based on several aspects, including material feasibility, media design, technical aspects, learning support, and scientific reasoning support. The results of the feasibility evaluation are presented in Table 7.

Table 7. Feasibility Evaluation Results by Aspect

Aspect	Percentage	Category
Material Feasibility	94.4%	Very Feasible
Media Feasibility	95.8%	Very Feasible
Technical Feasibility	95.8%	Very Feasible

Aspect	Percentage	Category
Learning Support	88.9%	Very Feasible
Scientific Reasoning Support	91.7%	Very Feasible
General Feasibility	100%	Very Feasible

This shows that the developed learning media meets the required standards in terms of content quality, media design, technical performance, and its ability to support learning and scientific reasoning. To provide a clearer overview of the consistency among validators, the overall feasibility scores from each validator are summarized in Table 8.

Table 8. Feasibility Score from Each Validator

Validator	Percentage	Category
Validator 1	98.44%	Very Feasible
Validator 2	85.94%	Very Feasible
Validator 3	96.88%	Very Feasible
Average	**93.75%**	**Very Feasible**

The results in Table 8 show that all validators consistently rated the developed learning media in the "very feasible" category. Although slight variations are observed among validators, the overall scores indicate a high level of agreement, confirming the reliability of the feasibility evaluation.

The validation process involved assessments of content suitability, media design, technical functionality, and usability aspects of the developed learning media. Several suggestions provided by the validators were used to improve the final product before implementation. One important revision concerned the measurement of elevator height during system operation. Validators noted that variations in pulley diameter caused by rope winding could affect the consistency of the stepper motor displacement at different height levels. To improve measurement accuracy during experiments, a measurement scale was attached directly to the elevator frame and used as the primary reference for recording height data during learning activities. This revision helped ensure that students obtained more accurate experimental measurements when calculating mechanical energy variables.

Instrument Reliability Results

The reliability of the scientific reasoning test was evaluated using Cronbach's alpha to ascertain the instrument's internal consistency. The test consisted of two indicators, namely control of variables (CV) and hypothetical–deductive reasoning (HDR), with each indicator represented by four items. The reliability results for each indicator are presented in Table 9.

Table 9. Instrument Reliability Results

Indicator	Items	Cronbach's Alpha	Category
Control of Variables (CV)	1–4	0.539	Moderate
Hypothetical–Deductive Reasoning (HDR)	5–8	0.502	Moderate

The results indicate that both indicators achieved moderate reliability levels. Although the Cronbach's alpha values were below the commonly recommended threshold of 0.70, these findings should be interpreted cautiously because each indicator consisted of only four items and was designed to measure complex scientific reasoning skills through a two-tier multiple-choice format. In exploratory educational research and small-scale instrument development studies, moderate reliability values may still provide useful information for evaluating learning outcomes and identifying students' reasoning patterns (Taber, 2018). Therefore, the reliability results in this study indicate moderate internal consistency, while also reflecting limitations related to the small number of items within each indicator.

Effectiveness Results

The effectiveness of the developed learning media in improving students' scientific reasoning skills was analyzed using pretest and posttest data obtained from a two-tier multiple-choice test.

Table 10. N-Gain by Indicator

Indicator	N-Gain	Category
Control of Variables (CV)	0.95	High
Hypothetical–Deductive Reasoning (HDR)	0.73	High

The results indicate that both indicators of scientific reasoning skills experienced a high level of improvement after the use of the developed learning media. The improvement was more pronounced in the control of variables (CV) indicator compared to hypothetical–deductive reasoning (HDR).

To provide a more detailed overview of students' learning improvement, descriptive statistical analysis of the pretest and posttest scores was conducted. The results are presented in Table 11.

Table 11. Descriptive Statistics

Test	N	Mean	SD	Min	Max
Pretest	26	32.38	13.58	8	58
Posttest	26	88.31	9.56	67	100

Prior to conducting the paired-sample t-test, a normality test was performed on the difference scores between pretest and posttest using the Shapiro–Wilk test because it is considered more appropriate for studies involving small sample sizes, particularly fewer than 50 participants (Mishra et al., 2019). Since this study involved 26 students, the Shapiro–Wilk test was selected to examine the normality of the difference scores. The results indicated that the difference scores were normally distributed ($p = 0.103 > 0.05$). Therefore, a paired-sample t-test was conducted to determine the significance of the difference between students' pretest and posttest scores. The results of the paired-sample t-test are presented in Table 12.

Table 12. Paired-Sample t-Test Results

Variable	t-value	Degrees of Freedom	Sig. (2-tailed)	Interpretation
Pretest–Posttest	19.08	25	<0.001	Significant

The paired-sample t-test results revealed a statistically significant difference between the pretest and posttest scores ($t = 19.08$, $p < 0.001$). This finding indicates a significant increase in students' scientific reasoning scores following the implementation of the developed Arduino-based interactive learning media. Consistent with these results, the descriptive statistics presented in Table 11 showed that the mean pretest score was 32.38 (SD = 13.58), whereas the mean posttest score increased to 88.31 (SD = 9.56). These findings suggest that students demonstrated higher scientific reasoning performance after participating in the learning activities using the developed media in mechanical energy learning.

Student Response Results

Students' responses toward the developed learning media were collected using a Likert-scale questionnaire covering several aspects, including motivational engagement, instructional usability, and conceptual understanding and scientific reasoning.

Table 13. Student Response Results

Aspect	Percentage	Category
Motivational Engagement	94.7%	Very Good
Instructional Usability	95.7%	Very Good
Conceptual Understanding and Scientific Reasoning	93.5%	Very Good
Average	**94.6%**	**Very Good**

The results indicate that students showed a highly positive response toward the developed learning media across all evaluated aspects. Overall, the findings suggest that the media is well-received and supports an engaging and user-friendly learning experience.

Discussion

The findings of this study indicate that students' learning experiences in physics are still dominated by conventional methods, which limits their conceptual understanding. The needs analysis revealed that lecture-based instruction is still prevalent, making it challenging for students to understand complex topics. This result is in line with other studies that have shown that the absence of hands-on activities can hinder students' conceptual understanding (Liu & Fang, 2023).

In terms of learning facilities, although the availability of learning media is relatively high, it has not been optimally utilized in classroom activities. This suggests that the issue in physics learning is not only the availability of tools but also how they are effectively integrated into the learning process, as highlighted in previous studies on technology integration in education (Hasas et al., 2024).

Students' difficulties in understanding mechanical energy concepts further confirm that conceptual learning challenges still exist. These results align with previous findings that limited experimental activities contribute to low conceptual understanding of energy concepts (Tong et al., 2025). Similarly, students' data literacy skills were found to be moderate, indicating that students still struggle to interpret experimental data such as graphs and tables. This is in line with Rahmawati et al. (2021), who emphasize that direct involvement in experiments can improve students' data interpretation skills.

The limited experience in scientific reasoning activities also indicates that students are rarely engaged in inquiry-based learning processes. Previous studies highlight that experimental-based learning plays an important role in developing scientific reasoning skills (Kavitha & Joshith, 2024).

The high demand for interactive learning media suggests that students need more engaging and experiment-based learning environments. This supports previous research indicating that students' motivation and conceptual comprehension may be improved by technology-based learning resources (Halawa, 2024).

In relation to the first research objective, the feasibility results indicate that the developed learning media is categorized as very feasible across content, media design, and technical aspects. This demonstrates that the media meets the required standards for classroom implementation and is suitable for supporting experimental learning activities. Furthermore, the results of the development stage show that the developed learning media has good accuracy and reliability, making it suitable for use in experimental learning activities.

In relation to the second research objective, the effectiveness results demonstrate a notable enhancement in students' scientific reasoning skills, particularly in terms of control of variables (CV) and hypothetical–deductive reasoning (HDR). This indicates that hands-on experiments combined with real-time data can support meaningful learning experiences, as supported by previous studies showing that technology-integrated learning can enhance students' understanding and engagement (Nurqualbiah et al., 2024).

The improvement in hypothetical–deductive reasoning (HDR) can be explained by the learning activities facilitated through the Arduino-based elevator system. During the experiment, students were encouraged to formulate predictions about how changes in mass and height would affect mechanical energy and elevator motion before conducting the experiment. Students then tested these predictions by directly manipulating variables and observing real-time experimental outcomes displayed by the system. This process allowed students to compare their initial hypotheses with empirical evidence, evaluate inconsistencies, and revise their reasoning based on observed results. Such iterative experimentation and evidence-based evaluation are essential components of hypothetical–deductive reasoning in physics learning (Thacker, 2023).

The higher N-Gain score in the control of variables (CV) indicator compared to hypothetical–deductive reasoning (HDR) may be related to the nature of the learning activities conducted during the experiment. Through the developed elevator system, students were directly involved in manipulating observable variables such as mass and height while maintaining other variables constant during experimentation. Repeated hands-on activities, combined with real-time visualization of mass, height, and travel time enabled students to immediately observe how changes in variables influenced the resulting mechanical energy calculations. This immediate feedback helped students identify relationships between variables more easily and supported the development of variable control skills.

In contrast, hypothetical–deductive reasoning involves more complex cognitive processes, such as generating hypotheses, predicting outcomes, and evaluating evidence through deductive thinking (Kalinowski & Pelakh, 2024). Although the inquiry-based learning activities facilitated these processes, the limited implementation time may have reduced students' opportunities to engage in deeper reflection and hypothesis evaluation. As a result, the learning activities implemented in this study appeared to provide stronger support for the development of control of variables skills than hypothetical–deductive reasoning skills.

Overall, these findings confirm that integrating interactive technology with experimental learning activities can effectively improve both students' conceptual understanding and scientific reasoning skills, while also receiving positive responses from students. These results reinforce previous research findings and highlight the potential of Arduino-based interactive learning media as an effective tool in physics education.

Implications

The findings of this study imply that the use of Arduino-based interactive learning media can serve as an effective alternative to conventional physics instruction. The integration of real-time data and hands-on experimental activities can enhance students' engagement and support the development of scientific reasoning skills.

This study also highlights the importance of incorporating inquiry-based learning approaches supported by technology to create more meaningful and student-centered learning environments, particularly in abstract topics such as mechanical energy.

Research Contribution

This study contributes to physics education by developing an Arduino-based elevator learning media that integrates real-time data measurement with experimental activities. Unlike previous studies that mainly focus on conceptual understanding, this research specifically emphasizes the improvement of scientific reasoning skills, particularly in the indicators of control of variables (CV) and hypothetical–deductive reasoning (HDR).

In addition, this study provides empirical evidence that combining interactive media with inquiry-based learning can effectively enhance students' scientific reasoning skills in experimental physics learning.

Limitations

This study has several limitations. First, the research was conducted in a single class, which may limit the generalizability of the findings. Second, the implementation was carried out within a limited duration, which may not fully reflect long-term learning outcomes. Third, the developed system still has minor measurement limitations due to calibration and mechanical factors.

Suggestions

Future research is recommended to involve a larger sample size and a longer implementation period to obtain more comprehensive results. Further studies may also improve the mechanical design and sensor calibration to enhance measurement accuracy.

In addition, future development can expand this type of learning media to other physics topics or integrate it with more advanced technologies to further improve interactivity and learning effectiveness.

CONCLUSION

This study successfully developed an Arduino-based interactive learning media using an elevator system for mechanical energy learning. The developed media was categorized as very feasible, with an average validation score of 93.75%, indicating that the system met the required standards in terms of content quality, media design, technical performance, and learning support. The implementation results showed an increase in students' scientific reasoning scores following the use of the developed learning media, as indicated by the increase in the mean score from 32.38 in the pretest to 88.31 in the posttest, with an overall N-Gain score in the high category. The paired-sample t-test further confirmed a statistically significant difference between pretest and posttest scores ($t = 19.08$, $p < 0.001$).

The improvement in scientific reasoning skills was particularly observed in the indicators of control of variables (CV) and hypothetical–deductive reasoning (HDR), with the control of variables indicator showing a higher level of improvement. The integration of hands-on experimentation, real-time data visualization, and inquiry-based learning activities enabled students to directly manipulate variables, observe experimental outcomes, and evaluate empirical evidence during the learning process.

In addition, students showed highly positive responses toward the developed learning media, with an average response percentage of 94.6%, indicating that the media was engaging, useful, and easy to use in physics learning. These findings suggest that the developed media may serve as an effective alternative for supporting meaningful and experimental-based physics learning, particularly in developing students' scientific reasoning skills in mechanical energy topics.

ACKNOWLEDGMENT

The authors would like to express their gratitude to SMAN 11 Kota Bengkulu for supporting the implementation of this research. Appreciation is also extended to all students who participated in this study.

AUTHOR CONTRIBUTION STATEMENT

DH, TH, and SA contributed to the design of the study, development of the learning media and research instruments, data collection, data analysis, and manuscript preparation. DH provided primary supervision, particularly in guiding the development of the media and research direction, while TH contributed to manuscript review and refinement to ensure scientific writing standards. SA conducted the research and drafted the manuscript.

AI DISCLOSURE STATEMENT

The authors used ChatGPT during the preparation of this work for language refinement and structuring purposes. After using the tool, the authors reviewed and edited the content and take full responsibility for the final manuscript.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

REFERENCES

Ainia, D. K. (2020). Merdeka Belajar Dalam Pandangan Ki Hadjar Dewantara Dan Relevansinya Bagi Pengembanagan Pendidikan Karakter. *Jurnal Filsafat Indonesia*, *3*(3), 95–101. https://doi.org/10.23887/jfi.v3i3.24525

Aliaslafti, A., Sali, M. N. M., Ravechandran, P. A., & Othman, S. A. (2019). Physics: Case Study Series I. In S. A. Othman (Ed.), *Rolling Object* (pp. 1–7). Penerbit UTHM.

Antika, I. A., Supeno, & Wahyuni, D. (2022). Pengaruh Model Problem-Based Learning Disertai Lkpd Berbasis Multirepresentasi Pada Pembelajaran Ipa Terhadap Scientific Reasoning Skills Siswa Smp. *LENSA (Lentera Sains): Jurnal Pendidikan IPA*, *12*(2), 97–104. https://doi.org/10.24929/lensa.v12i2.226

Asrizal, A., Annisa, N., Festiyed, F., Ashel, H., & Amnah, R. (2023). STEM-integrated Physics Digital Teaching Material to Develop Conceptual Understanding and New Literacy of Students. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7). https://doi.org/10.29333/ejmste/13275

Badr, A. M. M., Al-Abdi, B. S., Rfeqallah, M., Kasim, R., & Ali, F. A. M. (2024). Information Quality and Students' Academic Performance: the Mediating Roles of Perceived Usefulness, Entertainment and Social Media Usage. *Smart Learning Environments*, *11*(1). https://doi.org/10.1186/s40561-024-00329-2

Bao, L., & Koenig, K. (2019). Physics Education Research for 21st Century Learning. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–12. https://doi.org/10.1186/s43031-019-0007-8

Branch, R. M. (2009). *Instructional Design: The ADDIE Approach.* Springer. https://doi.org/10.1007/978-0-387-09506-6

Desutter, D., & Stieff, M. (2017). Teaching Students to Think Spatially through Embodied Actions : Design Principles for Learning Environments in Science , Technology , Engineering , and Mathematics. *Cognitive Research: Principles and Implications*, *2*(22). https://doi.org/10.1186/s41235-016-0039-y

Fawaiz, S., Handayanto, S. K., & Wahyudi, H. S. (2020). Eksplorasi Keterampilan Penalaran Ilmiah Berdasarkan Jenis Kelamin Siswa SMA. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *5*(7), 934–943. https://journal.um.ac.id/index.php/jptpp/article/view/13721

Ghazali, I. (2018). *Aplikasi Analisis Multivariate dengan Program IBM SPSS*. Badan Penerbit Universitas Diponegoro (Semarang).

Hadi, S., & Novaliyosi. (2019). TIMSS INDONESIA (Trends in International Mathematics and Science Study). *Prosiding Seminar Nasional & Call For Papers*, 562–569.

Halawa, M. (2024). The Influence of Information and Communication Technology-Based Learning Media on Enhancing Students' Learning Motivation. *Jurnal Pendidikan Vokasi Indonesia*, *3*(01), 13–18. https://doi.org/10.63401/jpvi.v3i01.140

Hasas, A., Enayat, W., Hakimi, M., & Ahmady, E. (2024). A Comprehensive Review Of ICT Integration In Enhancing Physics Education. *MAGNETON: Jurnal Inovasi Pembelajaran Fisika*, *2*(1), 36–44. https://doi.org/10.30822/magneton.v2i1.3106

Hendri, M., Rasmi, D. P., Andika, N., & Wibisana, S. S. (2025). Integration of Arduino Uno and IoT Concepts in the Development of Magnetic Field Learning Media: A Qualitative Descriptive Study. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 785–797. https://doi.org/10.29303/jppipa.v11i8.12178

Hingmane, G. O., & Rahmadonna, S. (2025). Feasibility Assessment of a Nursing Learning E-Book through Content and Media Expert Validation. *NUSRA: Jurnal Penelitian Dan Ilmu Pendidikan*, *6*(3), 492-499. https://doi.org/10.55681/nusra.v6i3.3794

Hockicko, P., Krišťák, L., & Němec, M. (2015). Development of Students' Conceptual Thinking by Means of Video Analysis and Interactive Simulations at Technical Universities. *European Journal of Engineering Education*, *40*(2), 145–166. https://doi.org/10.1080/03043797.2014.941337

Hsiao, H., Chen, J., Hong, J.-C., Chen, P., Lu, C., & Chen, S. Y. (2017). A Five-Stage Prediction-Observation-Explanation Inquiry- Based Learning Model to Improve Students ' Learning Performance in Science Courses. *EURASIA Journal of Mathematics Science and Technology Education*, *13*(7), 3393–3416. https://doi.org/10.12973/eurasia.2017.00735a

Jafar, A., Rosita, S., Agus, N., Fitrah, A. N., Satriani, & Riskawati. (2024). Belajar Fisika dengan Arduino: Eksperimen Motor DC untuk Memahami Konsep Daya, Momentum, dan Gaya Agustina. *Jurnal Artificial*, *2*(2), 80–89. https://doi.org/10.54065/artificial.524

Jian, Y. (2022). Influence of science text reading difficulty and hands-on manipulation on science learning : An eye-tracking study. *Journal of Research in Science Teaching*, *59*(3), 358–382. https://doi.org/10.1002/tea.21731

Kalinowski, S. T., & Pelakh, A. (2024). A Hypothetico-Deductive Theory of Science and Learning. *Journal of Research in Science Teaching*, *61*(6), 1362–1388. https://doi.org/10.1002/tea.21892

Kavitha, K., & Joshith, V. P. (2024). Pedagogical Incorporation of Artificial Intelligence in K-12 Science Education: A Decadal Bibliometric Mapping and Systematic Literature Review (2013-2023). *Journal of Pedagogical Research*, *8*(4), 437–465. https://doi.org/10.33902/JPR.202429218

Kotsis, K. T. (2026). Teaching Physics Concepts in Primary Education : Evidence from Hands-on Experiments , Inquiry , and Digital Technologies. *International Journal of Advanced Multidisciplinary Research and Studies*, *6*(1), 1322–1329. https://www.multiresearchjournal.com/admin/uploads/archives/archive-1769253341.pdf

Liu, G., & Fang, N. (2023). The Effects of Enhanced Hands-on Experimentation on Correcting Student Misconceptions about Work and Energy in Engineering Mechanics. *Research in Science and Technological Education*, *41*(2), 462–481. https://doi.org/10.1080/02635143.2021.1909555

Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive Statistics and Normality Tests for Statistical Data. *Annals of Cardiac Anaesthesia, 22(1),* 67–72. https://doi.org/10.4103/aca.ACA_157_18

Muchoyimah, S., Kusairi, S., & Mufti, N. (2020). Korelasi Penalaran Ilmiah dengan Penguasaan Konsep Siswa pada Topik Usaha dan Energi. *JRPF (Jurnal Riset Pendidikan Fisika)*, *4*(2), 104–109. https://journal2.um.ac.id/index.php/jrpf/article/view/15836

Nurqualbiah, S., Karim, M., & Karim, A. A. (2024). Integrating Technology in Physics Learning. *International Journal of Academic Research*, *14*(8), 651–663. https://doi.org/10.6007/IJARBSS/v14-i8/22432

Rahmaniasan, V., Liska Berlian, & Dwi Indah Suryani. (2022). Pengembangan Instrumen Tes Two-Tier Multiple Choice Berbasis HOTS Tema Pemanfaatan Gelombang untuk Menumbuhkan Kemampuan Berpikir Tingkat Tinggi Siswa Viera. *Jurnal Pendidikan MIPA*, *12*(1), 1–7. https://doi.org/10.37630/jpm.v12i3.706

Rahmawati, D., Rusilowati, A., & Hardyanto, W. (2021). The Effect of Practicum Activities on Improving Data Literacy for High School Students. *Physics Communication*, *5*(1), 12–17. http://journal.unnes.ac.id/nju/index.php/pc

Rodrigues, M. N. dos S., & Gomes, C. M. A. (2020). Testing the hypothesis that the deep approach generates better academic performance. *International Journal of Development Research, 10(12),* 42925–42935. https://doi.org/10.37118/ijdr.20579.12.2020

Rodriguez, F. M. L., & Cuesta, F. (2021). An Android and Arduino based Low-cost Educational Robot with Applied Intelligent Control and Machine Learning. *Applied Sciences*, *11(1), 1-26.* https://doi.org/10.3390/app11010048

Rohles, B., Backes, S., Fischbach, A., Amadieu, F., & Koenig, V. (2022). Creating Positive Learning Experiences with Technology: A Field Study on the Effects of User Experience for Digital Concept Mapping. *Heliyon*, *8*(4). https://doi.org/10.1016/j.heliyon.2022.e09246

Saadah, F., Muhajir, S. N., & Mulvia, R. (2025). Model Argument Driven Inquiry (Adi) Dengan Memanfaatkan Gamifikasi Untuk Meningkatkan Penalaran Ilmiah Siswa. *Relativitas: Jurnal Riset Inovasi Pembelajaran Fisika*, *8*(1), 58–71. https://doi.org/10.29103/relativitas.v8i1.21302

Sahlan, M. (2022). Development of multimedia learning autoplay media studio 8 on the material Muslim personal work ethic. In Proceedings of the International Conference on Islamic Studies (ICIS). UIN K.H. Abdurrahman Wahid Pekalongan. https://proceeding.uingusdur.ac.id/index.php/icis/article/view/829

Saputra, L. Z., Halim, M. A., & Busyairi, A. (2024). Studi Kajian Literatur: Analisis Miskonsepsi Materi Usaha dan Energi pada Siswa SMA. *Jurnal Penelitian Dan Pembelajaran Fisika Indonesia*. https://doi.org/10.29303/jppfi.v6i2.646

Shao, F., Tang, L., & Zhang, H. (2024). Video watching and hands-on experiments to learn science : what can each uniquely contribute ? *Disciplinary and Interdisciplinary Science Education Research*, *11*(1). https://doi.org/10.1186/s43031-024-00103-x

Sugiyono. (2013). *Metode Penelitian Kuantitatif, Kualitatif dan R&D*. ALFABETA, CV.

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Tasrif. (2023). Higher Order Thinking Skills (HOTS) dalam Pembelajaran Social Studies di Sekolah Menengah Atas. *Jurnal Pembangunan Pendidikan: Fondasi Dan Aplikasi*, *10*(1), 50–61. https://doi.org/10.21831/jppfa.v10i1.29490

Thacker, B. (2023). Inquiry-Based Experimental Physics : Twenty Years of an Evidence-Based , Laboratory-Based Physics Course for Algebra-Based Physics Students. *Physical Review Physics Education Research*, *19*(2), 020116. https://doi.org/10.1103/PhysRevPhysEducRes.19.020116

Tong, D., Wu, H., Ren, H., Wang, Z., Pan, S., & Bao, L. (2025). Promoting Knowledge Integration in Work and Mechanical Energy through Conceptual Framework and Cooperative Learning Instruction. *Physical Review Physics Education Research*, *21*(1), 010163. https://doi.org/10.1103/lj4wwsqb

Zahro, U. L., Serevina, V., & Astra, I. M. (2017). Pengembangan Lembar Kerja Siswa (LKS) Fisika dengan menggunakan Strategi Relating, Experiencing, Applying, Cooperating, Transferring (REACT) berbasis Karakter pada Pokok Bahasan Hukum Newton. *Jurnal Wahana Pendidikan Fisika*, *2*(1), 63–68. https://doi.org/10.17509/wapfi.v2i1.4906