



Development of STEM-Based Interactive Learning Media for Critical Thinking Skills in Renewable Energy: Solar Power Plants

Tyse Ramadhona, Ketang Wiyono , and Evelina Astra Patriot* 

Physics Education Study Program, Faculty of Teacher Training and Education, Universitas Srimijaya, Jl. Palembang-Prabumulih, KM 32, Ogan Ilir Regency, South Sumatra, Indonesia

* Corresponding author(s), e-mail: evelinaastrapatriot@fkip.unsri.ac.id

Article Info:

Article History:

received: 26 January 2026

accepted: 9 February 2026

available online: 10 February 2026

Keyword:

interactive learning media, STEM, critical thinking skills, renewable energy, solar power plants

<https://doi.org/10.26877/lpt.v5i1.360>

Copyright © 2026 by author(s).

Published by Lontar Physics Today.

This is an open access article under the CC BY license (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Abstract:

This study aims to develop an interactive STEM-based learning media on renewable energy-Solar Power Plant, to train high school students' critical thinking skills. The development of learning media in this study is development research that focuses on the stages of media design, media development, expert validation, and implementation through limited trials. Data collection was conducted through questionnaires. The validity of the learning media was assessed by experts at the development stage and received very high scores for media (97%), material (93%), and learning design (94%), thus demonstrating high validity. The practicality of the media is evident from the positive responses of students in the one-to-one trial (90%) and the small-group trial (94%), indicating that it is highly practical. These findings indicate that interactive STEM-based learning media on renewable energy-Solar Power Plant, material is feasible and can be used in learning. Further research is recommended to assess the effectiveness of learning media.

1. Introduction

In the 21st century, technological advances have occurred rapidly, transforming all aspects of life, including education. (Usparianti L et al., 2023). 21st-century education requires students to master various skills as preparation for facing multiple challenges and becoming successful individuals in their lives (Usparianti L et al., 2023). One of the skills that students must master in the 21st century is critical thinking (Asrizal et al., 2023; Heryani et al., 2023; Jayadi et al., 2020; Susilawati et al., 2020). Critical thinking skills are essential for students because they enable them to think logically, solve problems effectively, and make rational decisions (Asniar et al., 2022; Susilawati et al., 2020). In addition, the development of critical thinking skills in learning is also an effort to improve student learning outcomes (Asniar et al., 2022; Susilawati et al., 2020). Therefore, it is necessary to train students in critical thinking skills in the learning process (Asniar et al., 2022).

Physics is a discipline that aims to develop critical thinking skills and train them (Akhsan et al., 2023; Mardiana et al., 2022). In addition, physics is one of the basic sciences closely related to everyday life and natural phenomena. By studying physics, students can understand and explain natural phenomena in their surroundings, making physics highly relevant to everyday life (Mulya & Salim, 2023; Sadiyah, 2021). In practice, physics learning in high school not only helps students master physics principles and concepts but also requires students to be active and develop various important skills, such as critical and creative thinking skills, to face future challenges (Arrum Sari & Wiyono, 2025; Nesti et al., 2022; Permata Sari et

al., 2025; Pratiwi et al., 2025). However, data in the field indicate that physics is among the least popular subjects among students (Badriyah et al., 2023; Fitriani et al., 2020; Simaremare et al., 2022).

Previous studies have also shown that students' critical thinking skills in physics learning are still relatively low. Asniar et al. (2022) found that critical thinking skills among high school students in physics learning remain relatively low. Similar findings were reported by Ardiyanti & Nuroso (2021), who found that 30.6% of students had very low critical thinking skills, 55.6% were in the low category, and 13.8% were in the sufficient category. Another study reinforced these findings, reporting that 21% of students had moderate critical thinking skills, 64% had low critical thinking skills, and 15% had very low critical thinking skills (Susilawati et al., 2020). This occurs because physics learning is considered difficult and uninteresting due to the many physics concepts that are difficult to understand and the lack of utilisation of learning media and variety of learning methods (Amalisholeh et al., 2023; Dali et al., 2021; Mahmudah et al., 2022; Simaremare et al., 2022; Sulastri et al., 2024). In addition, rapid technological developments have reshaped the learning paradigm, including revised curricula, the use of innovative learning media, and the integration of technology into instruction (Rahayu et al., 2022). This makes teachers, as the primary facilitators of education, required to adapt to technological advances to enrich students' learning experiences in the 21st century.

One way to overcome this is by using interactive learning media. Learning media plays an important role as a means of conveying information between teachers and students during the learning process, which can improve the quality of learning through the presentation of interesting and interactive material, thereby strengthening students' understanding and thinking skills (Khanafi et al., 2025; Muthoharoh & Sakti, 2021; Pramuji et al., 2020; Sevtia et al., 2022). In physics learning, the use of learning media is very important because it helps students understand various phenomena being studied (Fitri et al., 2023). Along with technological developments and students' familiarity with using technology, the use of interactive and innovative learning media has become increasingly relevant (Utomo, 2023). However, the availability of learning media to support students' in-depth understanding of certain materials is still limited, so innovation in the development of interactive learning media is needed (Afifah et al., 2022; Khanafi et al., 2025).

One innovation in the development of learning media is to integrate learning approaches into the media being developed. One approach is STEM (Science, Technology, Engineering, and Mathematics). By combining the four fields of science, technology, engineering, and mathematics, the STEM approach not only encourages students to connect knowledge and real-life situations in problem solving, but also helps students practice critical thinking skills, especially in physics learning (Khotimah et al., 2025; Septarini & Kholiq, 2021; Sury et al., 2022). Renewable energy is one of the topics in physics learning that requires interesting learning media (Ewar et al., 2023; Pawarangan et al., 2024).

Renewable energy is one of the subjects taught in Phase E of 10th-grade high school. One of the subtopics covered in this course is renewable energy sources. In Indonesia, solar energy is a highly promising renewable energy source, particularly through Solar Power Plants (SPPs). This is due to Indonesia's location on the equator, which receives sunlight every day throughout the year (Mayasari, Arya Samman, et al., 2022). However, in the practice of learning about renewable energy, this material is generally presented theoretically, making it less interesting and challenging for students to participate actively (Harchristanto & Utami, 2023). Therefore, learning innovations are needed to support the implementation of the Merdeka curriculum, which emphasises meaningful, contextual, and student-centred learning.

In line with this, under BSAKP Decree No. 33 of 2022, Learning Outcomes Phase E of the Merdeka Curriculum emphasises mastery of concepts and the application of science through scientific process skills. Thus, students are expected to be responsive to global issues and play an active role in contextual problem-solving. One of the strategic issues examined in this phase is renewable energy, which aligns with the Sustainable Development Goals (SDGs). Through this learning process, students are not only guided to master physics concepts conceptually but also to develop scientific attitudes and noble character, such as honesty, objectivity, critical and creative thinking, independence, innovation, teamwork, and global diversity awareness. Therefore, developing interactive, contextual, technology-based physics learning media on renewable energy-Solar Power Plants, material is essential to support the optimal achievement of Learning Outcomes Phase E and to improve the quality and meaningfulness of the learning process.

Previous studies have examined the development of learning media. Lima et al. (2023) developed a micro-hydro power plant (PLTMH) teaching aid as a valid and practical medium for teaching renewable energy concepts. Furthermore, Delima et al. (2023) successfully developed a renewable energy teaching aid based on solar cells for science education that is valid (suitable). Research conducted by Adiyatma & Diyana (2024) successfully developed physics learning media based on an articulate storyline 3, which is categorised as very feasible for use as teaching media. In addition, Pramadanti et al. (2021) also successfully developed physics learning media using STEM-based smartphones that are feasible for use. However, research on the development of interactive STEM-based learning media designed to train critical thinking skills in renewable energy- Solar Power Plants, materials remains very limited. In addition, research on the validity and practicality of renewable energy-Solar Power Plant, material learning media as an initial stage of product development remains very limited.

In addition, based on research conducted by (Ramadhona et al., 2025) Based on research conducted by (Ramadhona et al., 2025) through an analysis of the need for interactive STEM-based learning media development on renewable energy material-Solar Power Plant, it was found that even though students had studied renewable energy material in accordance with the curriculum, many still had difficulty understanding the concept of Solar Power Plant due to limited visual and interactive media and monotonous learning methods. The study also found that most students were accustomed to using technological devices and considered STEM-based interactive learning media to be very important and interesting, and potentially capable of improving their understanding of renewable energy-Solar Power Plant material. These findings confirm that developing STEM-based interactive learning media on renewable energy, specifically Solar Power Plant materials, remains essential to optimise physics learning in schools. Therefore, research was conducted to develop interactive STEM-based learning media on renewable energy-Solar Power Plant material, to train high school students' critical thinking skills. This research was limited to the development and testing of products to determine the validity and practicality of the learning media developed.

Based on the above description, this study was conducted to develop STEM-based interactive learning media on renewable energy material-Solar Power Plant (SPP), to train high school students' critical thinking skills. This study focused on the development and limited testing stages to analyze the validity and practicality of the developed media. In line with this objective, this study aimed to answer the following research questions:

- (1) What is the design structure of the STEM-based interactive learning media on renewable energy-SPP that was developed?

- (2) What is the level of validity of the learning media based on expert validation results?
- (3) What is the level of practicality of the learning media based on user responses?

2. Literature Review

2.1 *Critical Thinking Skills*

Critical thinking skills are fundamental to 21st-century skills (Wahyuni & Sari, 2020) and support success in learning (Wayudi et al., 2020). Critical thinking skills are one of the most important skills for individuals, as they enable people to think logically, face and solve various problems well, and make rational decisions regarding the actions to be taken (Susilawati et al., 2020). Critical thinking is a meaningful, reasoned, and purposeful way of thinking that can be used to solve problems logically and accurately (Doang et al., 2022). Critical thinking also has the potential to improve students' analytical skills in solving problems by considering the gap between reality and objective truth (Setiawan et al., 2022; Susilawati et al., 2020).

Critical thinking skills help students analyse problems logically and effectively and consider various factors when making decisions. Critical thinking skills are essential in education because they help students learn and think rationally, solve problems, and make sound decisions. In physics education, critical thinking skills are essential because they help students connect concepts to their applications in everyday life (Nurasiah et al., 2025). In addition, these skills are essential because physics learning requires a deep understanding of concepts and the application of scientific principles to solve real-world problems (Amelia & Chusni, 2024). Critical thinking skills have several indicators that can serve as references in physics education. Ennis proposes five indicators of critical thinking, namely, providing simple explanations, building basic skills, drawing conclusions, providing further explanations, and measuring strategies and tactics (Wijayanti & Siswanto, 2020). These indicators are relevant to physics learning because they reflect the scientific thinking required of students when analysing and solving physics problems logically and systematically. Therefore, critical thinking skills are essential for students (Winarti et al., 2022).

2.2 *Interactive Learning Media*

The term media derives from the Latin “medius,” meaning “middle,” “intermediary,” or “conveyer” (Hasanah, 2020; Rahman et al., 2023; Yusup et al., 2023). According to Gulo & Harefa (2022), media is a means of conveying information to recipients so that they can understand the message. Media plays an important role in the learning process because it serves as an intermediary through which educators convey messages to students (Fadilah et al., 2023; Sitepu, 2021). Pane (2023) states that media in learning are communication tools used to convey information to students and to arouse interest, attention, feelings, and thoughts, thereby increasing their engagement in the learning process. Thus, it can be concluded that learning media play a crucial role in education, conveying educational information to students, facilitating the learning process, and supporting the achievement of learning objectives.

Learning media has two important elements, namely hardware or equipment in the form of tools for presenting information and software in the form of information to be learned by students (Pane, 2023). Software is one of the media that can be used in learning and is relevant to technological advances in the current digital era (Afifah et al., 2022). In addition, smartphones or gadgets are one of the media that can support the learning process (Alifah et al., 2023; Kartini et al., 2020). These digital media can be in the form of interactive videos or mobile applications that can make students active during the learning process (Pranata & Firmansyah, 2023). In digital media, the material presented can be in the form of audio and visuals that are contextual, interesting, and interactive (Umam & Zaini, 2013). In addition, the

integration of technology in learning can also improve student learning outcomes (Chairudin & Dewi, 2021). The use of digital media in the learning process can provide opportunities for students to seek more extensive information through internet access, develop critical thinking skills, and problem-solving skills (Alifah et al., 2023).

The familiarity of students in using technology in their daily lives also makes the use of interactive and innovative learning media increasingly relevant (Utomo, 2023). Interactive learning media is media that allows students to actively and interactively engage with learning materials through various available features, such as simulations (Jafnihirida et al., 2023). In addition, interactive learning media have the potential to increase students' interest and involvement in the teaching and learning process by integrating several types of elements, such as audio, animated videos, and text (Arofah & Rinaningsih, 2021; Pranata & Firmansyah, 2023; Raspati et al., 2023; Rosmiati et al., 2023). Media is one of the supporting factors for successful learning processes (Harsiwi & Arini, 2020). The use of interactive learning media can also improve concept mastery, learning achievement, and critical thinking skills (Harsiwi & Arini, 2020). Thus, interactive learning media are a vital component of the learning process in schools.

In physics education, learning media play a crucial role in helping students understand the phenomena under study (Fitri et al., 2023). Renewable energy sources are a topic in physics education that requires the use of learning media (Ewar et al., 2023). Renewable energy is an important topic to be taught in order to shape students who are aware and prepared to become agents of change in supporting the provision of clean and affordable energy (Yuksel, 2019). This is also consistent with the observation that the current primary energy source, namely fossil fuels, is limited and environmentally harmful, so the introduction and understanding of alternative energy sources should be instilled from an early age (Ramadhona et al., 2025). One example of a renewable energy source is solar energy, which can be utilised via solar panels to generate electricity (Khanafi et al., 2025). Renewable energy materials not only provide knowledge of new technologies and methods for generating energy, but also emphasise the importance of critical thinking skills (Amelia & Chusni, 2024).

However, various studies show that students' critical thinking skills are still low (Amelia & Chusni, 2024; Anggraini et al., 2025; Dermawan et al., 2023). Physics learning also still faces challenges in developing critical thinking skills, which affects students' low learning outcomes (Yusra et al., 2025). The lack of learning media that train critical thinking skills and learning models that enable students to be active in the learning process are causes of students' low critical thinking skills. Therefore, the use of interactive learning media that facilitate critical thinking skills and present material visually, attractively, and in an easily understood manner is needed to make the learning process more meaningful. However, to date, media designed to support students' understanding of renewable energy materials is still very limited (Khanafi et al., 2025). Therefore, innovation in the development of interactive learning media is still very much needed (Afifah et al., 2022).

2.3 STEM

STEM stands for the four disciplines: Science, Technology, Engineering, and Mathematics. In addition, STEM is an approach to learning that integrates these four disciplines (Sury et al., 2022). The integration of STEM in learning is an effective way to develop individuals' skills and cognitive abilities (Rohmah et al., 2021). The STEM approach is also recognised as an important means of improving learning outcomes, critical thinking skills, and students' readiness to face 21st-century challenges (Murniati et al., 2023; Nugroho et al., 2021; Sihombing et al., 2024). STEM plays an important role in learning because it

requires students to solve problems in everyday life and shapes individuals into creative, independent, logical thinkers and technologically literate individuals (Widya et al., 2022).

The STEM approach has several characteristics, including: focusing on real-world problems and their solutions; teaching open inquiry and exploration; involving students in productive teamwork; and applying rigorous mathematics and science concepts learned by students in the learning process (Ejiwale, 2012). In addition, in the STEM approach, real-life objects are used as a context for applying mathematical and scientific concepts (Anggraeni, 2021). The STEM approach is also able to develop and improve students' technical abilities, enabling them to solve problems and understand the learning material as a whole (Anggraeni, 2021).

2.4 Solar Power Plant (SPP)

Solar power plants are power plants that utilise solar energy to generate electricity. Solar energy is a renewable energy obtained through sunlight, which is inexhaustible and does not cause pollution (Ferdyson & Windarta, 2023; Kharisma et al., 2024). Solar power plants have several advantages over other power plants, namely that they are more environmentally friendly, do not produce pollution, and have an unlimited energy source (Hidayat et al., 2021). However, the initial installation of a solar power plant is quite expensive (Hidayat et al., 2021). Solar power plants convert sunlight into electrical energy using photovoltaics (Dwisari et al., 2023). Photovoltaics, also known as solar cells, are devices that convert solar radiation into electrical energy (Usman, 2020). The electrical current generated by photovoltaics is direct current or DC, which can be used immediately or stored in batteries so that it can be used at night (Usman, 2020).

Solar power plants are a means of meeting a community's electricity needs in an environmentally friendly manner (Gifson et al., 2020). Solar power plants consist of several components, namely solar panels, solar charge controllers, batteries, and inverters (Mayasari, Samman, et al., 2022; Rifaldi et al., 2023). The workflow of a solar power plant can be seen in Figure 1.

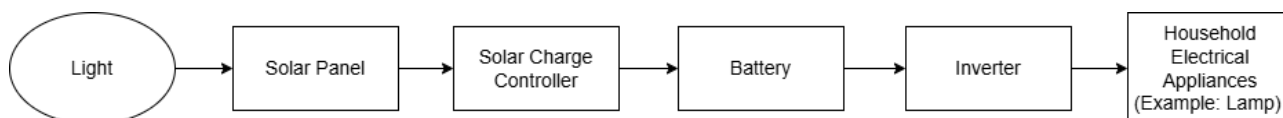


Figure 1. Solar Power Plant Workflow

Based on Figure 1, the solar power generation system process begins with sunlight being captured by solar panels. Solar panels convert the photon energy from sunlight into direct current (DC) electrical energy (Mayasari, Samman, et al., 2022; Rifaldi et al., 2023). The electrical energy generated is then fed into a solar charge controller, which regulates the voltage supplied to the battery to prevent overcharging or overdischarging (Mayasari, Samman, et al., 2022). Next, the electricity generated is stored in batteries for use when there is no sun (Mayasari, Samman, et al., 2022; Rifaldi et al., 2023). The stored DC electricity is then converted into AC electricity through an inverter so that it can be used to operate household electrical appliances (Mayasari, Samman, et al., 2022; Rifaldi et al., 2023). The integration of functions among these components shows that the solar power system operates sequentially and supports each component in generating usable electrical energy.

Each component in a solar power system is directly related to fundamental physical concepts, such as energy, electric current, voltage, and power. Solar panels produce electrical power in the form of voltage and current, the magnitudes of which are influenced by sunlight intensity and the panel

characteristics (Jaenul et al., 2022). If the weather is constantly changing, solar cells cannot produce maximum electrical energy (Jaenul et al., 2022). The electrical power generated by solar panels can be calculated according to

$$P = VI \quad (1)$$

where P is electrical power (watts), V is voltage (volts), and I is current (amperes). The voltage and current at the solar panel terminals can be measured using a multimeter connected to the panel.

In the developed interactive learning media, the SPP system is presented as a learning material with interactive simulations that incorporate weather conditions. These simulations allow students to observe differences in SPP performance under sunny and cloudy conditions, particularly in changes in voltage, current, and generated electrical power. Under sunny conditions, higher solar irradiance increases the output current and voltage of solar panels, thereby increasing electrical power generation. Conversely, in cloudy conditions, reduced sunlight intensity reduces current and voltage, thereby lowering the electrical power generated by solar panels. Through this simulation, students not only receive information passively but also actively explore the cause-and-effect relationship between weather conditions and the output of a solar power plant. Students can compare observation results across various weather conditions, analyse changes in voltage and current, and conclude their effects on electrical power using Equation 1.

3. Method

3.1 Research Design

This research is a development study, namely, the development of an interactive STEM-based learning media on PLTS (photovoltaic) to train high school students' critical thinking skills. This study focuses on the stages of media design, media development, expert validation to determine the level of media validity, and implementation, namely, limited trials, to determine the practicality of the learning media. However, this study does not include testing the media's effectiveness on students' critical thinking skills using test instruments. The analysis stages have been carried out in previous studies (Ramadhona et al., 2025). The results of this research serve as the basis for developing learning media in this study.

3.2 Design

This stage follows the analysis stage. In this stage, researchers begin designing learning media by defining its structure and appearance. In the design stage, researchers will create flowcharts to illustrate the workflow and structure of the learning media. In addition, researchers also compile storyboards to explain the scenario for using learning media, including the appearance, images, text, and buttons.

3.3 Media Development and Validation

After the learning media design was completed, the researchers developed the learning media using Canva and Articulate Storyline 3, based on the previous design. The result of this development was then referred to as prototype 1. Prototype 1 was then evaluated independently by the researcher and supervisor. If the learning media were deemed feasible from the researcher's and supervisor's perspectives, a validity test would then be conducted. The validity test was conducted with three groups of experts: media, subject matter, and learning design. The results of the learning media validity test were then used as the basis for prototype 2. Data collection was carried out using the walkthrough technique and validation sheets for experts. The validation sheets contained responses and suggestions from validators regarding the learning media that had been developed. The expert validation sheet grid used in this study is shown in Tables 1-3. The Appendix presents the expert validation instruments, including the Expert Material Instrument in

Table 8, the Media Expert Instrument in Table 9, and the Learning Design Expert Instrument in Table 10.

Table 1. *Content Expert Instrument Guidelines (Kurnia & Sunaryati, 2023)*

Indicator	Statement Number
Content suitability	1, 2, 3, 4, 5, 6
Presentation suitability	7, 8, 9, 10, 11,12
Content suitability with STEM	13, 14, 15, 16, 17
Content suitability with critical thinking skills	18, 19, 20
Language suitability	21, 22, 23

Table 2. *Media Expert Instrument Guidelines (Kurnia & Sunaryati, 2023)*

Indicator	Statement Number
Content Quality	1, 2, 3, 4, 5
Media Display	6, 7, 8, 9, 10, 11, 12
Visual Aspects	13, 14, 15
Execution	16, 17, 18, 19, 20
Audio Aspects	21, 22, 23

Table 3. *Learning Design Expert Instrument Guidelines*

Indicator	Statement Number
Alignment of Learning Objectives	1, 2
Alignment of Materials with Learning Objectives	3, 4
Structure and Flow of Learning	5, 6, 7
Active Involvement of Learners	8, 9
Alignment of Evaluation	10, 11
Motivation and Appeal of Learning	12, 13
Clarity of Learning Instructions	14, 15

The data obtained from the learning media validation stage was analysed using a Likert scale. The results from the validation sheets completed by three experts were then processed to determine the validity level of the learning media using percentage calculations, using the Expert Validation Results $HVA(\%)$ according to

$$HVA (\%) = \frac{\sum S}{S_{\max}} \times 100\% \quad (2)$$

where $\sum S$ is the total validation score and S_{\max} is the maximum score. The validation results were categorized into five levels of validity, namely highly valid (80.01–100), valid (60.01–80), less valid (40.01–60), invalid (20.01–40), and highly invalid (0–20) (Wiyono, Pasaribu, et al. 2025). This study only validated the learning media. The learning outcome test instruments were not validated because the study focused on the development and feasibility of the media. Revisions were made based on the validators' input and suggestions, resulting in prototype 2, which was then tested on students to determine the practicality of the learning media.

3.4 Implementation

At this stage, prototype 2, validated across all three materials, was then applied to students. This stage was divided into three parts: the one-to-one trial, the small-group trial, and the field trial. The one-to-one trial was conducted to assess the practicality of the learning media and involved three students. At this stage, the students involved had different levels of ability (Branch, 2010). The result of this stage is called prototype 3. After the one-to-one trial stage is complete, the learning media are then tested on a small group. The optimal number of students for the small group trial stage is 8-20 people (Branch, 2010).

Prototype 3 was tested on 9 students to determine the practicality of the developed media. The results of the small-group trial showed that the interactive STEM-based learning media on renewable energy- Solar Power Plant were valid and practical and could be used in learning.

Data collection on the practicality of learning media involved students from Pagar Alam State High School 1 in the odd semester of the 2024/2025 academic year. The one-to-one and small-group trial stages were conducted by distributing questionnaires to 11th-grade students. The questionnaires were given to students to assess their responses to the learning media developed. The purpose of distributing these questionnaires was to identify the practicality of the learning media that had been developed. The questionnaires contained students' responses to three aspects, namely appearance, navigation, quality of learning media, and ease of learning media, as well as suggestions and comments from students. The values obtained from the analysis of the questionnaire data were in the form of average percentages *HEOS*(%) from the one-to-one trial and small group trial stages according to

$$HEOS (\%) = \frac{S_q}{S_{qmax}} \times 100\% \quad (3)$$

where S_q is the score obtained from the questionnaire and S_{qmax} is the maximum questionnaire score. The HEOS calculation results were then categorized by media practicality level: very practical ($86 \leq HEOS \leq 100$), practical ($70 \leq HEOS < 86$), less practical ($56 \leq HEOS < 70$), and impractical ($HEOS < 56$) (Wiyono, 2015). The data collection process during the trial phase obtained permission from the school and informed consent from the students involved in the study. All data obtained was used solely for research purposes, maintaining the confidentiality of the respondents' identities.

4. Result

This research is a development study that produced an interactive STEM-based learning medium on renewable energy-solar power plant, designed to facilitate the development of critical thinking skills in high school students. The research was conducted at SMA Negeri 1 Pagar Alam. The stages in the development of the medium included design, development, expert validation, and implementation through limited trials.

3.1 Design Stage

The design stage of the learning media was carried out based on the analysis conducted by Ramadhona et al. (2025). The analysis indicated that students still had difficulty understanding the concept of renewable energy, particularly solar power plants (PLTS), due to limited visual media and a lack of interactive and exploratory learning activities. In addition, the learning process tends to be oriented towards conventional material delivery, which does not fully facilitate the development of students' critical thinking skills. These findings became the main basis for designing learning media that not only present material informatively but also provide a more visual, interactive, and contextual learning experience. Therefore, the media is designed to facilitate students' observation of phenomena, exploration of relationships between concepts, and simple analysis through simulation features and interactive exercises. The STEM approach is structurally integrated into the design, enabling the presentation of science, technology, engineering, and mathematics concepts holistically and supporting the development of critical thinking skills.

The design stage involved creating flowcharts and storyboards. This design aimed to ensure that the flow of learning media use was systematic and easy for students to understand, and to provide an

initial overview of the screen display in the learning media. The flowchart created can be seen in Figure 2.

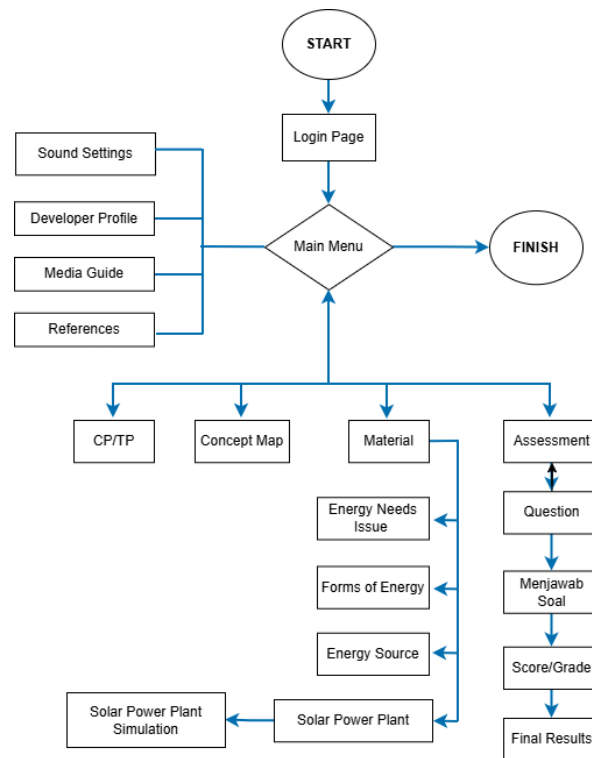


Figure 2. *Learning Media Flowchart*

As shown in Figure 2, the learning flow begins on the login page and proceeds to the main menu, which serves as a navigation centre. Students are then directed to specific learning features based on the objectives to be achieved.

- 1) The CP/TP menu and concept map serve to help students understand learning outcomes, learning objectives, and the interrelationships between renewable energy concepts. This stage trains students to identify the learning focus and build initial understanding in a structured manner. Next, in the materials menu, students learn about energy needs, energy forms and sources, and solar SPP. The material is presented in stages to encourage students to analyse energy availability issues and compare various energy sources based on their characteristics and impacts.
- 2) Critical thinking skills training is instilled more concretely through the solar power plant simulation feature. In this section, students are directed to observe changes in weather conditions (sunny and cloudy) and to analyse the relationships between voltage and current and between electrical power and current. This simulation activity encourages students to make observations, analyse relationships among variables, and draw conclusions from the data.
- 3) In addition, the assessment menu is designed to measure students' conceptual understanding and critical thinking skills after completing the entire learning series. Students are asked to answer questions related to the concept of renewable energy-Solar Power Plant, then receive a score or grade as feedback on their learning outcomes.

The results of this systematically organized design stage are then used as the basis for the learning media development process in the next stage.

3.2 Development and Validation Stage

After design, the learning media were developed using Canva and Articulate Storyline 3. This stage was carried out to produce learning media. In addition, during this stage, the validity of the learning media produced was tested through the involvement of three experts. The media was then revised based on their suggestions to produce valid media ready for student testing. The learning media produced can be seen in Figure 3-6.



Figure 3. Initial display of the learning media. (a) Login page, (b) Main page.



Figure 4. Material page

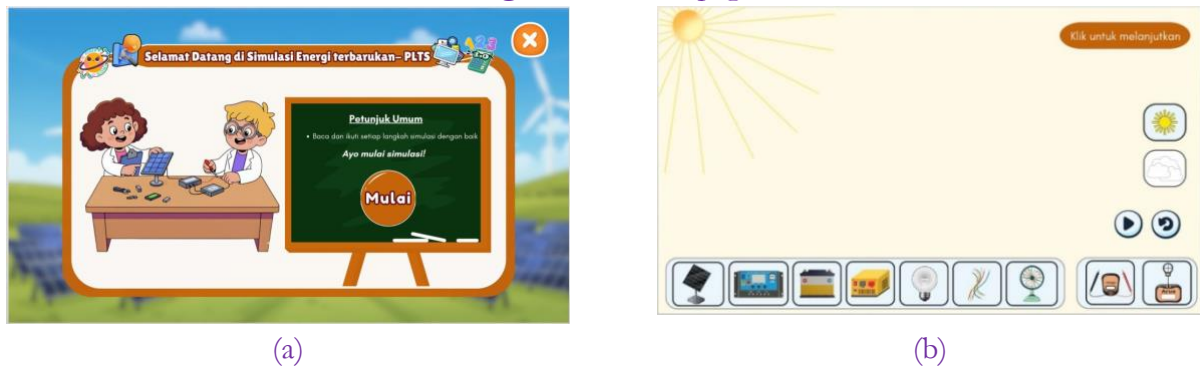


Figure 5. (a) and (b) simulation pages

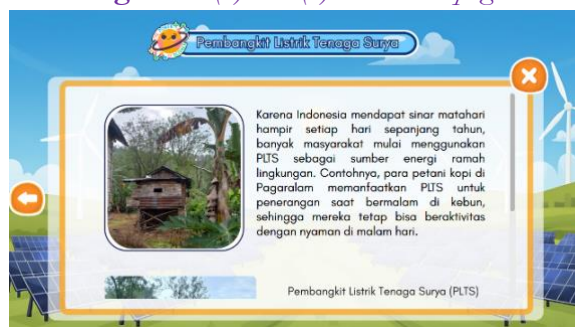


Figure 6. Local context integration

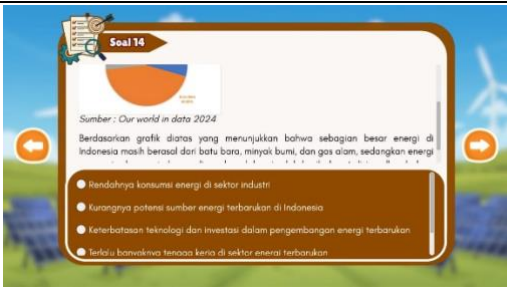
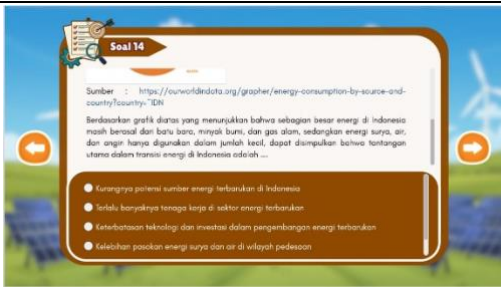


The initial results of the learning media development are referred to as prototype 1. Prototype 1 was then independently evaluated by the researcher and the supervisor. Subsequently, when prototype 1 was deemed feasible, the media validity test was conducted by experts. The validity test was conducted with three experts: two media and materials experts (two lecturers) and a learning design expert (a teacher). The results of the learning media validation test can be seen in Table 7.

Table 4. Expert validation results

Aspects	Score Percentage	Category
Media	90%	Very Valid
	97% (After revision)	Very Valid
Materials	93%	Very Valid
Learning Design	90%	Very Valid
Average validation	92,5%	Very Valid

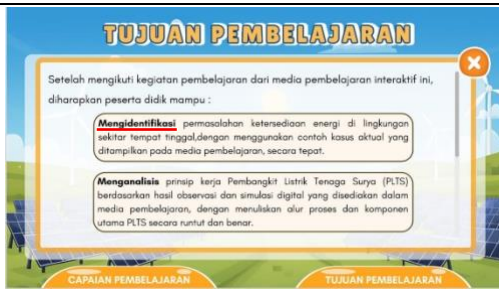
Based on Table 7, the expert validation results indicate that the developed STEM-based interactive learning media achieved an average percentage of 92.5%, classified as highly valid. The media component in the initial validation stage scored 90%, and this increased to 97% after revisions based on suggestions and expert input. The revisions included improvements to the media display, the clarity of the learning flow, and the presentation of material to facilitate student understanding. The media before and after revision are shown in Table 8.

Table 5. Media display before and after revision

Before Revision	After Revision
 <p>The source for question 14 is not yet a complete link.</p>	 <p>The source of the graph in question 14 has been updated to a full link.</p>
 <p>The learning outcomes remain two-sided and fixed, or cannot be scrolled.</p>	 <p>Learning outcomes have been made one-sided to prevent scrolling.</p>

Before Revision

After Revision



The learning objective remains (C1): identifying; it must be changed to (C4): analysing. KKO (C1) has been changed to analysing (C4).



The visualization of energy types on the concept map has not been adjusted, and the connecting words for energy sources are confusing and need to be repositioned. The visualisation of energy types on the concept map has been adjusted, and the location of the energy source connector has been corrected.



Provide video settings (e.g., speed-up/slow-down). Video settings (speedup/slowdown) are provided.

Previously, after the video, there were no follow-up questions, only the video itself.



A follow-up question has been added after the strategic issue video.



Before Revision

After Revision

Define kWh

kWh has been defined.

There were no follow-up questions after the video on the definition of energy.

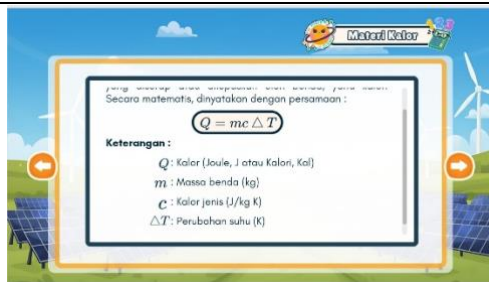


A discussion question has been added after the video on the definition of energy.

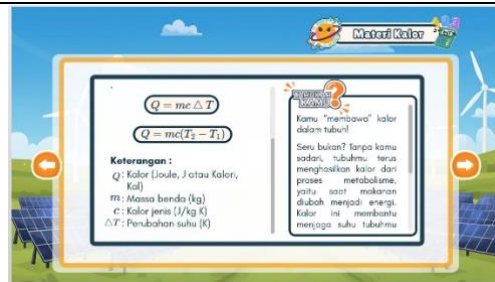
There is no information about scrolling in the user manual.



Information about scrolling has been added to the instructions for use



The heat equation has not been described, and the consistency of symbols has not been corrected. In addition, unique facts have not been added to the material on heat energy. Although the materials on kinetic, potential, and electrical energy have been supplemented with similar content, only the material on heat energy is attached to this research documentation.



The heat equation has been elaborated, and the consistency of symbols has been improved. In addition, unique facts have been added to the heat energy material. Although the kinetic, potential, and electrical energy materials have been supplemented with similar content, only the heat energy material is attached to this research documentation.



There is no navigation to the previous material on solar panel components.



Navigation to previous material has been added to the solar panel component.

3.3 Implementation

The implementation stage is the trial stage of prototype 2, which has been validated by experts for students. This stage is divided into two parts: the one-to-one trial and the small-group trial. The one-to-one and small-group trial stages are conducted to assess the practicality of the learning media. The results of the one-to-one trial stage can be seen in Table 6.

Table 6. Results of student responses to the one-to-one trial phase

Aspects	Total score	Maximum score	Score percentage
Appearance	80	90	89%
Navigation	80	90	89%
Quality of Learning Media	55	60	92%
Ease of Learning	82	90	91%
Average percentage			90%
Category			Very Practical

Based on Table 9, the results from the one-to-one trial stage showed an average practicality percentage of 90% in the very practical category. This indicates that the developed STEM-based interactive learning media have met the criteria for appearance, navigation, media quality, and ease of learning. At this stage, no revisions were made, so the media produced in the one-to-one trial stage is referred to as prototype 3 and is declared suitable for testing in the next stage. The results of the small group trial stage can be seen in Table 7.

Table 7. Results of student responses during the small group trial stage

Aspects	Total score	Maximum score	Score percentage
Appearance	260	270	96%
Navigation	250	270	93%
Quality of Learning Media	172	180	96%
Ease of Learning	252	270	93%
Average percentage			94%
Category			Very Practical

Based on Table 10, the small-group trial results showed that the learning media achieved an average practicality percentage of 94% in the very practical category. These results indicate an increase in practicality relative to the previous stage. The learning media were revised in response to students' suggestions and feedback, resulting in a final STEM-based interactive learning medium that is practical and suitable for physics and science instruction.

5. Discussion

5.1 Interpretation of Finding

The development of interactive learning media is driven by the need for media aligned with the curriculum and educational developments in the 21st century. This is based on a preliminary study of research conducted by Ramadhona et al. (2025), which found that STEM-based interactive learning media on renewable energy-PLTS to train high school students' critical thinking skills is still very much needed in physics/science learning. The need for this learning media stems from a learning environment still dominated by oral instruction and conventional media, resulting in uneven learning outcomes among students. In addition, this research indicates that the development of learning media is also guided by the applicable curriculum, namely the independent curriculum. Renewable energy-PLTS material is relevant to the independent curriculum as indicated in the learning outcomes of phase E regarding renewable energy. Phase E Learning Outcomes of the Merdeka Curriculum emphasize contextual learning, problem

solving, technology utilization, and the strengthening of critical thinking skills and scientific attitudes, making it relevant to be developed through a STEM approach.

The media design stage produces a storyboard and flowchart for the learning media. The storyboard provides an overview of the interactive learning media to be developed and serves as a guide for their development. The flowchart illustrates the flow of the learning media from the login page to the assessment. The storyboard and flowchart that have been designed form the basis for developing the media. The learning media is developed using Articulate Storyline 3 software and the Canva application. After development, the validity of the learning media was tested. The results of expert validation showed that the developed learning media met the eligibility criteria in three aspects, namely media, material, and learning design, in accordance with the categories used by Wiyono, Pasaribu, et al. (2025). A highly valid score in the media aspect indicates that the quality of content, appearance, visual aspects, feasibility, and audio aspects have met the principles of digital learning media design. In terms of content, the validation results indicated that the content aligned with the learning outcomes, was conceptually accurate, was systematically structured, and was in line with STEM and critical thinking skills.

Meanwhile, in terms of learning design, the validation results show that the category is highly valid. This is reflected in the suitability of the learning objectives, which are clearly formulated and supported by learning materials. The structure and flow of learning are systematically and logically organized, making it easier for students to follow each stage. In addition, integrating simulations and thought-provoking questions encourages active student participation and increases motivation and interest in learning. The learning evaluation presented is also aligned with the learning objectives and the material studied. Learning instructions are also clearly conveyed, enabling students to understand the learning activities well. These findings indicate that the integration of the STEM approach is not only realized through the presentation of material, but also through the structure of learning activities that connect contextual phenomena, interactive simulations, and the analysis of relationships between variables.

The implementation stage, which included limited trials with students, produced learning media categorized as highly practical. The practicality test at the implementation stage was divided into two parts: one-to-one and small group trials. The results of the one-to-one and small-group trials show that the media received very high ratings in appearance, navigation, media quality, and ease of use, based on Wiyono's (2015) categories. The consistency of practicality results across students with different academic abilities indicates that the media is highly usable and accessible. This indicates that the developed interface design and navigation structure can facilitate more independent, learner-centered learning. Additionally, these findings show that the developed learning media are highly practical and can be used in physics or science learning in schools.

Several prior studies have examined the development of valid and practical STEM-based interactive learning media. Nurmala et al. (2021) developed valid, practical STEM-based science learning media using Articulate Storyline 3, making them suitable for STEM education. Arjana & Suastra (2022) have developed learning media in the form of an interactive GeoGebra simulation to support the implementation of basic mechanics-based STEM lectures that are valid and practical, enabling their use in learning. In addition, Ristiani et al. (2020) also developed STEM-based science learning media that are valid and suitable for physics instruction. Based on these studies, the researchers' learning media, which are highly valid and practical, are suitable for teaching physics on renewable energy.

Although it shares similarities with previous studies that used Articulate Storyline and the STEM approach, this study has distinct characteristics. The main difference lies in the material's focus and the

objectives of media development. The learning media developed in this study specifically address the subject of renewable energy-Solar Power Plant, presented through interactive simulations of the relationship between weather conditions, voltage, current, and electrical power, and are explicitly designed to train students' critical thinking skills. The media not only deliver content but also serve as vehicles for independent exploration through simulations, context-based exercises, and dynamic navigation, thereby encouraging students to analyse energy issues in everyday life. In addition, the media has evolved to integrate local context related to the use of solar power plants by coffee farmers, making learning more contextual and closer to students' daily lives and helping them understand the practical application of renewable energy concepts in their surroundings. Therefore, the uniqueness of this research lies in the integration of renewable energy materials, interactive PLTS simulations, and local context into the media, and in the goal of training critical thinking skills within a single digital learning media platform.

5.2 Implications

The results of this study provide practical implications: interactive STEM-based learning media on renewable energy materials-Solar Power Plants, can serve as an alternative to physics or science learning media, aligning with the needs of the 21st-century curriculum and learning. This medium helps overcome the dominance of oral learning and conventional media by offering more visual, interactive, and contextual learning. With the support of interactive simulations and easy navigation on digital devices, this medium has the potential to increase student engagement in physics learning, particularly in the study of renewable energy materials.

Pedagogically, the application of this learning media has implications for strengthening learner-centred learning. Students' critical thinking skills are developed through simulations of solar power plants and the presentation of thought-provoking questions that encourage them to analyse the relationships among weather conditions, voltage, current, and electrical power. These exploratory activities enable students not only to passively accept concepts but also to build understanding through observation, reasoning, and problem-solving processes that are contextualised in everyday life.

In addition, this study has broader implications for the implementation of the Merdeka Curriculum and for the future development of physics education. This STEM-based interactive learning media supports phase E learning outcomes that emphasise the use of technology, contextual learning, and the strengthening of 21st-century skills. In a broader context, this approach can be applied to renewable energy learning at the high school level to help improve students' understanding of energy concepts and raise awareness of sustainability issues through technology-based science learning. The media developed in this research has the potential to support physics learning relevant to global issues, such as the energy transition and environmental sustainability, and can serve as an alternative for adaptive physics learning innovation to meet modern educational needs at the global level.

5.3 Limitations

This study has several limitations. The developed learning media can only be used online because all content is uploaded to a web-based platform, namely GitHub Pages, and their use depends heavily on students' internet connection availability and stability. In addition, the evaluation answer-collection feature is not directly integrated into the media; therefore, students must use additional services, such as Google Drive, to submit their assignments or assessments. The development software also has limitations in supporting advanced programming, so interactions in the solar power plant simulation remain basic and cannot provide in-depth automated feedback on student activities. Another limitation of this study

lies in the scope of the learning media testing. The STEM-based interactive learning media developed were tested only in one-to-one and small-group trials, so they have not yet been evaluated at a larger class scale. In addition, because this study focused on testing the validity and practicality of the media, the quantitative analysis of the impact of media use or the effectiveness of learning media in improving students' critical thinking skills was not conducted in depth. This limitation indicates that further research is needed, particularly to test the effectiveness of media through field trials and to develop more complex interactive features.

6. Conclusion

This study successfully developed interactive STEM-based learning media on renewable energy material-Solar Power Plant (SPP), designed to train high school students' critical thinking skills. Expert validation results showed that the media was highly valid across all three aspects: media, material, and learning design. Practicality tests through one-to-one and small-group trials showed that the media was easy to use, had a good appearance and navigation, and effectively supported the learning process from students' perspectives. However, this study only covered the validation and practicality stages, so the effectiveness of the media in improving critical thinking skills and conceptual understanding has not been tested. Therefore, further research is needed through more extensive field trials to quantitatively assess the effectiveness of learning media and to evaluate their impact on critical thinking skills and a deeper understanding of renewable energy concepts.

Authors Contribution

Tyse Ramadhona: Methodology, Media development, Data collection, Interpretation of results, Writing – original draft, Writing – review & editing. **Ketang Wiyono:** Supervision, Methodological guidance, Writing – review & editing. **Evelina Astra Patriot:** Conceptualization, Supervision, Methodological guidance, Writing – review & editing

Acknowledgements

The author would like to thank the supervisor, the validators, SMA Negeri 1 Pagar Alam, and the physics teacher for their support, input, and cooperation in conducting this research and in writing this article. The author hopes this article is helpful.

Ethical statement

This study involved human participants (high school students) and was conducted with official research permission obtained from the South Sumatra Education Office and the participating school, SMA Negeri 1 Pagar Alam, as evidenced by an official letter of approval (Approval Number: 420/0095/SMA.1/Disdik. SS/2025 and 420/1.745/PL/SMAN.1/2025). Prior to data collection, verbal informed consent was obtained from all participants. Participants were informed about the study's purpose, procedures, and the confidentiality of the collected data. Participation was voluntary, and no personal identifying information was disclosed. All research procedures were conducted in accordance with educational research ethics standards and the principles of the Declaration of Helsinki.

Declaration of AI use

The authors declare that artificial intelligence (AI) tools were only used for language editing and grammar correction. All ideas, data analysis, interpretation, and conclusions are entirely the responsibility of the authors.

Conflict of Interest

No conflict of interest.

Supplementary Materials and Data Availability

Supporting materials accompanying this study include interactive learning media, validation tools, and practicality questionnaires. Due to ethical considerations and student participant involvement, raw data containing individual responses can be obtained from the corresponding author upon reasonable request. All materials provided are sufficient to support replication and verification of this study's findings.

References

- Adiyatma, J., & Diyana, T. N. (2024). Pengembangan Media Pembelajaran Fisika Berbasis Articulate Storyline Dengan Topik Gerak Lurus. *JUPEIS: Jurnal Pendidikan Dan Ilmu Sosial*, 3(1), 67-74. <https://doi.org/10.57218/jupeis.Vol3.Iss1.953>
- Afifah, N., Kurniawan, O., & Noviana, E. (2022). Pengembangan media pembelajaran interaktif pada pembelajaran bahasa indonesia kelas III Sekolah Dasar. *Jurnal Kiprah Pendidikan*, 1(1), 33-42. <https://doi.org/10.33578/kpd.v1i1.24>
- Akhsan, H., Putra, G. S., Wiyono, K., Romadoni, M., & Furqon, M. (2023). Development of A STEM-Based Introduction to Quantum Physics Module on the Sub-Subject of Potential Variations in the Physics Education Study Program. *Jurnal Penelitian Pendidikan IPA*, 9(9), 7408–7412. <https://doi.org/10.29303/jppipa.v9i9.3577>
- Alifah, H. N., Virgianti, U., Sarin, M. I. Z., Hasan, D. A., Fakhriyah, F., & Ismaya, E. A. (2023). Systematic Literature Review: Pengaruh Media Pembelajaran Digital pada Pembelajaran Tematik Terhadap Hasil Belajar Siswa SD. *Jurnal Ilmiah Dan Karya Mahasiswa*, 1(3), 103–115. <https://doi.org/10.54066/jikma-itb.v1i3.463>
- Amalishsholeh, N., Sutrio, S., Rokhmat, J., & Gunada, I. (2023). Analisis Kesulitan Belajar Peserta Didik pada Pembelajaran Fisika di SMAN 1 Kediri. *Empiricism Journal*, 4, 356–364. <https://doi.org/10.36312/ej.v4i2.1387>
- Amelia, N., & Chusni, M. M. (2024). Analisis Keterampilan Berpikir Kritis Dalam Pembelajaran Fisika Pada Materi Energi Terbarukan. *Biochephy Journal of Science Education*, 4(1), 248–252. <https://doi.org/10.52562/biochephy.v4i1.1114>
- Anggraeni, S. A. (2021). *Pengembangan Modul Dengan Pendekatan Stem Pada Pokok Bahasan Fisika Materi Fluida Dinamis Untuk Siswa Sma Kelas XI*.
- Anggraini, W., Saqila, M. S., Suryadi, A., & Suwarna, I. P. (2025). Peningkatan Kemampuan Berpikir Kritis Peserta Didik pada Materi Energi Terbarukan melalui PjBL-STEM dengan Design Thinking. *Jurnal Pendidikan Matematika Dan Sains*, 13(2), 321–335. <https://doi.org/10.21831/jpms.v13i2.87690>
- Arjana, I. G., & Suastra, I. W. (2022). Pengembangan Simulasi Interaktif Berbasis Geogebra Dalam Mendukung Pelaksanaan Perkuliahan Fisika Mekanika Dasar Berbasis STEM. *Jurnal Pendidikan Dan Pembelajaran IPA Indonesia*, 12(3), 2022. <https://doi.org/10.23887/jppii.v12i3.54895>
- Arofah, S., & Rinaningsih. (2021). Meta Analisis Efektivitas Multimedia Interaktif Untuk Meningkatkan Cognitive Skill Peserta Didik Dalam Belajar Kimia. *UNESA Journal of Chemical Education*, 10(1), 84–93. <https://doi.org/10.26740/ujced.v10n1.p84-93>

- Arrum Sari, N., & Wiyono, K. (2025). Development of STEM-Based Dynamic Fluid Material E-Module in the Framework of the Perjaya Dam for Grade XI High School Students. *Jurnal Penelitian Pendidikan IPA*, 11(5), 979–985. <https://doi.org/10.29303/jppipa.v11i5.6660>
- Asniar, A., Nurhayati, N., & Khaeruddin, K. (2022). Analisis Keterampilan Berpikir Kritis Dalam Pembelajaran Fisika Peserta Didik Di SMAN 11 Makassar. *Jurnal Sains Dan Pendidikan Fisika (JSPF)*, 18(2), 140–151. <https://doi.org/10.35580/jspf.v18i2.31622>
- Asrizal, A., Marjuni, M., Habibah, R., & Asiah, S. (2023). Meta-Analysis of the Effect of E Module on Students' Critical and Creative Thinking Skill in Science Learning. *Jurnal Penelitian Pendidikan IPA*, 9(6), 141–147. <https://doi.org/10.29303/jppipa.v9i6.2696>
- Badriyah, B., Setiyo, R. D., Firdausi, Z. El, Nuqia, K., Mahardika, I. K., & Baktiarso, S. (2023). Manfaat PhET Simulasi Dalam Menopang Sarana dan Prasarana. *Jurnal Ilmiah Wahana Pendidikan*, Januari, 9(2), 84–90. <https://doi.org/10.5281/zenodo.7564905>
- Branch, R. M. (2010). Instructional design: The ADDIE approach. In *Instructional Design: The ADDIE Approach*. Springer US. <https://link.springer.com/book/10.1007/978-0-387-09506-6>
- Chairudin, M., & Dewi, R. M. (2021). Pengembangan Bahan Ajar Buku Saku Digital Berbasis Problem Based Learning Pada Mata Pelajaran Ekonomi. *Edukatif: Jurnal Ilmu Pendidikan*, 3(3), 951–962. <https://edukatif.org/index.php/edukatif/index>
- Dali, E. S., Londa, K., & Komansilan, A. (2021). Analisis Kesulitan Siswa Dalam Memecahkan Soal Fisika Pada Materi Listrik Statis di SMP Negeri 1 Tumpaan di Era Covid-19. *Jurnal Pendidikan Fisika Charm Sains E-ISSN*, 2(2), 114–119. <https://doi.org/10.53682/charmsains.v2i2.117>
- Delima, E. M., Mayub, A., & Nursa'adah, E. (2023). Pengembangan alat peraga energi terbarukan berbasis solar cell pada pembelajaran IPA. *Jurnal Pendidikan Mipa*, 13(2), 284–290. <https://doi.org/10.37630/jpm.v13i2.889>
- Dermawan, O., Defriyanto, Junaidah, Ayu, S. M., Busmayaril, Jayusman, & Gemilang, S. S. (2023). The influence of STEM-based blended learning model assisted by schoology on critical thinking skills. *Young Scholar Symposium On Science And Mathematics Education, And Environment*, 2595(1), 040015. <https://doi.org/10.1063/5.0123682>
- Doang, W., Gunayasa, I. B. K., & Setiawan, H. (2022). Hubungan Budaya Membaca dengan Keterampilan Berpikir Kritis Siswa Kelas V di SDN 3 Lenek Daya Tahun 2020/2021. *Jurnal Ilmiah Profesi Pendidikan*, 7(2b), 579–584. <https://doi.org/10.29303/jipp.v7i2b.538>
- Dwisari, V., Sudiarti, & Yushardi. (2023). Pemanfaatan Energi Matahari: Masa Depan Energi Terbarukan. *OPTIKA: Jurnal Pendidikan Fisika*, 7(2), 376–384. <https://doi.org/10.37478/optika.v7i2.3322>
- Ejiwale, J. A. (2012). Facilitating teaching and learning across STEM fields. *Journal of STEM Education: Innovations and Research*, 13(3). URL: <https://www.jstem.org/jstem/index.php/JSTEM/article/view/1711>
- Ewar, H. A., Nasar, A., & Ika, Y. E. (2023). Pengembangan Alat Peraga Pembangkit Listrik Tenaga Panas Bumi (PLTP) Sebagai Media Pembelajaran Fisika Pada Materi Sumber Energi Terbarukan. *OPTIKA: Jurnal Pendidikan Fisika*, 7(1), 128–139. <https://doi.org/10.37478/optika.v7i1.2777>
- Fadilah, A., Nurzakiah, K. R., Kanya, N. A., Hidayat, S. P., & Setiawan, U. (2023). Pengertian Media, Tujuan, Fungsi, Manfaat dan Urgensi Media Pembelajaran. *Journal of Student Research (JSR)*, 1(2), 1–17. <https://doi.org/10.55606/jsr.v1i2.938>

- Ferdyson, F., & Windarta, J. (2023). Overview Pemanfaatan dan Perkembangan Sumber Daya Energi Surya Sebagai Energi Terbarukan di Indonesia. *Jurnal Energi Baru Dan Terbarukan*, 4(1), 1–6. <https://doi.org/10.14710/jebt.2023.15714>
- Fitri, E. A., Karyadi, B., & Johan, H. (2023). Analisis Kebutuhan: Pemanfaatan Teknologi sebagai Media Pembelajaran Fisika bagi Peserta didik di Pulau Enggano. *Jurnal Pendidikan Tambusai*, 7(1), 1789–1794. URL: <https://jptam.org/index.php/jptam/article/view/5487/4600>
- Fitriani, R. S., Puspitari, T. O., & Melisa, D. (2020). Deskripsi Sikap Siswa Dalam Kesenangan Belajar Fisika Dan Ketertarikan Memeperbanyak Waktu Belajar Fisika Di SMAN Batanghari. *JIFP (Jurnal Ilmu Fisika Dan Pembelajarannya)*, 4(1), 1–5. <https://doi.org/10.19109/jifp.v4i1.4868>
- Gifson, A., Siregar, M. R., & Pambudi, M. P. (2020). Rancang Bangun Pembangkit Listrik Tenaga Surya (PLTS) On Grid Di Ecopark Ancol. *TESLA: Jurnal Teknik Elektro*, 22(1), 23–33. <https://doi.org/10.24912/tesla.v22i1.7333>
- Gulo, S., & Harefa, A. O. (2022). Pengembangan media pembelajaran interaktif berbasis powerpoint. *Educativo: Jurnal Pendidikan*, 1(1), 291–299. <https://doi.org/10.56248/educativo.v1i1.40>
- Harchristanto, B. A., & Utami, W. S. (2023). Solar System Education Application Using Markerless Augmented Reality (AR) on The Android Platform. *International Journal Software Engineering and Computer Science (IJSECS)*, 3(3), 377–385. <https://doi.org/10.35870/ijsecs.v3i3.1844>
- Harsiwi, U. B., & Arini, L. D. D. (2020). Pengaruh Pembelajaran Menggunakan Media Pembelajaran Interaktif terhadap Hasil Belajar siswa di Sekolah Dasar. *Jurnal Basicedu*, 4(4), 1104–1113. <https://doi.org/10.31004/basicedu.v4i4.505>
- Hasanah, N. (2020). Pelatihan Penggunaan Aplikasi Microsoft Power Point Sebagai Media Pembelajaran pada Guru SD Negeri 050763 Gebang. *Jurnal Pengabdian Kepada Masyarakat (JPKM)*, 1(2), 34–41. URL: <https://jurnal.stkipalmaksum.ac.id/index.php/jpkm/article/view/113>
- Heryani, T. P., Suwarma, I. R., & Chandra, D. T. (2023). Development of STEM-Based Physics Module with Self-Regulated Learning to Train Students Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, 9(6), 4245–4252. <https://doi.org/10.29303/jppipa.v9i6.3578>
- Hidayat, T. N., Subordo, R., & Sutrisno, S. (2021). Analisis Output Daya Pada Pembangkit Listrik Tenaga Surya Dengan Kapasitas 10Wp, 20Wp, dan 30Wp. *Jurnal CRANKSHAFT*, 4(2), 9–18. <https://doi.org/10.24176/crankshaft.v4i2.6013>
- Jaenul, A., Manfaluthy, M., Pramodja, Y., & Anjara, F. (2022). Pembuatan Sumber Listrik Cadangan Menggunakan Panel Surya Berbasis Internet of Things (IoT) dengan Beban Lampu dan Peralatan Listrik. *Formosa Journal of Science and Technology*, 1(3), 143–156. <https://doi.org/10.55927/fjst.v1i3.838>
- Jafnihirda, L., Rizal, F., & Eka Pratiwi, K. (2023). Efektivitas Perancangan Media Pembelajaran Interaktif E-Modul. *INNOVATIVE: Journal Of Social Science Research*, 3(1), 227–239. URL: <https://j-innovative.org/index.php/Innovative/article/view/2734>
- Jayadi, A., Putri, D. H., & Johan, H. (2020). Identifikasi Pembekalan Keterampilan Abad 21 Pada Aspek Keterampilan Pemecahan Masalah Siswa Sma Kota Bengkulu Dalam Mata Pelajaran Fisika. *Jurnal Kumparan Fisika*, 3(1), 25–32. <https://doi.org/10.33369/jkf.3.1.25-32>
- Kartini, K. S., Tri, N., & Putra, A. (2020). Respon Siswa Terhadap Pengembangan Media Pembelajaran Interaktif Berbasis Android. *Jurnal Pendidikan Kimia Indonesia*, 4(1), 12–19. URL: <https://ejournal.undiksha.ac.id/index.php/JPK/index>

- Khanafi, A., Harijanto, A., & Meilina, I. L. (2025). Pengembangan Diorama Sumber Energi Terbarukan Berbasis Energi Surya Dan Arduino Uno Sebagai Media Pembelajaran Fisika. *Jurnal Pendidikan Dan Pembelajaran IPA Indonesia*, 15(1), 52–61. URL: <https://ejournal.undiksha.ac.id/index.php/JPPH/article/download/93088/31912>
- Kharisma, A., Pinandita, S., & Jayanti, A. E. (2024). Literature Review: Kajian Potensi Energi Surya Alternatif Energi Listrik. *Jurnal Energi Baru Dan Terbarukan*, 5(2), 145–154. <https://doi.org/10.14710/jebt.2024.23956>
- Khotimah, M. H., Wiyono, K., & Sriyanti, I. (2025). Integrasi Kearifan Lokal dalam Pendidikan STEM: Studi Awal Pengembangan Lembar Kerja Peserta Didik Kata kunci. *JIIP (Jurnal Ilmiah Ilmu Pendidikan)*, 8(5), 4634–4640. <https://doi.org/10.54371/jiip.v8i5.7790>
- Kurnia, I. R., & Sunaryati, T. (2023). Media Pembelajaran Video Berbasis Aplikasi Canva Untuk Meningkatkan Minat Belajar Siswa. *Jurnal Educatio FKIP UNMA*, 9(3), 1357–1363. <https://doi.org/10.31949/educatio.v9i3.5579>
- Lima, Y. D., Nasar, A., & Astro, R. B. (2023). Pengembangan alat peraga pembangkit listrik tenaga mikrohidro (PLTMH) Sebagai media pembelajaran fisika pada konsep energi terbarukan. *LENSA (Lentera Sains): Jurnal Pendidikan IPA*, 13(2), 127–136. <https://doi.org/10.24929/lensa.v13i2.291>
- Mahmudah, R., Zulirfan, Z., & Rahmad, M. (2022). Analysis of Physics Learning Difficulties in the Topic of Quantum Phenomena of Madrasah Aliyah Students in Indragiri Hulu. *Journal of Physics: Conference Series*, (1), 1–6. <https://doi.org/10.1088/1742-6596/2309/1/012089>
- Mardiana, N., Prayogi, S. Y., S, S., Haslina, S., & Harizan, M. (2022). Android-Based Digital Teaching Materials as Online Learning in New Normal Era to Improve Physics HOTS for High School Students. *Journal of Natural Science and Integration*, 5(1), 90. <http://dx.doi.org/10.24014/jnsi.v5i1.15468>
- Mayasari, F., Arya Samman, F., Muslimin, Z., Waris, T., Ejah Umraeni Salam, A., Chaerah Gunadin, I., Sari Areni, I., Syam Akil, Y., Rachmaniar Sahali, I., & Budi Arief, A. (2022). Pengenalan Panel Surya sebagai Salah Satu Sumber Energi Terbarukan untuk Pembelajaran di SMA Negeri 1 Takalar. In *Jurnal Tepat (Teknologi Terapan Untuk Pengabdian Masyarakat)*, 5(2). https://doi.org/10.25042/jurnal_tepat.v5i2.271
- Mayasari, F., Samman, F., Muslimin, Z., Waris, T., Salam, A. E. U., Gunadin, I. C., Sari Areni, I., Syam Akil, Y., Sahali, I. R., & Budi Arief, A. (2022). Pengenalan Panel Surya sebagai Salah Satu Sumber Energi Terbarukan untuk Pembelajaran di SMA Negeri 1 Takalar. *Jurnal Tepat (Teknologi Terapan Untuk Pengabdian Masyarakat)*, 5(2), 147–160. https://doi.org/10.25042/jurnal_tepat.v5i2.271
- Mulya, A., & Salim, A. N. (2023). Upaya peningkatan hasil belajar fisika melalui model pembelajaran problem based learning. *Jurnal Pemikiran Dan Pengembangan Pembelajaran*, 5(2), 661–666.
- Murniati, M. E., Harijanto, A., & Maryani, M. (2023). Respon Siswa Terhadap Media Pembelajaran Articulate Storyline 3 Dengan Pendekatan STEM Pada Materi Gerak Parabola. *COMPTON (Jurnal Ilmu Pendidikan Fisika)*, 9(2), 152–160. <https://doi.org/10.30738/cjipf.v9i2.14440>
- Muthoharoh, V., & Sakti, N. C. (2021). Media Pembelajaran Interaktif Menggunakan Adobe Flash CS6 Untuk Pembelajaran IPS Siswa Sekolah Menengah Atas. *EDUKATIF: JURNAL ILMU PENDIDIKAN*, 3(2), 364–375. <https://doi.org/10.31004/edukatif.v3i2.315>
- Nesti, E. W., Medriati, R., & Purwanto, A. (2022). Analisis Kebutuhan Pengembangan Media Pembelajaran Fisika Berbasis Aplikasi Lectora Inspire. *Jurnal Ilmiah Pendidikan Fisika*, 6(2), 379. <https://doi.org/10.20527/jipf.v6i2.5144>

- Nugroho, O. F., Permanasari, A., Firman, H., & Riandi, R. (2021). The Importance of Stem Based Education in Indonesia Curriculum. *Pedagonal: Jurnal Ilmiah Pendidikan*, 5(2), 56–61. <https://doi.org/10.33751/pedagonal.v5i2.3779>
- Nurasiah, S., Saefullah, A., & Antarnusa, G. (2025). Pengaruh E-Modul Fisika Terintegrasi ESD Pada Topik Energi Terbarukan Terhadap Kemampuan Berpikir Kritis Siswa. *Jurnal Pendidikan Fisika Undiksha*, 15(1), 24. <https://doi.org/10.23887/jjpf.v15i1.93000>
- Nurmala, S., Triwoelandari, R., & Fahri, M. (2021). Pengembangan Media Articulate Storyline 3 pada Pembelajaran IPA Berbasis STEM untuk Mengembangkan Kreativitas Siswa SD/MI. *Jurnal Basicedu*, 5(6), 5024–5034. <https://doi.org/10.31004/basicedu.v5i6.1546>
- Pane, E. P. (2023). *Konsep Dasar Media Pembelajaran*. Perkumpulan Rumah Cemerlang Indonesia Anggota IKAPI Jawa Barat.
- Pawarangan, I., Tumewu, W. A., Mawuntu, V. J., & Kumendong, I. M. (2024). Persepsi Siswa Terhadap Penggunaan Modul Praktikum Bio Baterai Dalam Pembelajaran Fisika SMA Materi Energi Terbarukan. *Charm Sains: Jurnal Pendidikan Fisika*, 5(3), 99–105. <https://doi.org/10.53682/charmsains.v5i3.402>
- Permata Sari, D., Wiyono, K., & Siahaan, S. M. (2025). Integration of Palembang LRT in the E-Module for Alternating Current Electricity STEM: A Study of Validity, Practicality, and Effectiveness. *Jurnal Penelitian Pendidikan IPA*, 11(11), 944–957. <https://doi.org/10.29303/jppipa.v11i11.13105>
- Pramadanti, M., Subiki, S., & Harijanto, A. (2021). Media pembelajaran fisika menggunakan smartphone dengan pendekatan stem (science, technology, engineering, and mathematics). *ORBITA: Jurnal Pendidikan Dan Ilmu Fisika*, 7(2), 318–326. <https://doi.org/10.31764/orbita.v7i2.5842>
- Pramuji, L., Permanasari, A., & Ardianto, D. (2020). Multimedia interaktif berbasis stem pada konsep pencemaran lingkungan untuk meningkatkan kemampuan berpikir kritis siswa. *Journal of Science Education and Practice*, 2(1), 1–15. <https://doi.org/10.33751/jsep.v2i1.1699>
- Pranata, E., & Firmansyah, M. D. (2023). Media Pembelajaran Interaktif Terhadap Keluarga Harmonis Dengan Menggunakan Model Pengembangan Four-D. *Jurnal Informasi Dan Teknologi*, 112–121. <https://doi.org/10.60083/jidt.v5i3.408>
- Pratiwi, V. S. M., Wiyono, K., & Ismet, I. (2025). Integrating Palembang's Local Wisdom into a STEM-Based e-Module on Particle Dynamics to Foster Students' Creative Thinking Skills. *Jurnal Pendidikan MIPA*, 26(1), 476–498. <https://doi.org/10.23960/jpmipa/v26i1.pp476-498>
- Rahayu, R., Iskandar, S., & Abidin, Y. (2022). Inovasi Pembelajaran Abad 21 dan Penerapannya di Indonesia. *Jurnal Basicedu*, 6(2), 2099–2104. <https://doi.org/10.31004/basicedu.v6i2.2082>
- Rahman, M., Nursyabilah, I., Astuti, P., Syam, M. I., Mukramin, un, & Kurnawati, W. O. I. (2023). Pemanfaatan Media Sosial Sebagai Media Pembelajaran. *Journal on Education*, 05(03), 10647–10653. <https://doi.org/10.31004/joe.v5i3.1890>
- Ramadhona, T., Wiyono, K., & Patriot, E. A. (2025). Analisis Kebutuhan Pengembangan Media Pembelajaran Interaktif Berbasis Stem Materi Energi Terbarukan-PLTS. *Journal of Instructional and Developmental Researches*, 5(6), 635–647. <https://doi.org/10.53621/jider.v5i6.662>
- Raspati, M. R., Sarwenty, P. N., Aksaningtyas, L. L., Tondang, B. A., Chevin, V. A., Saraswati, R. R. M. D., & Aldo, D. (2023). Sistem Informasi Ragam Batik di Indonesia Sebagai Media Pembelajaran Menggunakan Multimedia Interaktif. *IDEALIS: InDonEsiA Journal Information System*, 6(2), 90–98. <https://doi.org/10.36080/idealism.v6i2.3032>

- Rifaldi, M., Alham, R., Ihsan, M. N., & Sugianto, M. (2023). Analisis Efisiensi Sistem Pembangkit Listrik Tenaga Surya sebagai Sumber Energi Baru Terbarukan. *RETROTEKIN: Jurnal Rekayasa Tropis, Teknologi Dan Inovasi*, 1(1), 16–24. URL: <https://api.semanticscholar.org/CorpusID:266858540>
- Ristian, S. M., Triwoelandari, R., & Yono, Y. (2020). Pengembangan Media Pembelajaran Lectora Inspire Versi 12 Pada Mata Pelajaran IPA Berbasis STEM untuk Menumbuhkan Karakter Kreatif Siswa. *Jurnal Basicedu*, 5(1), 30–40. <https://doi.org/10.31004/basicedu.v5i1.613>
- Rohmah, H. N., Suherman, A., & Utami, I. S. (2021). Penerapan Problem Based Learning Berbasis STEM pada Materi Alat Optik untuk Meningkatkan Kemampuan Berpikir Kritis Peserta Didik. *Jurnal Penelitian Pembelajaran Fisika*, 12(2), 117–123. <https://doi.org/10.26877/jp2f.v12i2.7900>
- Rosmiati, M., Sulistiyah, S., Farabi, N. A., & Susanti, S. (2023). Pengembangan Animasi Interaktif Sebagai Media Pembelajaran Kebudayaan Indonesia Dengan Model ADDIE. *Multinetics*, 9(1), 79–88. <https://doi.org/10.32722/multinetics.v9i1.5846>
- Sadiyah, H. (2021). Pemahaman siswa terhadap hasil belajar fisika pada materi suhu dan kalor di sma negeri 2 kota jambi. *Journal Evaluation in Education (JEE)*, 2(2), 59–62. <https://doi.org/10.37251/jee.v2i2.153>
- Septarini, R. A., & Kholiq, A. (2021). Pengembangan media prest untuk meningkatkan keterampilan berpikir kritis peserta didik SMA pada materi momentum dan impuls. *Inovasi Pendidikan Fisika*, 10(1), 32–38. URL: <https://ejournal.unesa.ac.id/index.php/inovasi-pendidikan-fisika/article/view/37475>
- Setiawan, T. Y., Destrinelli, & Wulandari, B. A. (2022). Keterampilan Berfikir Kritis Pada Pembelajaran IPA Menggunakan Model Pembelajaran Radec di Sekolah Dasar: Systematic Literature Review. *Justek: Jurnal Sains Dan Teknologi*, 5(2), 133–141. <https://doi.org/10.31764/justek.v5i2.11421>
- Sevtia, A. F., Taufik, M., & Doyan, A. (2022). Pengembangan Media Pembelajaran Fisika Berbasis Google Sites untuk Meningkatkan Kemampuan Penguasaan Konsep dan Berpikir Kritis Peserta Didik SMA. *Jurnal Ilmiah Profesi Pendidikan*, 7(3), 1167–1173. <https://doi.org/10.29303/jipp.v7i3.743>
- Sihombing, R. A., Muslim, M., Winarno, N., & Rahman, T. (2024). Enhancing Quality Education in Indonesia: A Literature Review of STEM-ESD Landscape Contributions. *Article in Journal of Science Learning*, 7(3), 213–226. <https://doi.org/10.17509/jsl.v7i3.69046>
- Simaremare, A., Promono, N. A., Putri, D. S., Mallisa, F. P. P., Nabila, S., & Zahra, F. (2022). Pengembangan Game Edukasi Fisika Berbasis Augmented Reality pada Materi Kinematika untuk Siswa SMA. *Jurnal Ilmiah Pendidikan Fisika*, 6(1), 203–213. <https://doi.org/10.20527/jipf.v6i1.4893>
- Sitepu, E. N. (2021). Media Pembelajaran Berbasis Digital. *Prosiding Pendidikan Dasar*, 1(1), 242–248. <https://doi.org/10.34007/ppd.v1i1.195>
- Sulastr, H. P., Irvani, A. I., & Warliani, R. (2024). Pengembangan Modul Digital Fisika Berbasis Project Based Learning (PjBL) Dalam Meningkatkan Minat Belajar Peserta Didik. *OPTIKA: Jurnal Pendidikan Fisika*. URL: <https://api.semanticscholar.org/CorpusID:271024265>
- Sury, K., Wiyono, K., & Siahaan, S. M. (2022). Effectiveness of Using E-learning at STEM-based Physics Learning to Improve Communication Skills of High School Students. *Jurnal Ilmiah Pendidikan Fisika*, 6(3), 539. <https://doi.org/10.20527/jipf.v6i3.5781>
- Susilawati, E., Agustinasari, A., Samsudin, A., & Siahaan, P. (2020). Analisis Tingkat Keterampilan Berpikir Kritis Siswa SMA. *Jurnal Pendidikan Fisika Dan Teknologi*, 6(1), 11–16. <https://doi.org/10.29303/jpft.v6i1.1453>

- Umam, K., & Zaini, I. (2013). Penerapan Media Digital Dalam Pembelajaran Apresiasi Batik Kelas X SMA Negeri 1 Blega. *Jurnal Pendidikan Seni Rups*, 01(1), 100–105. URL: <https://www.neliti.com/publications/246793/penerapan-media-digital-dalam-pembelajaran-apresiasi-batik-kelas-x-sma-negeri-1>
- Usman, M. K. (2020). Analisis Intensitas Cahaya Terhadap Energi Listrik Yang Dihasilkan Panel Surya. *Jurnal POLEKTRO: Jurnal Power Elektronik*, 9(2), 53–58. URL: <http://ejournal.poltektegal.ac.id/index.php/power elektro>
- Usparianti L, Y., Marlina, L., & Wiyono, K. (2023). Analysis of Physics E-LKPD Needs Based on Problem-Based Learning to Improve Students' Critical Thinking Skills. *Jurnal Pendidikan Fisika Dan Teknologi*, 9(1), 177–184. <https://doi.org/10.29303/jpft.v9i1.5093>
- Utomo, F. T. S. (2023). Inovasi Media Pembelajaran Interaktif Untuk Meningkatkan Efektivitas Pembelajaran Era Digital Di Sekolah Dasar. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 8(2), 3635–3645. URL: https://www.researchgate.net/publication/374494541_INOVASI_MEDIA_PEMBELAJARAN_INTERAKTIF_UNTUK_MENINGKATKAN_EFEKTIVITAS_PEMBELAJARAN_ERA_DIGITAL_DI_SEKOLAH_DASAR
- Wahyuni, D., & Sari, M. (2020). Efektifitas e-Modul Berbasis Problem Solving Terhadap Keterampilan Berfikir Kritis Peserta Didik. *Natural Science: Jurnal Penelitian Bidang IPA Dan Pendidikan IPA*, 6(2), 180–189. URL: <https://files01.core.ac.uk/download/pdf/354969016.pdf>
- Wayudi, M., Suwatno, S., & Santoso, B. (2020). Kajian Analisis Keterampilan Berpikir Kritis Siswa Sekolah Menengah Atas. *Jurnal Pendidikan Manajemen Perkantoran*, 5(1), 67–82. <https://doi.org/10.17509/jpm.v5i1.25853>
- Widya, W., Yusmanila, Y., Zaturrahmi, Z., & Ikhwan, K. (2022). Praktikalitas E-Module Berbasis Model Creative Problem Solving (CPS) untuk Materi Fluida Dinamis Terintegrasi Keterampilan Abad 21. *Edukatif: Jurnal Ilmu Pendidikan*, 4(4), 5700–5707. <https://doi.org/10.31004/edukatif.v4i4.3313>
- Wijayanti, R., & Siswanto, J. (2020). Profil Kemampuan Berpikir Kritis Siswa SMA pada Materi Sumber-sumber Energi. *Jurnal Penelitian Pembelajaran Fisika*, 11, 109. <https://doi.org/10.26877/jp2f.v11i1.5533>
- Winarti, N., Maula, L. H., Amalia, A. R., Pratiwi, N. L. A., & Nandang, N. (2022). Penerapan Model Pembelajaran Project Based Learning Untuk Meningkatkan Kemampuan Berpikir Kritis Siswa Kelas III Sekolah Dasar. *Jurnal Cakrawala Pendas*, 8(3), 552–563. <https://doi.org/10.31949/jcp.v8i2.2419>
- Wiyono, K. (2015). Pengembangan model pembelajaran fisika berbasis ICT pada implementasi kurikulum 2013. *Jurnal Inovasi Dan Pembelajaran Fisika*, 2(2), 123–131. URL: <https://garuda.kemdiktisaintek.go.id/documents/detail/472077>
- Wiyono, K., Pasaribu, A., Patriot, E. A., Pratiwi, S. M. V., Khotimah, M. H., & Anjani, R. P. (2025). Development of STEM-Based Physics E-Teaching Materials in the Context of South Sumatra Local Wisdom for High School Students. *Jurnal Penelitian Pendidikan IPA*, 11(1), 575–583. <https://doi.org/10.29303/jppipa.v11i1.9707>
- Yuksel, Y. E. (2019). Energy, Environment and Education. In *Environmentally-Benign Energy Solutions* (pp. 177–190). Springer. https://doi.org/10.1007/978-3-030-20637-6_9
- Yusra, R. A., Kusumah, F. H., & Suryadi, A. (2025). Pengaruh PjBL-STEM terhadap Peningkatan Keterampilan Berpikir Kritis pada Materi Energi Terbarukan dalam Mendukung Pendidikan yang

Berkualitas. *Jurnal Pendidikan Matematika Dan Sains*, 13(Special_issue), 26–37.
https://doi.org/10.21831/jpms.v13ispecial_issue.86537

Yusup, A. H., Azizah, A., Rejeki, E. S., Silviani, M., Mujahidin, E., & Hartono, R. (2023). Literature Review: Peran Media Pembelajaran Berbasis Augmented Reality Dalam Media Sosial. *Jurnal Pendidikan Indonesia: Teori, Penelitian Dan Inovasi*, 3(5), 210–217.
<https://doi.org/10.59818/jpi.v3i5.575>

Appendix. Research Instruments

Expert Validation Instrument.

Table 8 presents the Expert Material Instrument used to evaluate the suitability of content, presentation, integration of STEM aspects, critical thinking components, and language use in the developed learning media.

Table 8. *Expert Material Instrument*

No	Indicators	Statement
1	Content suitability	<ol style="list-style-type: none"> 1. There are learning objectives and goals. 2. The material in the interactive learning media is in line with the learning objectives. 3. The material on renewable energy-Solar Power Plant is presented correctly and accurately in a scientific manner. 4. The material covers the core concepts of renewable energy and Solar Power Plant. 5. The videos or learning illustrations used are in line with the material on renewable energy- Solar Power Plant. 6. The assessment or exercise features provided are relevant to the learning objectives.
2	Presentation suitability	<ol style="list-style-type: none"> 7. Presenting material through videos or animations makes it easier for students to understand the concept of renewable energy- Solar Power Plant. 8. The sequence of material presentation is arranged chronologically from basic concepts to applications. 9. The visual display (layout, icons, images) is in line with the theme of renewable energy- Solar Power Plant. 10. The presentation of material is supplemented with real-life examples of solar power plant usage, making it easy to understand. 11. The use of animations, images, sound, or video is harmoniously integrated to support learning. 12. The sentence structure used is clear and easy to understand.
3	Content suitability with critical STEM	<ol style="list-style-type: none"> 13. The material is presented scientifically and accurately in accordance with scientific principles. 14. The media displays examples of technology applications relevant to the concept of renewable energy. 15. Simulations and activities in the media allow students to explore how changes in variables affect the performance of a solar power plant. 16. The material includes appropriate quantitative measures and simple calculations related to energy that support students' mathematical understanding. 17. The media integrates Science, Technology, Engineering, and Mathematics in an integrated manner when discussing solar power plants and other renewable energy sources.
4	Content suitability with critical thinking skills	<ol style="list-style-type: none"> 18. The material in the learning media allows students to logically analyze the concepts of energy, energy sources, and the impact of energy exploitation. 19. Simulations and examples of solar power plant applications provide opportunities for students to draw conclusions and make decisions based on data or variable changes. 20. The material on the impact of energy exploitation and use, as well as the utilization of local energy sources, trains students to evaluate energy solution options rationally and provide appropriate reasons.
5	Language suitability	<ol style="list-style-type: none"> 21. The language used is easy to understand. 22. The language used is communicative and interactive. 23. The language used complies with the rules of the Indonesian language.

Table 9 shows the Media Expert Instrument used to assess content quality, media display, visual aspects, execution, and audio components of the learning media.

Table 9. *Media Expert Instrument*

No	Indicators	Statement
1	Content Quality	<ol style="list-style-type: none"> 1. Consistency between images and the material studied. 2. The text used is clear and easy to understand.

		3. The content is accurate and consistent with scientific concepts. 4. The sequence of material presentation is coherent and logical. 5. Examples and illustrations support understanding of concepts.
2	Media Display	6. Accuracy in combining colors. 7. Clarity in the use of navigation buttons. 8. Neat and uncluttered media display layout. 9. Icon/button sizes are appropriate and easy for users to reach. 10. An attractive and consistent interface. 11. Clear contrast between text and background colors. 12. Consistent page design across all media sections.
3	Visual Aspects	13. Images/animations are displayed with good resolution. 14. Illustrations are used sparingly so as not to distract from the focus. 15. The composition of visual elements is balanced and not cluttered.
4	Execution	16. Ease of operating learning media. 17. Clarity and accuracy of usage instructions. 18. Buttons, menus, and features respond well. 19. Media is easily accessible on various devices (mobile phones/laptops). 20. Interactive features (simulations, quizzes, etc.) are easy to use.
5	Audio Aspects	21. The audio quality in the video is clear, and there is no noise. 22. The audio volume is balanced between narration, music, and effects. 23. The use of background music (if any) does not interfere with concentration.

Table 10 presents the Learning Design Expert Instrument used to evaluate the instructional design of the learning media, including the alignment of learning objectives with the presented material, the structure and flow of learning activities, the suitability of evaluation methods, and the clarity of learning instructions provided.

Table 10. *Learning Design Expert Instrument*

No	Indicators	Statement
1	Alignment of Learning Objectives	1. Learning objectives are formulated in accordance with the desired learning outcomes 2. Learning objectives are presented clearly and are easy to understand
2	Material–Objective Alignment	3. The material presented is relevant to the learning objectives 4. Learning activities are aligned with the skills to be trained, namely, critical thinking skills
3	Structure and Flow of Learning	5. The learning flow in the media is structured in a coherent and logical manner 6. The sequence of presentation supports gradual understanding 7. Transitions between sections are clear and well-defined
4	Active Involvement of Learners	8. Simulations on media encourage students to actively participate 9. Media provides opportunities for students to explore concepts independently
5	Alignment of Evaluation	10. The form of evaluation is in line with the learning objectives 11. The evaluation questions reflect the critical thinking skills that are to be trained
6	Motivation and Appeal of Learning	12. Media can attract students' interest in learning through interactive displays or activities 13. Media provides a real-world context related to renewable energy to increase the relevance of learning
7	Clarity of Learning Instructions	14. Every activity on the media is accompanied by clear instructions 15. The instructions are easy for students to understand without excessive guidance from teachers