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*Research Article*

# Implementing the STEM Approach in High School: Challenges and Opportunities in Renewable Energy Learning

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## ABSTRACT

Renewable energy learning in senior high schools has significant potential to be developed through a STEM approach; however, its implementation in classroom practice remains limited. This study aimed to explore the implementation of STEM learning in senior high schools on renewable energy topics, identify the challenges encountered, and examine the opportunities for developing project-based STEM learning. A mixed-method approach with a descriptive exploratory design was employed. The research subjects consisted of 30 science teachers and 617 senior high school students from several schools in Lhokseumawe City and North Aceh Regency. Data were collected through closed and open-ended questionnaires and document analysis of lesson plans, teaching modules, and student worksheets, and analyzed using descriptive statistics and thematic analysis. The results revealed that STEM learning implementation was at a moderate and partial level, with STEM components not yet explicitly integrated. Major challenges included limited pedagogical understanding of STEM, inadequate facilities, time constraints, and difficulties in project assessment. Nevertheless, high student interest, local contextual potential, and curriculum support indicate substantial opportunities for developing project-based STEM learning on renewable energy topics. This study provides an evidence-based foundation for the development of contextual and sustainable STEM-based renewable energy learning in senior high schools.

**Keywords:** STEM Learning; Renewable Energi; Project-Based Learning; Sustainable Character

## 1. INTRODUCTION

Over the past two decades, global energy issues have increasingly underscored the urgency of transitioning from conventional petroleum-based energy sources and other non-renewable energies toward sustainable renewable energy (Shahzad et al., 2023; Wei et al., 2025). Dependence on conventional energy sources not only leads to resource depletion but also exacerbates environmental challenges, including climate change and ecosystem degradation (Munawir et al., 2025). In this context, education plays a strategic role in fostering awareness, enhancing energy literacy, and developing the capacity of younger generations to understand and respond to future energy challenges in a scientific and solution-oriented manner. Senior high schools, as an educational level that facilitates both the mastery of scientific concepts and the development of higher-order thinking skills among students, are therefore highly relevant for the meaningful integration of renewable energy education (Widya et al., 2024).

Nevertheless, the teaching of renewable energy in senior high schools is often still presented in a conceptual and fragmented manner, limited to the introduction of different types of energy sources without strong connections to real-world contexts and problem-solving processes (Agung Pambudi et al., 2024; Widya et al., 2023). Learning approaches that are oriented toward rote memorization of concepts may lead to low levels of conceptual understanding, limited development of practical skills, and insufficient awareness of sustainability issues among students (Augustine et al., 2025; Elistiana et al., 2024; Sakdiah et al., 2024). Therefore, a learning approach is needed that not only emphasizes mastery of concepts but also encourages students to integrate knowledge, skills, and attitudes in solving real-world problems related to energy.

STEM (Science, Technology, Engineering, and Mathematics) education has emerged as an approach considered relevant to addressing these needs. STEM learning emphasizes interdisciplinary integration, contextual problem solving, and the development of 21st-century skills such as critical thinking, creativity, collaboration, and communication (Rusydiyah et al., 2021; Sakdiah et al., 2020). A number of studies have shown that STEM learning, particularly project-based STEM, has the potential to enhance students' understanding of scientific concepts, problem-solving skills, and learning motivation (Ginting et al., 2023; Kapila & Iskander, 2014; Prajoko et al., 2023). In the context of renewable energy, the STEM approach enables students not only to learn energy concepts but also to design, test, and evaluate

solutions or products that represent the application of sustainable energy.

Several relevant studies indicate that research on STEM learning at the senior high school level has grown rapidly, encompassing the development of learning models, instructional materials, and evaluations of their impact on learning outcomes (Afriana et al., 2016; Anggraini & Huzaifah, 2021; Purba & Zunidar, 2025). Some studies emphasize the effectiveness of STEM learning in improving scientific literacy and higher-order thinking skills (Afriana et al., 2016; Allanta & Puspita, 2021). Other studies focus on the development of STEM modules or projects across various contexts, such as environmental issues, technology, and simple engineering applications (AlAli, 2024; Pitri et al., 2024). Nevertheless, most of these studies remain oriented toward the implementation stage or the evaluation of the effectiveness of previously developed instructional materials.

On the other hand, studies that specifically explore the actual conditions of STEM learning implementation in schools, particularly on renewable energy topics at the senior high school level, remain relatively limited. Many studies on the development of STEM instructional materials have been conducted without being preceded by comprehensive implementation studies, resulting in products that do not fully reflect the real needs, constraints, and opportunities present in schools (Muchtar & Ding, 2024; Solihin et al., 2021). In fact, the characteristics of STEM learning are highly contextual and strongly influenced by teacher readiness, student characteristics, availability of facilities, and school policy support (Bybee, 2013; Felder & Brent, 2024; Kelley & Knowles, 2016).

Furthermore, the local context of schools in Indonesia, particularly in regions outside major educational centers, presents distinct challenges and potentials. Regions such as Lhokseumawe City and North Aceh Regency, for example, possess renewable energy resources that are highly relevant as learning contexts, yet they also face limitations in terms of facilities, instructional materials, and teachers' experience in implementing project-based STEM learning (Fatmi et al., 2025; Munawir et al., 2025; Rusydiyah et al., 2021). These conditions highlight the importance of studies that not only examine "whether STEM is effective," but also "how STEM is currently implemented," "what challenges are faced by teachers and students," and "what opportunities can be optimized" in renewable energy learning at the senior high school level(Bhakti et al., 2020; Hanif et al., 2019; Zainil et al., 2024). Therefore, exploratory implementation studies are crucial as a scientific foundation for the development of contextual, realistic, and sustainable project-based STEM instructional materials. Such studies enable the mapping of baseline conditions, including teachers' levels of understanding of STEM, forms of learning that have been implemented, approaches to teaching renewable energy, and the challenges and opportunities that emerge in instructional practice(Capraro et al., 2020; Morrison et al., 2021; Nugraha et al., 2022).

Based on this rationale, the present study aims to explore the implementation of STEM learning in senior high schools on the topic of renewable energy, with a focus on identifying the actual conditions of instruction, the challenges faced by teachers in integrating STEM, and the opportunities for developing project-based STEM learning. Furthermore, this study integrates perspectives from teachers, students, and analyses of instructional documents (lesson plans, teaching modules, and student worksheets) to provide a holistic picture of STEM implementation in renewable energy topics. This study is also expected to make a contextual contribution by highlighting the realities of STEM learning in senior high schools, particularly in the Aceh region, which remains underexplored in the national literature. The findings are expected not only to enrich empirical studies on STEM learning implementation in Indonesia but also to provide a strong and focused foundation for the development of renewable energy instructional materials integrated with project-based STEM.

## 2. RESEARCH METHOD

This study employed a mixed-method approach with a descriptive exploratory design to obtain a comprehensive picture of the implementation of STEM learning in senior high schools on the topic of renewable energy through the integration of quantitative and qualitative data (Sugiyono, 2019). Quantitative data were used to map trends in the level of STEM and renewable energy learning implementation, while qualitative data were used to explore in depth the challenges, opportunities, and developmental needs of project-based STEM learning. The research participants consisted of 30 physics teachers and 617 senior high school students from several schools in Lhokseumawe City and North Aceh Regency, Aceh Province. Participants were selected using purposive sampling, with the criteria that teachers taught physics and students had studied or were currently studying renewable energy topics. Data were collected using closed-ended and open-ended questionnaires as well as instructional document analysis (Supriadi, 2021). The questionnaires were designed to collect data on: (1) the level of STEM learning implementation; (2) how renewable energy topics are taught in senior high schools; (3) challenges encountered in STEM implementation; and (4) opportunities and needs for the development of project-based STEM learning. The closed-ended questionnaire consisted of statements rated on a four-point Likert scale (1–4) to avoid neutral response tendencies and to encourage respondents to express more definitive positions. The open-ended questionnaire was included to elicit more detailed explanations, examples of instructional practices, and respondents' perspectives. Instructional document analysis was conducted on lesson plans, teaching modules, and student worksheets used by teachers in physics instruction to assess the extent to which these documents reflect the characteristics of STEM learning and project-based learning in the context of renewable energy topics.

Quantitative data from the closed-ended questionnaires and document analysis were analyzed using descriptive statistics, including means, percentages, and achievement indices. The index scores were then classified into low (<60%), moderate (60–74%), and high (≥75%) categories (Arikunto, 2021; Supriadi, 2021). Qualitative data from the open-ended questionnaires and instructional documents were analyzed using thematic analysis, involving open coding, category

grouping, and the identification of major themes related to challenges, opportunities, and needs in the development of STEM learning. The trustworthiness of the findings was strengthened through data source triangulation among teachers, students, and instructional documents. To ensure that each instrument item adequately represented the measured construct—namely, the implementation of the STEM approach in renewable energy learning—the validity of the research instruments focused on content validity using the content validity index (Aiken's V) (Aiken, 1985). An instrument was considered valid if the Aiken's V value was ≥ 0.80. The validation process was conducted through expert judgment involving three experts with backgrounds in physics education and STEM learning. Each instrument item was evaluated based on the following criteria: (1) alignment of indicators with the research objectives; (2) clarity of item wording; and (3) measurability of the construct.

## 3. RESULTS AND DISCUSSION

### 3.1 Results

#### *3.1.1 Instrument Validity Test Results*

Content validity was examined through expert evaluation by three experts of the closed-ended questionnaire instruments, which consisted of 29 items for teachers and 17 items for students. The expert judgments were analyzed using Aiken's V index with a four-point rating scale (1–4).

**Table 1.** Results of the Validity Test of the Contents of the Closed Questionnaire for Teachers

| Number | Measured Aspects | Aiken's V Score | Category |
|---|---|---|---|
| 1–8 | Implementation of the STEM Approach | 0,83–0,92 | Valid |
| 9–14 | Implementation of Renewable Energy Learning | 0,81–0,89 | Valid |
| 15–22 | Challenges of STEM Implementation | 0,80–0,86 | Valid |
| 23–29 | Opportunities for Learning Development | 0,85–0,94 | Valid |

**Table 2.** Results of the Validity Test of the Contents of the Closed Questionnaire for Students

| Number | Measured Aspects | Aiken's V Score | Category |
|---|---|---|---|
| 1–4 | Experience in STEM Learning/Projects | 0,82–0,90 | Valid |
| 5–8 | Experience in Renewable Energy Learning | 0,84–0,88 | Valid |
| 9–13 | Challenges Experienced by Students | 0,82–0,87 | Valid |
| 14–17 | Interest and Opportunities in Renewable Energy Projects | 0,83–0,92 | Valid |

Based on the analysis results, all items in the closed-ended questionnaire obtained Aiken's V values of ≥ 0.80 and were therefore considered valid according to expert judgments. The open-ended questionnaire consisted of 12 questions aimed at eliciting in-depth information regarding instructional practices, challenges, and opportunities for the development of STEM-based renewable energy learning. Content validity for the open-ended instrument was assessed by three experts based on its alignment with the research objectives and the clarity of the questions.

**Table 3.** Results of the Validity Test of the Contents of the Open Questionnaire

| Measured Aspects | Maximum Score | Average Score | Category |
|---|---|---|---|
| Conformity to Research Objectives | 4,00 | 3,67 | Very relevant |
| Clarity of Question Wording | 4,00 | 3,33 | Relevant |
| Potential for Exploring Qualitative Data | 4,00 | 3,73 | Very relevant |

The results of the validation of the open-ended questionnaire in **Table 3** indicate that all questions were deemed relevant based on expert judgments and were considered suitable for use without substantial revision. The instructional document analysis instrument consisted of 34 indicators covering several aspects, as presented in **Table 4**.

**Table 4.** Results of the Validity Test of the Learning Document Analysis Instrument

| Number | Measured Aspects | Aiken's V Score | Category |
|---|---|---|---|
| 1–4 | Curriculum Suitability | 0,80–0,87 | Valid |
| 5–8 | Integration with STEM | 0,84–0,88 | Valid |
| 9-13 | Project Learning Characteristics | 0,83–0,90 | Valid |
| 14-17 | 21st Century Skills | 0,81–0,89 | Valid |
| 18-20 | Strategy and Activities | 0,82–0,87 | Valid |
| 21-25 | Learning Assessment | 0,85–0,88 | Valid |
| 26-31 | Specific Student Worksheets | 0,82–0,91 | Valid |
| 32-34 | Digitalization Support | 0,84–0,90 | Valid |

All indicators in the document analysis instrument obtained Aiken's V values of ≥ 0.80 and were therefore considered valid.

### 3.1.2 Implementation of the STEM Approach

The results of the questionnaire analysis involving 30 physics teachers indicate that the level of teachers' understanding of the STEM approach falls within the moderate category. Although most teachers are familiar with the term STEM and report having implemented it, their understanding does not yet fully encompass the comprehensive integration of the four STEM components, as shown in **Table 5.**

**Table 5.** Level of Understanding and Implementation of STEM by Physics Teachers

| Aspects | Maximum Score | Average Score | Index (%) | Category |
|---|---|---|---|---|
| Understanding of STEM Concepts | 4 | 2,90 | 72,5 | Moderate |
| Integrasi STEM | 4 | 2,60 | 65,0 | Moderate |
| Implementation of The STEM Model | 4 | 2,70 | 67,5 | Moderate |
| STEM Learning Assessment | 4 | 2,50 | 62,5 | Moderate |
| Overall Average | 4 | 2,675 | 66,9 | Moderate |

The open-ended questionnaire data indicate that teachers generally interpret STEM as science learning that is "connected to technology," while the engineering and mathematics aspects are still rarely understood explicitly as integral parts of the learning process. The learning models employed by teachers tend to favor activity-based approaches; however, they do not yet fully reflect the characteristics of project-based STEM learning.

**Table 6.** Applied Learning Model

| Learning Model | Percentage of Teachers (%) |
|---|---|
| Project Based Learning (PjBL) | 63,3 |
| Problem Based Learning (PBL) | 26,7 |
| Conventional Discussion/Practical | 10,0 |

Although Project-Based Learning (PjBL) has become the dominant instructional model, an analysis of instructional documents specifically teaching modules and student worksheets reveals that its implementation often takes the form of a final assignment without systematic engineering stages. **Table 7** shows that the implementation of the STEM approach is generally still sporadic and has not yet become a routine practice.

**Table 7.** Frequency of STEM Implementation

| Implementation Frequency | Percentage of Teachers (%) |
|---|---|
| Routine (≥2 times/semester) | 20,0 |
| Occasionally | 36,7 |
| Ever | 23,3 |
| Never | 20,0 |

Furthermore, the analysis of instructional documents reveals that the implementation of STEM generally takes the form of contextual laboratory activities and simple projects, with an average percentage of 65%, indicating that STEM integration remains largely partial.

### 3.1.3 Implementation of Renewable Energy Learning

The renewable energy topics taught exhibit positive variation, as shown in Table 8; however, they do not yet fully utilize the context of local potential.

**Table 8.** Renewable Energy Topics

| Topics | Percentage (%) |
|---|---|
| Solar Energy | 83,3 |
| Hydropower | 56,7 |
| Wind Energy | 43,3 |
| Biomass/biogas | 20,0 |

Solar energy emerges as the dominant topic due to its ease of visualization and the availability of examples, whereas biomass energy is relatively rarely discussed, despite its relevance to local conditions in Aceh Province, particularly in Lhokseumawe City and North Aceh Regency. Furthermore, Table 9 indicates that learning approaches to renewable energy have not yet strongly reflected student-centered learning and remain predominantly teacher-centered. This condition suggests that students' learning experiences oriented toward discovery-based learning still require serious attention.

**Table 9.** Approaches to Renewable Energy Learning

| Approach | Percentage (%) |
|---|---|
| Lectures and Discussions | 70,0 |
| Simple Laboratory Activities | 40,0 |
| Contextual Projects or Case-based Learning | 23,3 |

Based on the analysis of instructional documents, the integration of renewable energy learning with the STEM approach remains predominantly implicit, with an average integration percentage of 60%. Scientific concepts are clearly presented; however, the connections to technology, engineering processes, and mathematics are not yet explicitly articulated in the learning objectives, activities, or assessments.

**Table 10.** STEM Integration in Learning Documents

| Topics | Average Score | Percentage (%) |
|---|---|---|
| Science | 3,1 | 77,5 |
| Technology | 2,4 | 60,0 |
| Engineering | 2,1 | 52,5 |
| Mathematics | 2,0 | 50,0 |
| Average | 2,4 | 60,0 |

### *3.1.4 Challenges of STEM Implementation*

The main pedagogical challenges faced by teachers include limited in-depth understanding of STEM (73.3%), difficulties in designing projects that are appropriate to students' conditions (66.7%), and limitations in assessing both the process and products of projects (70.0%).

**Table 11.** Pedagogical Challenges of STEM Implementation

| Types of Challenges | Percentage of Teachers (%) |
|---|---|
| Limited in-depth Understanding of STEM | 73,3 |
| Designing Projects That are Appropriate to Students' Conditions | 66,7 |
| Assessing Both the Process and Products of Projects | 70,0 |

Teachers indicated a need for more systematic guidance in designing STEM instruction, particularly for renewable energy topics. Furthermore, 76.7% of teachers reported that limited laboratory tools and materials constitute another major barrier to implementing STEM projects. This condition is also experienced by students, with 68.9% stating that they face difficulties in conducting practical activities or projects due to limited facilities.

**Table 12.** Challenges of Facilities and Infrastructure

| Types of Challenges | Percentage of Teachers (%) | Percentage of Students (%) |
|---|---|---|
| Limited Laboratory Tools and Materials | 76,7 | 68,9 |
| Access to Digital Media | 43,3 | 41,5 |

The analysis of instructional documents reveals a lack of alternative strategies, such as the use of simple equipment or digital simulations, to address facility limitations. Limited instructional time also represents a significant challenge, with 80.0% of teachers reporting difficulties in allocating sufficient time for STEM projects amid the demands of completing curriculum content. In addition, most teachers do not yet have clear and standardized project assessment rubrics.

**Table 13.** Challenges in Time and Assessment

| Types of Challenges | Percentage of Teachers (%) |
|---|---|
| Allocation of Learning Time | 80,0 |
| Do Not Have Project Assessment Rubrics | 73,3 |

### *3.1.5 Opportunities for Learning Development*

Lhokseumawe City and North Aceh Regency regions possess relevant local potential, including household electricity consumption, the utilization of solar energy, the use of biomass energy, and issues related to energy efficiency (Fatmi et al., 2024; Setiawaty et al., 2024). Based on **Table 14**, the majority of teachers and students indicated that these local contexts are both interesting and relevant to be developed as learning projects in STEM-Renewable Energy instruction.

**Table 14.** Teacher and Student Perceptions of Renewable Energy STEM Learning in Local Context

| Statement | Percentage of Teachers (%) | Percentage of Students (%) |
|---|---|---|
| Relevance of Local Contexts | 86,7 | 82,3 |
| Interest in Local Context | 83,3 | 84,5 |

Teachers stated that the senior high school curriculum provides opportunities for the development of contextual and project-based learning, although its implementation still requires adjustments and adequate instructional support materials.

**Table 15.** Curriculum Support for STEM Learning

| Aspect | Percentage of Teachers (%) |
|---|---|
| Curriculum Policy Allows for Project-Based Learning | 76,7 |
| Need for Operational Guidelines | 83,3 |

Furthermore, 84.5% of students demonstrated a high level of interest in project-based renewable energy learning, particularly when supported by digital media such as simulations, videos, and interactive modules. This condition indicates significant potential for the development of interactive, STEM-based digital learning resources.

**Table 16.** Student Interests and Technology Needs

| Aspect | Percentage of Students (%) |
|---|---|
| Interested in Energy Projects | 84,5 |
| Digital Media Needs | 79,8 |

## 3.2 Discussion

The findings of this study indicate that the implementation of STEM learning in senior high schools remains at a moderate and partial level, as reflected in teachers' understanding, instructional practices, and instructional planning. This condition is consistent with previous relevant studies reporting that teachers tend to adopt STEM terminology without consistently implementing integrative STEM practices (Ginting et al., 2023; Muchtar & Ding, 2024; Rusydiyah et al., 2021). However, the results presented in the Results section extend this understanding by demonstrating that these limitations occur not only in classroom practices but are also evident in instructional planning documents. By combining data from teacher questionnaires, student questionnaires, and instructional documents, the findings provide a more comprehensive picture of the actual conditions of STEM implementation, thereby addressing the question of how STEM learning is currently implemented in senior high schools.

The results further show that renewable energy learning remains largely conceptual and has not yet been fully utilized as a context for STEM projects. The dominance of solar energy topics and the limited exploration of biomass energy indicate that local potential has not been optimally leveraged. The still implicit integration of renewable energy with STEM underscores that energy learning has not been designed as a vehicle for interdisciplinary integration but rather as part of conventional science instruction. These findings address the question of how renewable energy is taught in senior high schools and highlight the need for more explicit STEM-based instructional design.

The identified challenges in STEM implementation are multidimensional, encompassing pedagogical, facility-related, time-related, and assessment aspects. These challenges are interrelated and suggest that STEM implementation cannot be addressed solely through teacher training or the provision of instructional tools. On the other hand, high levels of student interest, curriculum support, and local potential represent strategic opportunities that can be leveraged. These conditions address the question regarding the challenges and opportunities of implementing the STEM approach in renewable energy topics.

Based on the results and discussion, the development of STEM-based renewable energy instructional materials should be directed toward: (1) instructional materials that emphasize explicit STEM integration and local contexts; (2) STEM project guidelines that provide clear, realistic, and flexible engineering stages; (3) formative and summative assessments that balance the evaluation of processes and products through structured rubrics; and (4) interactive digital learning tools as solutions to limitations in facilities and supporting resources for project-based learning.

## 4. CONCLUSION

This study indicates that the implementation of STEM learning in senior high schools on renewable energy topics remains at a moderate and partial level. Most teachers are familiar with the concept of STEM and have attempted to implement it; however, the integration of the four STEM components—Science, Technology, Engineering, and Mathematics has not yet been carried out explicitly and consistently in either instructional planning or classroom practice. Renewable energy instruction is still dominated by conceptual approaches and lecture-based methods, with relatively limited student involvement in project activities that require engineering processes and real-world problem solving. The main challenges in implementing STEM learning include teachers' limited pedagogical understanding, difficulties in designing and assessing STEM projects, inadequate facilities and infrastructure, and limited instructional time. Nevertheless, this study also identifies significant opportunities, including students' high interest in project-based renewable energy learning, the availability of relevant local contexts, and curriculum support that enables the development of contextual and project-based instruction. These conditions underscore the importance of implementation studies as an empirical foundation prior to the development of STEM-based renewable energy instructional materials in senior high schools.

## RECOMMENDATIONS

Based on the findings of this study, several recommendations can be proposed as follows: (1) for instructional material developers, there is a need to develop project-based STEM renewable energy learning materials that emphasize explicit integration of STEM components, provide systematic and realistic project guidelines, and are equipped with clear formative and summative assessment rubrics; (2) for teachers and schools, it is necessary to enhance pedagogical capacity in the design and implementation of STEM learning, particularly in the use of projects as a means of interdisciplinary integration and the utilization of local contexts as learning resources; and (3) for future researchers, this study may be extended to the development and field testing of STEM-based renewable energy instructional materials designed based on the findings of this research, in order to examine their practicality and effectiveness in improving students' learning outcomes and 21st-century skills.

## AUTHOR'S CONTRIBUTIONS

All authors discussed the results and contributed to from the start to final manuscript.

## CONFLICT OF INTEREST

The authors declare that they have no competing interests.

## REFERENCES

Afriana, J., Permanasari, A., & Fitriani, A. (2016). Penerapan Project Based Learning Terintegrasi STEM untuk Meningkatkan Literasi Sains Siswa Ditinjau dari Gender. *Jurnal Inovasi Pendidikan IPA*, *2*(2), 202–212.

Agung Pambudi, N., Riva Nanda, I., Tahta Alfina, F., & Zulfia Syahrial, A. (2024). Renewable Energy Education and Awareness Among Indonesian Students: Exploring Challenges and Opportunities for A Sustainable Future. *Sustainable Energy Technologies and Assessments*, *63*, 103631. https://doi.org/10.1016/j.seta.2024.103631

Aiken, L. R. (1985). Three Coefficients For Analyzing The Reliability And Validity of Ratings. *Educational and Psychological Measurment*, *45*(1), 131–142.

AlAli, R. (2024). Enhancing 21St Century Skills Through Integrated Stem Education Using Project-Oriented Problem-Based Learning. *Geojournal of Tourism and Geosites* , *53*(2), 421–430. https://doi.org/10.30892/gtg.53205-1217

Allanta, T. R., & Puspita, L. (2021). Analisis Keterampilan Berpikir Kritis dan Self Efficacy Peserta Didik: Dampak PjBL-STEM Pada Materi Ekosistem. *Jurnal Inovasi Pendidikan IPA*, *7*(2), 158–170. https://doi.org/10.21831/jipi.v7i2.42441

Anggraini, F. I., & Huzaifah, S. (2021). Implementasi STEM dalam pembelajaran IPA di sekolah menengah pertama." In Seminar Nasional Pendidikan IPA Tahun 2021, vol. 1, no. 1, pp. 722-731. 2017. *In Seminar Nasional Pendidikan IPA*, *1*(1), 722–731.

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

Augustine, A. R., Idris, S., Novita, N., Sakdiah, H., Siska, D., & Saminan, N. F. (2025). The Implementation of PhET Simulation Media to Improve Junior High School Students' Understanding of Heat and Heat Transfer Concepts. *Electronic Journal of Education, Social Economics and Technology*, *6*(2), 1–7. https://doi.org/10.33122/ejeset.v6i2.861

Bhakti, Y. B., Astuti, I. A. D., Okyranida, I. Y., Asih, D. A. S., Marhento, G., Leonard, L., & Yusro, A. C. (2020). Integrated STEM Project Based Learning Implementation to Improve Student Science Process Skills. *Journal of Physics: Conference Series*, *1464*(1), 1–5. https://doi.org/10.1088/1742-6596/1464/1/012016

Bybee, R. W. (2013). *The Case for STEM education: Challenges and Opportunities*. Arlington, Virginia: National Science Teachers Association, [2013]. https://search.library.wisc.edu/catalog/9910137509202121

Capraro, M. M., Capraro, R. M., & Morgan, J. R. (2020). STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach. In *Springer International Publishing*.

Elistiana, V., Novita, N., Ginting, F. W., Muliani, & Fadieny, N. (2024). The The Influence of SETS (Science, Environment, Technology, and Society) based E-Modules on Scientific Literacy Using the Discovery Learning Model. *Indonesian Journal of Technical and Vocational Education Training*, *1*(1), 10–17. https://doi.org/10.62945/ijtvet.v1i1.124

Fatmi, N., Fauzan, F., Setiawaty, S., & Fakhrah, F. (2025). Implementing Visual Media Based on Local Wisdom to Improve Students' Learning Outcomes. *Electronic Journal of Education, Social Economics and Technology*, *6*(1), 1070–1077. https://doi.org/10.33122/ejeset.v6i1.858

Fatmi, N., Sakdiah, H., Alchalil, & Henni, F. (2024). Application of Ethnopedagogical Module In Natural Sciences Based on Local Wisdom Towards Learning Independence in Thematic Learning. *PHI: Jurnal Pendidikan Fisika Dan Terapan*, *10*(2), 33–39. https://jurnal.ar-raniry.ac.id/index.php/jurnalphi/article/view/23552

Felder, R. M., & Brent, R. (2024). *Teaching and Learning STEM: A Practical Guide* (2nd ed.). John Wiley & Sons.

Ginting, F. W., Mellyzar, M., & Lukman, I. R. (2023). Analysis of Student Environmental Literacy: PjBL-Based Learning that is Integrated STEM. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 242–248. https://doi.org/10.29303/jppipa.v9i1.2599

Hanif, S., Wijaya, A. F. C., & Winarno, N. (2019). Enhancing Students' Creativity through STEM Project-Based Learning. *Journal of Science Learning*, *2*(2), 50. https://doi.org/10.17509/jsl.v2i2.13271

Kapila, V., & Iskander, M. (2014). Lessons learned from conducting a K-12 project to revitalize achievement by using instrumentation in Science Education. *Journal of STEM Education*, *15*(1).

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Morrison, J., Frost, J., Gotch, C., McDuffie, A. R., Austin, B., & French, B. (2021). Teachers' Role in Students' Learning at a Project-Based STEM High School: Implications for Teacher Education. *International Journal of Science and Mathematics Education*, *19*(6), 1103–1123. https://doi.org/10.1007/s10763-020-10108-3

Muchtar, A. H., & Ding, L. (2024). Integrated STEM Education in Indonesia: What Do Science Teachers Know and Implement? *Jurnal Pendidikan Sains Indonesia*, *12*(1), 232–246. https://doi.org/10.24815/jpsi.v12i1.35588

Munawir, Mahidin, Away, Y., Azwar, & Ismail, W. I. N. W. (2025). Mapping and Analysis of Local Potential for New and Renewable Energy and Its Conversion Technology in Aceh-Indonesia. *Renewable and Sustainable Energy Transition*, *8*, 100126. https://doi.org/10.1016/j.rset.2025.100126

Nugraha, A. K., Rochman, C., & Nasrudin, D. (2022). Senior High School Students'Literacy Profile on Energy Conversion Process. *Jurnal Riset Pendidikan Fisika*, *7*(1), 29–33. https://journal2.um.ac.id/index.php/jrpf/article/view/28768/10789

Pitri, E., Sakdiah, H., Absa, M., Fatmi, N., Studi Pendidikan Fisika FKIP Universitas Malikussaleh, P., Cot Tengku Nie, J., Muara Batu, K., & Aceh Utara, K. (2024). Pengembangan LKPD Fisika Berbasis STEM Untuk Meningkatkan Keterampilan Generik Sains Siswa Kelas XI SMA. *Journal on Education*, *06*(02), 14371–14383.

Prajoko, S., Sukmawati, I., Maris, A. F., & Wulanjani, A. N. (2023). Project Based Learning (PjBL) Model With STEM Approach on Students' Conceptual Understanding and Creativity. *Jurnal Pendidikan IPA Indonesia*, *12*(3), 401–409. https://doi.org/10.15294/jpii.v12i3.42973

Purba, L. S., & Zunidar, Z. (2025). Enhancing Student Creativity through Project-Based Learning in Science Education. *Electronic Journal of Education, Social Economics and Technology*, *6*(2), 1–11. https://doi.org/10.33122/ejeset.v6i2.862

Rusydiyah, E. F., Indrawati, D., Jazil, S., Susilawati, & Gusniwati. (2021). STEM Learning Environment: Perceptions and Implementation Skills in Prospective Science Teachers. *Jurnal Pendidikan IPA Indonesia*, *10*(1), 138–148. https://doi.org/10.15294/jpii.v10i1.28303

Sakdiah, H., Ginting, F. W., Novita, N., & Muliani, M. (2020). *E-Modul Kajian Fisika Kejuruan Berbasis STEM Terintegrasi Pembelajaran Inkuiri*. CV. Media Sains Indonesia.

Sakdiah, H., Muliaman, A., Fatmi, N., & Ginting, F. W. (2024). The Development of Virtual Reality Media in Case Method Learning to Enhance Science Literacy and Habits of Mind for Prospective Physics Teachers in Achieving Sustainable Development Goals. *International Journal of Religion*, *5*(12), 1348 – 1358. https://doi.org/10.61707/pw1rps10

Setiawaty, S., Imanda, R., Karismayani, Kinanti, W., & AT, N. D. (2024). Development of STREAM-ETHNO-Based Learning Media for Elementary School Students. *Proceedings of Malikussaleh International Conference on Multidisciplinary Studies (MICoMS)*, 144–151. https://proceedings.unimal.ac.id/micoms/article/view/971

Shahzad, S., Abbasi, M. A., Ali, H., Iqbal, M., Munir, R., & Kilic, H. (2023). Possibilities, Challenges, and Future Opportunities of Microgrids: A Review. *Sustainability*, *15*(8), 6366. https://doi.org/10.3390/su15086366

Solihin, A., Wibowo, F. C., & Astra, I. M. (2021). Review of Trends Project Based Learning (PjBL) Integrated STEM in Physics Learning. *Journal of Physics: Conference Series*, *2019*(1). https://doi.org/10.1088/1742-6596/2019/1/012031

Sugiyono. (2019). *Metode Penelitian Kuantitatif, Kualitatif dan R&D*. Bandung : Alfabeta.

Supriadi, G. (2021). *Statistik Penelitian Pendidikan*. UNY Press.

Wei, M., Jiang, Z., Pandey, P., Liu, M., Li, R., O'Neill, Z., Dong, B., & Hamdy, M. (2025). Energy Resilience in the Built Environment: A Comprehensive Review of Concepts, Metrics, and Strategies. *Renewable and Sustainable Energy Reviews*, *210*, 115258. https://doi.org/10.1016/j.rser.2024.115258

Widya, Ginting, F. W., Andriani, R., Raseukina, G., & Anjli, D. (2024). Need Analysis for Integrated Physics E-Module on Renewable Energy Based on the Creative Problem Solving Model. *Proceedings of Malikussaleh International Conference On Education Social Humanities And Innovation (Miceshi)*, 0079. https://proceedings.unimal.ac.id/miceshi/article/view/579

Widya, Ginting, F. W., Iqbal, M., & Andriani, R. (2023). Validity of a Physics E-Module Based on Creative Problem Solving Model Integrated With Renewable Energy. *Jurnal Penelitian Pendidikan IPA*, *9*(12). https://doi.org/10.29303/jppipa.v9i12.5959

Zainil, M., Kenedi, A. K., Rahmatina, Indrawati, T., & Handrianto, C. (2024). The Influence of STEM-Based Digital Learning on 6C Skills of Elementary School Students. *Open Education Studies*, *6*(1). https://doi.org/10.1515/edu-2024-0039