

Development of STEM-Based Renewable Energy E-Learning with Bot (RENEWBOT) on Renewable Energy Topics

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Abstract

ABSTRACT

This study aims to develop and validate a STEM-based learning media called Renewable Energy E-Learning with Bot (RENEWBOT), which is integrated with artificial intelligence (AI) to enhance students' conceptual understanding of renewable energy topics. The research employed a research and development (R&D) method adapted from the Borg and Gall model, consisting of five stages: needs analysis, model design, prototype development, limited implementation, and evaluation. The study involved 10th-grade students from a public high school in Jakarta, with approximately 60 participants selected through purposive sampling. Data were collected using observation sheets, questionnaires, and a learning outcome test comprising 30 multiple-choice items. The results indicate that the developed media is valid, practical, and effective in improving students' conceptual understanding, as evidenced by the increase in posttest scores and normalized gain (N-gain). Furthermore, the integration of AI-based chatbot features supports interactive and adaptive learning, enabling students to engage more actively with the material. In conclusion, the RENEWBOT media has strong potential to support STEM-based learning and improve students' understanding of renewable energy concepts in a more contextual and engaging manner.

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INTRODUCTION

In recent decades, technological advancements have brought about significant transformations in the world of education, particularly in terms of developing students' conceptual understanding, critical thinking skills, and problem-solving abilities. The integration of technologies such as artificial intelligence (AI), big data, the Internet of Things (IoT), and online learning platforms has changed the way students access and interpret information. Nevertheless, one of the main challenges in physics education is students' difficulty in understanding abstract concepts, including those related to renewable energy. Concepts of renewable energy such as solar, wind, hydro, biomass, and geothermal energy are often hard to grasp because not all of

their phenomena can be directly observed. Conventional, teacher-centered learning that relies on verbal explanations has proven ineffective in creating meaningful learning experiences (Setiawati et al., 2025). Consequently, students tend to memorize without deep understanding, making it difficult for them to connect knowledge to real-life contexts.

To address this issue, a learning model is needed that actively engages students in constructing their own knowledge. One relevant approach is STEM (Science, Technology, Engineering, and Mathematics), which integrates various disciplines to develop critical thinking, creativity, and problem-solving skills (Fauziyah & Wijayanti, 2024). This approach enables students to understand concepts in a more contextual and practical manner, including when studying renewable energy topics. However, the implementation of STEM in physics education still faces challenges, particularly regarding the provision of interactive learning media capable of bridging abstract concepts to make them more concrete.

The STEM approach aligns with constructivist theory, which emphasizes that knowledge is actively constructed by students through learning experiences. Within this framework, students do not merely receive information but are actively engaged in processes of exploration, analysis, and problem-solving. Therefore, learning supported by interactive technology is crucial to help students build more meaningful understanding (Sandrone et al., 2021).

Furthermore, the integration of technology in learning plays a vital role in supporting students' knowledge construction. The presentation of material that combines visual and interactive elements can help students organize information more systematically. In this regard, artificial intelligence (AI)-based technology offers advantages in providing adaptive learning experiences that respond to students' individual needs (Strielkowski et al., 2025). This allows students to understand concepts more deeply while reducing the cognitive load arising from the complexity of the material.

Along with these developments, artificial intelligence (AI) has opened new opportunities for educational innovation. One application of AI is the chatbot, which functions as a virtual assistant to provide quick, personalized, and interactive learning support (Wu et al., 2020). However, the implementation of AI in education, particularly in STEM-based renewable energy learning, remains underdeveloped. Additionally, infrastructure limitations and low digital literacy pose challenges to the optimal utilization of this technology.

This gap highlights the need to develop learning media that integrates the STEM approach with AI technology. Academically, this study contributes to enriching technology-based learning models with a more contextual and innovative approach. Practically, this study offers a solution in the form of interactive learning media that can help students understand renewable energy concepts more easily and engagingly.

Based on this, the objective of this study is to develop and validate a STEM-based Renewable Energy E-Learning with Bot as a learning medium that utilizes an AI chatbot to improve students' conceptual understanding of renewable energy material. This objective serves as the foundation for the design, implementation, and evaluation in the conducted research.

METHOD

This study employs a research and development (R&D) methodology by adapting a modified Borg and Gall model. The selection of this method is based on the research objective, which is to develop a STEM tool called Renewable Energy E-Learning with Bot (RENEWBOT) that integrates artificial intelligence (AI) to enhance students' conceptual understanding of renewable energy topics. The research procedure was carried out through five main stages: needs analysis, model design, media prototype development, limited implementation, and evaluation to test the product's validity, practicality, and effectiveness.

The research subjects were 10th-grade students at a public high school in Jakarta. The research population included all 10th-grade students, while the sample was selected using purposive sampling, taking into account the availability of technological facilities supporting the

use of AI-based media. The pilot test was conducted in two classes with a total of approximately 60 students. Physics teachers instructing 10th-grade classes were also involved as respondents to assess the practicality of the developed learning media.

The instruments used in this study included observation sheets, questionnaires, and learning outcome tests. The observation sheets were used to record student and teacher activities during the learning process. Questionnaires were administered to measure students' and teachers' perceptions of the media's practicality. The achievement test was used to measure students' conceptual understanding of renewable energy material, consisting of 30 multiple-choice items. The validity of the instruments was established through expert judgment involving physics education lecturers and instructional technology experts using a Likert scale, while the reliability of the test was analyzed using Cronbach's Alpha coefficient, with a criterion of ≥ 0.70 indicating reliability.

The research procedure began with a needs analysis through observation of conventional physics instruction to identify the challenges students faced in understanding renewable energy concepts. The next stage involved designing STEM-based learning media integrated with an AI chatbot (RENEWBOT). A prototype of the media was then developed to provide interactive learning services, such as content delivery, practice questions, and automated responses to student inquiries. A pilot test was conducted in two 10th-grade classes over three sessions, each lasting 90 minutes. Subsequently, an evaluation was performed through an analysis of the product's validity, practicality, and effectiveness.

Research data was analyzed using both quantitative and qualitative approaches. Validity data was analyzed based on expert evaluations using a Likert scale to determine the appropriateness of the instrument's content. Practicality data was analyzed descriptively based on survey scores from teachers and students. The effectiveness of the learning media was analyzed using the normalized gain (N-gain) test based on the difference between pretest and posttest scores of students' conceptual understanding, with criteria of high (>0.7), moderate (0.3–0.7), and low (<0.3) (Hake, 1998).

RESULTS AND DISCUSSION

Results:

In general, the trend in the annual number of scientific publications on the integration of technology in education particularly those related to artificial intelligence (AI), e-learning, and STEM approaches shows an upward trajectory.

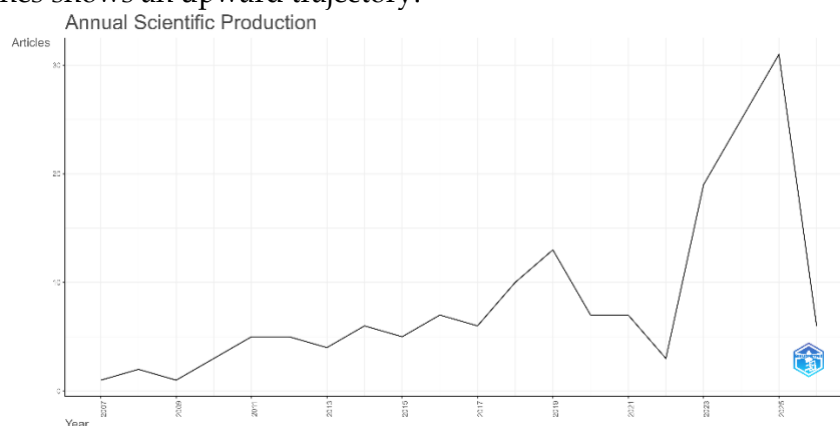


Figure 1. Analysis of Annual Scientific Production

In the early period (2007–2012), the volume of publications was still relatively low, at less than five articles per year, indicating that the use of cutting-edge technology in learning was still limited. Entering the 2013–2019 period, there was a gradual increase, reflecting the growing attention to the use of digital technology in science education.

However, during the 2020–2022 period, fluctuations with a temporary downward trend were observed. This situation can be attributed to a period of transition and adjustment within the global education system. Furthermore, since 2023, there has been a very significant increase, reaching its peak in 2025, with more than 30 articles published. This surge indicates a growing interest in technology-based learning innovations, including the development of AI-powered interactive learning media and the integration of STEM approaches in efforts to understand complex scientific concepts, such as renewable energy.



Figure 2. The Analysis of The Most Relevant Sources

Based on Figure 2, an analysis of the most relevant publication sources indicates that research on the integration of technology in education particularly regarding AI, STEM, and e-learning is dominated by conference proceedings and reputable, indexed international journals. The source with the highest number of publications is the ASEE Annual Conference and Exposition, with a total of 38 documents, reflecting that this topic is widely discussed in global academic forums focused on engineering education and learning innovation.

Additionally, the Journal of Physics: Conference Series and Proceedings - Frontiers in Education Conference also make significant contributions, with 6 publications each. This indicates that the field of science education, particularly physics, is a key focus in the development of technology-based learning. Other sources, such as Sustainability (Switzerland), also contributed 3 publications, signaling a strong connection between educational research and sustainability issues, including renewable energy.

A number of other journals and proceedings, including Education Sciences, Frontiers in Education, IEEE Transactions on Power Systems, and IOP Conference Series: Earth and Environmental Science, each contributed approximately 2 publications. This demonstrates that research in this field is multidisciplinary, encompassing aspects of education, technology, and energy.

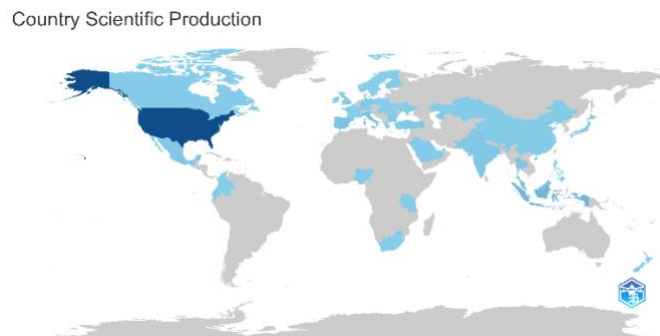


Figure 3. Country Scientific Production

Based on Figure 3, the distribution of scientific output by country indicates that research contributions related to the integration of technology in education particularly AI, e-learning, and STEM approaches are spread globally, though still dominated by developed nations. The United

Additionally, the involvement of interdisciplinary journals like “Energies” suggests that the development of renewable energy education is not only pedagogically relevant but also closely tied to sustainability issues and real-world technological needs.

Theoretically, these findings make an important contribution by demonstrating that the STEM approach remains relevant as a primary learning framework in the digital age. The integration of AI in the form of a learning chatbot allows students to interact directly with the material, receive immediate feedback, and build understanding independently. This supports constructivist theory, which emphasizes that knowledge is actively constructed by learners through meaningful learning experiences. Thus, the use of RENEWBOT can help students convert abstract renewable energy concepts into something more concrete and easily understood.

The practical implications of this research are quite broad. Teachers can utilize AI-based tools like RENEWBOT to support renewable energy learning in a more interactive manner, for example through simulations, practice exercises, and chatbot-based discussions. This not only enhances student engagement but also helps develop critical thinking and problem-solving skills. For policymakers, these findings indicate the importance of developing and providing easily accessible AI-based learning tools, as well as training for teachers on integrating such technology into STEM-based learning.

A limitation of this study lies in the analysis, which relied solely on the Scopus database, thus excluding literature from other databases such as Web of Science or Google Scholar. Additionally, the results of this study remain bibliometric in nature and have not yet fully tested the effectiveness of the media’s implementation directly on a larger scale. Therefore, further research is recommended to conduct experimental trials in the classroom to determine the impact of using RENEWBOT on students’ conceptual understanding and critical thinking skills.

Overall, this study contributes to linking the STEM approach with the use of artificial intelligence in learning, particularly regarding renewable energy content. This not only enriches academic discourse but also opens new opportunities for the development of more adaptive, interactive, and relevant learning innovations to meet the demands of the digital age.

CONCLUSION

The findings of this study indicate that the development of the STEM-based “Renewable Energy E-Learning with Bot (RENEWBOT)” learning platform, integrated with artificial intelligence (AI), holds strong potential for enhancing students' conceptual understanding of renewable energy topics. Based on an analysis of publication trends, relevant sources, and keyword mapping, it appears that the integration of AI technology in learning is growing and aligns with the demands of 21st-century education, particularly in supporting critical thinking and problem solving skills.

From a theoretical perspective, this study contributes to the development of STEM-based physics learning enriched with smart technology, thereby providing a more contextual, adaptive, and interactive learning experience. From a practical standpoint, the RENEWBOT platform can serve as an innovative alternative for teachers in delivering renewable energy content, helping students grasp complex concepts through a more engaging and accessible approach.

However, this study still has limitations, particularly regarding the limited scope of the analysis and the fact that implementation has not yet been widely carried out. Therefore, future research is recommended to test the effectiveness of this medium across various grade levels and school contexts, as well as to conduct long-term evaluations of its impact on student learning outcomes.

Overall, the integration of the STEM approach with AI-based chatbot technology in renewable energy education not only contributes to improving students’ conceptual understanding but also supports the development of technological literacy and students’ readiness to face the challenges of the digital age.

AUTHOR CONTRIBUTION STATEMENT

The author is responsible for the conceptualization and design of the study, data collection and processing of bibliometric data, data analysis, interpretation of results, and the writing and revision of the manuscript.

AI DISCLOSURE STATEMENT

In writing this article, the author acknowledges the use of several digital tools to enhance the efficiency and quality of the work. Bibliometric analysis was conducted using the Bibliometrix package in R software to process and visualize the research data. Additionally, the author utilized artificial intelligence (AI)-based tools to assist with language refinement, paraphrasing, and the organization of ideas.

The use of these technologies was limited to technical and linguistic support. All stages from research design, data interpretation, and critical analysis to the final decision regarding the manuscript's content were entirely carried out by the author. The manuscript has also undergone a thorough manual review and editing process to ensure accuracy, originality, and compliance with academic publication ethics standards.

Thus, the author affirms that full responsibility for the integrity, authenticity, and validity of the research findings and arguments presented in this publication remains entirely with the author.

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