Artificial Intelligence Assisted Renewable Energy Case Based Learning Integrated with Science Process Skills and Digital Literacy

1a* Yaspin Yolanda, 1a Wahyu Arini, 1b Anna Fauziah, 2 E. Effendi, 3 Imam Arif Pribadi

1a Faculty of Science and Technology; 1b Graduate program, Teacher Professional Education, Universitas PGRI Silampari, Lubuklinggau, Indonesia
2 Department of Physics Education, Universitas Nurul Huda, East OKU, Indonesia
3 Faculty of Nuclear Science and Engineering, National Research Tomsk Polytechnic University, Rusia.

*Corresponding Author e-mail: yaspinyolanda@unpari.ac.id

Abstract

The lack of understanding and interest among students in learning science and the scarcity of energy are very interesting topics to study using case-based learning. The novelty lies in the use of Case Based Learning and Artificial Intelligence related to renewable energy. The objectives of the study are (1) to identify the Hypothetical Learning Trajectory (HLT) of renewable energy based on learning barriers, and (2) to measure scientific process skills and digital literacy. The sample consisted of 120 high school students in Lubuklinggau. The research design was a Lesson Study approach. Implementation occurred over two cycles in collaboration with teachers to design renewable energy learning materials, including lesson plans (RPP), Student Worksheets (LKPD) 1 and 2. AI tools used included Padlet, Kahoot, and Cap Cut. Data collection involved documentation, observation, and interviews. Data analysis was conducted using quantitative descriptive methods. Learning difficulties were identified in students' inability to conduct investigations, analyze data, and communicate graphs effectively. LKPD 1 and 2 were found to be highly valid with a validity test score of 0.92, making them suitable for use. Additionally, there was an increase in students' average science process skills by 0.87, categorized as high, and digital literacy by 0.88, categorized as highly skilled. Its contribution lies in integrating digital LKPD that is easy to access and engaging due to AI integration. Furthermore, the LKDP developed involves students conducting experiments and field observations to measure the efficiency of biomass stoves fueled by rice husks, wood chips, and LPG stoves. Another interesting finding is that students with low abilities experienced a very high increase in digital literacy. The next step is to develop diagnostic test instruments for science literacy, digital literacy, and learning modalities.

Keywords: Artificial Intelligence; Renewable Energy; Science Process Skills; Lesson Study; Digital Literacy

INTRODUCTION

Biomass energy is a renewable energy based on local wisdom in Lubuklinggau with the integration of modern technology based on the environment as an environmentally friendly and sustainable energy. One form of local wisdom is the use of biomass stoves made from sawdust waste and rice husk waste. The implementation

of the use of biomass stoves as renewable energy is seen in cooking activities as an alternative to overcome the scarcity and high cost of LPG gas (Pan et al., 2024). However, in school learning physics learning still seems scary too many formulas that must be memorised. So that students are less motivated to follow physics learning at school. Based on these problems, in order for physics learning in schools to be able to attract students' interest in learning, there needs to be a learning design that can contextualise the material into real cases, for example how students are invited to be involved in designing biomass stoves and comparing and analysing the amount of heat energy efficiency produced from biomass stoves with LPG stoves (P. Kumar et al., 2023; Walmsley et al., 2023).

Although the issue of renewable energy has become a global focus and has begun to be integrated into educational curricula, the application of digital technology in learning design for this topic still faces various obstacles (Sanusi et al., 2022). Several studies have developed digital learning media, such as animations, interactive videos, and e-modules, but most are still limited to information delivery functions alone. Systematic aspects of digital-based learning design have not been widely explored (Liang et al., 2024). Additionally, in-depth studies that discuss the integration of digital technology into structured learning design tailored to students' needs remain relatively scarce (Alzahrani, 2024). Furthermore, most research has not considered learner characteristics or local contexts, despite the fact that understanding of renewable energy concepts is significantly influenced by geographical, social, and economic factors. This situation highlights the existing gap in the approach to digitalization of case-based learning and adaptation to the use of learning technology (Sanusi et al., 2022).

Biomass energy is a renewable energy source based on local wisdom in Lubuklinggau, integrated with modern, environmentally friendly, and sustainable technology. One form of local wisdom is the use of biomass stoves made from wood waste and rice husk waste. The application of biomass stoves as renewable energy is evident in cooking activities as an alternative to address the scarcity and high cost of LPG gas (Perea-Moreno et al., 2019). However, in physics education at school, the subject matter still feels intimidating due to the numerous formulas that must be memorized. This makes students less motivated to engage in physics learning at school. Based on this issue, to make physics learning in schools more engaging for students, a learning design is needed that can contextualize the material into real-world cases, such as involving students in designing biomass stoves and comparing and analyzing the thermal energy efficiency produced by biomass stoves with LPG stoves (Ali et al., 2024; Perea-Moreno et al., 2019).

The use of Artificial Intelligence technology in 21st-century learning requires teachers to be adaptable, as technology has become an integral part of students' lives and the world of education (Su, 2023). This adaptation is essential to ensure that teachers can teach effectively, engagingly, and relevantly in the digital age, as well as prepare students to face future challenges. Artificial Intelligence (AI) in education offers various benefits that can help maximize teachers' time and efficiency in learning (Gökcek Taraç & Nale, 2025). AI has the ability to provide adaptive learning materials so that each student can receive a learning experience tailored to their individual needs and abilities (Gökcek Taraç & Nale, 2025; Halpin, 2025). Additionally, AI plays a crucial role in enhancing the efficiency of digital-based teaching tools. AI enables

teachers and students to learn anytime and anywhere. Currently, there are numerous AI platforms such as Canva, Chatbot, Cap Cut AI, Padlet, and Kahoot, which are AI applications used to create teaching tools, learning reflections, assessments, and AI-based learning videos. Furthermore, the AI-based tools or platforms mentioned above can assist teachers in developing and designing teaching materials, creating lesson content, conducting assessment activities, engaging in discussions using AI platforms, and presenting materials simply by providing a brief topic accompanied by keywords. Thus, AI simplifies the learning process for both teachers and students, making it more effective (Bai & Zhang, 2025; Holl, 2024). By adapting to technology, teachers can create more effective, creative, and engaging learning experiences tailored to students' needs in the digital age (Guan et al., 2024). With Artificial Intelligence, students are expected not only to learn to master the material but also to understand the purpose of what they are learning, connect it to their future, and realize how the knowledge they acquire can be applied in real life.

Based on previous research, CBL can improve collaboration and communication skills and encourage students to learn more directly. Students are motivated by the challenges given by teachers at school. The development of learning designs that integrate artificial intelligence into the didactic design of renewable energy-based Case Based Learning (CBL) is essential to improve students' science process skills. The higher the scientific process skills, the better the understanding of concepts, critical thinking abilities, and student learning outcomes (Emblen-Perry, 2022). These skills also help students independently discover and develop scientific facts and concepts, as well as cultivate the attitudes and values required in learning (Anderson et al., 2024; de Leng et al., 2024).

To ensure the effectiveness of this learning design implementation, the Lesson Study model is applied as a collaborative approach in designing, implementing, and reflecting on the learning process systematically and continuously (Woranetsudathip et al., 2021). Lesson Study allows lecturers and teaching teams to improve teaching practices through empirical analysis based on direct experience in the classroom, so that learning can be more targeted to improve teachers' teaching skills (Aas et al., 2024; Roorda et al., 2024). Based on this background, this research aims to develop and implement a digitalised renewable energy learning design by highlighting the potential of local wisdom, and evaluate its effectiveness through the Lesson Study approach. It is hoped that the results of this research can contribute to the development of innovative, contextualised and adaptive science learning models to the dynamics of 21st century education.

The problem-solving approach above uses a case-based learning approach, because of the problem of energy scarcity in the village, reducing the environmental impact of fossil fuel use, increasing energy security, and encouraging sustainable economic growth. So that the need for renewable energy becomes a major community need. For this reason, Case Based Learning (CBL) is a learning approach that places students in real situations or relevant cases to solve problems and develop science process skills. This approach encourages students to apply the knowledge they learn to solve cases in real-world scenarios, and is expected to improve science process skills. Furthermore, the implementation of learning design using Lesson Study with sharing task and jumping task strategies aims to stimulate students' literacy and science process skills. Lesson Study is conducted collaboratively by a group of

students as prospective science teachers, this approach aims to improve the learning competence of prospective science teachers (Roorda et al., 2024).

The gap in previous research related to case-based learning is the lack of research that uses CBL in classroom learning. CBL research so far has focused more on measuring critical thinking skills and problem solving skills at the lecture level (Anderson et al., 2024). Furthermore, it is still found that many teachers in schools have difficulty in implementing case-based learning for science materials. This is due to the basic abilities of students who are still relatively low, namely still understanding the basics of science knowledge, not applying knowledge in real cases in the classroom. This gap is caused by theoretical knowledge gained in lectures that does not adequately explain how case-based learning facilitates the transfer of knowledge to new situations (Daly et al., 2024; Emblen-Perry, 2022). There is a need for more comprehensive theory development on how feedback in case-based learning can be maximised for effective learning in the classroom.

Based on previous research, research focused only on using discovery learning to generate learning trajectories in learning Archimedes' law, didactically designing the concept of hydrostatic pressure (Arab & Saeedi, 2024; Nasseri et al., 2024). Furthermore, research related to the use of Case Based Learning using Jumping Task in the context of electrical circuits can improve critical thinking and problem solving skills (Moon & Chang, 2024; Ulfa et al., 2021). Some of the results of these studies indicate a positive effect on the formation of students' concept understanding of the material and other potential effects such as improved learning outcomes, critical thinking skills and problem solving(de Leng et al., 2024). However, previous studies have not measured science process skills as a graduate output, and there is still a lack of case-based learning literature that is needed to improve students' digital literacy and science process skills.

Based on interviews with teachers and observations of renewable energy issues in the field, it appears that the scarcity of LPG gas has led to high prices, causing difficulties for the community in their kitchen activities. Considering the above case, energy issues need to be integrated into classroom learning because they relate to real-world problems that need to be solved, namely by introducing case-based learning in the classroom, which is expected to improve students' scientific process skills. Research on case-based learning integrated into science education is still limited, as teachers have not fully understood the steps and syntax of CBL (Arab & Saeedi, 2024), resulting in suboptimal implementation. Furthermore, preparing cases, supporting materials, and the necessary facilities for CBL also requires thorough preparation (Ulfa et al., 2021). Ensuring that all students are actively involved in the learning process, especially in discussions and problem-solving, can be a challenge. Based on interviews with science teachers at the school, there are no practical guidelines on how to design and structure learning to effectively implement case-based learning across various educational levels and disciplines, resulting in a lack of experience in designing case-based learning during university education. A strategy that can be used to help improve teachers' and students' knowledge and skills in learning is lesson study (Woranetsudathip et al., 2021).

Lesson study is a training strategy or method that aims to improve teacher competence by collaboratively planning (plan), implementing and observing, reflecting (see) and redesigning (redesign) (Aas et al., 2024; Roorda et al., 2024). In its

classroom application, the Lesson Study system is a collaborative learning, where students' learning activities use two tasks, namely Sharing Task and Jumping Task. The process of designing learning tools with Lesson Study approach has been studied by many researchers before. One of them is the development of project-based learning tools on Archimedes' Law material, which is proven to be able to improve students' concept understanding more deeply (Putri Damayanti & Sumarni, 2020). Another study highlighted the importance of digital literacy analysis as well as sharing task and jumping task strategies in the topic of electrical circuits, while the application of the inquiry approach through Lesson Study proved effective in improving learning outcomes and familiarising students with critical thinking. In addition, contextual learning based on Lesson Study also showed positive contributions to students' creative thinking and problem-solving skills (Bintoro et al., 2021; Kandaga et al., 2021; Putri Damayanti & Sumarni, 2020). These findings indicate that Lesson Study is able to strengthen the learning design process so that it has a more positive impact on the effectiveness of classroom learning.

The novelty of this research is (a). The learning design of local wisdom-based renewable energy material, namely biomass stoves as a Green Economy, through case-based learning, (b). Lesson Study implementation using Sharing Task and Jumping Task strategies as a jumping strategy in improving students' science literacy and process skills in accordance with the principles and characteristics of collaborative and participatory learning. (c). The novelty of this research is to present a new approach by incorporating Artificial Intelligence (AI) technology into a Case Based Learning (CBL) learning model that has not been widely explored in the context of renewable energy topics. (d). This research emphasises deep learning by structuring higher-order thinking processes in case-based learning. (e). Another novelty of this research is measuring the improvement of science process skills, so it is expected to be able to introduce Artificial Intelligence-based renewable energy learning models that are responsive to curriculum needs, especially in aspects of digital literacy, sustainable science process skills.

METHOD

Research Design

This study employed a Design Research methodology, which is appropriate for systematically developing and evaluating educational innovations in authentic classroom settings. The specific design model used in this study is a three-phase structure consisting of: Preparing for the Experiment, Design Experiment, and Retrospective Analysis. To enhance collaborative professional development and classroom-based inquiry, this research was integrated with the Lesson Study approach. Lesson Study provides a structured framework where planning, implementation, and reflection are conducted collaboratively by researchers, practicing teachers, and pre-service teachers.

In this study, the Lesson Study process was carried out in two full cycles involving physics education students participating in a field teaching practicum (PPL), university lecturers, and physics teachers from senior high schools (SMA/SMK/MA) in Lubuklinggau. Each stage of the Design Research corresponds to a specific phase in the Lesson Study model: PLAN, DO, SEE, and REDESIGN. These stages are outlined in Table 1, which presents a detailed alignment of activities such

as mapping student readiness, designing case-based learning (CBL) scenarios, conducting open class teaching, diagnosing science process skills, and revising learning designs. The integration of Design Research and Lesson Study enabled a systematic exploration of instructional design effectiveness, supported by ongoing observation and feedback loops.

Table 1. Stages of Design Research with Lesson Study

Design Research	Lesson Study Stage	Activitiy
Preparing for The Experiment	**PLAN**	1. Students participating in the PPL programme conducted an initial mapping of students based on learning readiness. 2. PPL students conduct FGDs with peer lecturers and physics teachers at school in designing case-based learning scenarios. 3. Designing HLT. 4. Develop pilot experiment of LKPD 1 sharing task and LKPD 2 jumping task. 5. PPL students prepare observation instruments. 6. PPL students prepare science process skills assessment guide.
The Design Experiment	**DO**	7. PPL students as model teachers conduct open class using Case Based Learning model. 8. Lecturers, physics teachers as observers observed the learning process, observed the application of Pilot Experiment using Case Based Learning and observed student activities in groups during Sharing Task and Jumping Task. 9. Open class activities were carried out during 2 cycles of the DO Phase. 10. Observers observed the achievement of student science process skills indicators during learning.
The Restopective Analysis	**SEE**	11. Analyse data during the Pilot Experiment and Teaching Experiment stages using walkthroughs, documentation, observation, interview techniques. 12. Comparing HLT with ALT 13. All observers reflected on the results of observations delivered to students as tutors in a forum with resource persons and observers. 14. Conducted 2 cycles SEE Phase
	REDESIGN	15. Refine the Pilot Experiment of Case Based Learning based learning design. 16. Conducted 3 cycles Redesign Stage

Furthermore, the instructional model developed within this research is rooted in Case-Based Learning (CBL). CBL involves several structured phases: problem orientation, student organization, guided investigation, development of solutions, and evaluation analysis. These stages promote critical and contextual thinking around complex scientific topics such as renewable energy, the core subject matter of this study (Anderson et al., 2024; de Leng et al., 2024). In order to enrich the CBL process, this study also integrated Artificial Intelligence (AI) tools into the learning design. The use of AI supported various student-centered activities, such as information retrieval, modeling, simulation, and reflection.

Research Participants and Sampling

The participants of this study consisted of 120 tenth-grade students (Class X) from various SMA/SMK/MA schools in Lubuklinggau City, selected through a purposive sampling technique. This sampling method was chosen to ensure that the selected participants were aligned with the specific learning objectives of the study, particularly in the context of introducing renewable energy topics through Case-Based Learning (CBL).

The purposive sampling focused on including schools and students who met criteria relevant to the goals of the study, especially in terms of cognitive readiness and classroom accessibility for implementing innovative digital learning tools. Although not randomized, the sample was adequate for evaluating the feasibility, practicality, and effectiveness of the developed lesson plans and learner worksheets (LKPD).

In addition to the student participants, the study involved a unique collaboration with physics education students undertaking their field teaching practicum (Program Pengalaman Lapangan – PPL). A total of four PPL students served as model teachers, conducting the learning sessions in real classroom settings during the Lesson Study cycles. These PPL students not only implemented the instructional materials but also played an integral role in the planning (PLAN), teaching (DO), and reflection (SEE) stages of the Lesson Study.

Moreover, the research engaged university lecturers and school-based physics teachers as observers and co-researchers. This interdisciplinary and cross-institutional collaboration ensured that both academic rigor and classroom practicality were considered in designing, implementing, and revising the learning materials.

This composition of participants reflects the dual focus of the study: improving high school students' scientific process skills and digital literacy, while simultaneously enhancing the pedagogical competence of pre-service teachers through real-world teaching experience and reflective practice.

Learning Design and Implementation

The instructional design in this study was centered on the development and implementation of renewable energy-based learning tools, guided by the Case-Based Learning (CBL) model. The design process was conducted collaboratively through two full Lesson Study cycles, involving researchers, physics teachers, and pre-service teachers (PPL participants). The aim was to foster both science process skills and digital literacy among students using context-rich, technology-supported instructional strategies.

The primary learning materials developed were: Lesson Plans tailored to renewable energy topics; Learner Worksheet (LKPD) 1-Sharing Task, designed to facilitate collaborative problem analysis; Learner Worksheet (LKPD) 2-Jumping Task, structured to encourage independent, higher-order problem solving. These materials were designed iteratively through the PLAN-DO-SEE stages of Lesson Study, ensuring that each learning cycle was informed by observation, reflection, and revision.

The CBL model employed in the learning design consisted of five phases: (1) Orientation to the problem: introducing real-world issues related to renewable energy; (2) Student organization: forming collaborative groups; (3) Guided investigation: encouraging exploration supported by AI and teacher scaffolding, (4) Development of solutions: producing evidence-based arguments and artifacts; and (5) Evaluation and analysis: reflecting on learning outcomes and strategies (Anderson et al., 2024; de Leng et al., 2024).

To enhance inquiry and student agency, Artificial Intelligence (AI) tools were integrated throughout the learning activities. These tools supported diverse functions such as information retrieval, digital modeling, visualization of data, and feedback generation. This technological enhancement aimed to align classroom practice with the demands of digital-age learning environments, providing students with authentic tasks that required both scientific reasoning and technological proficiency.
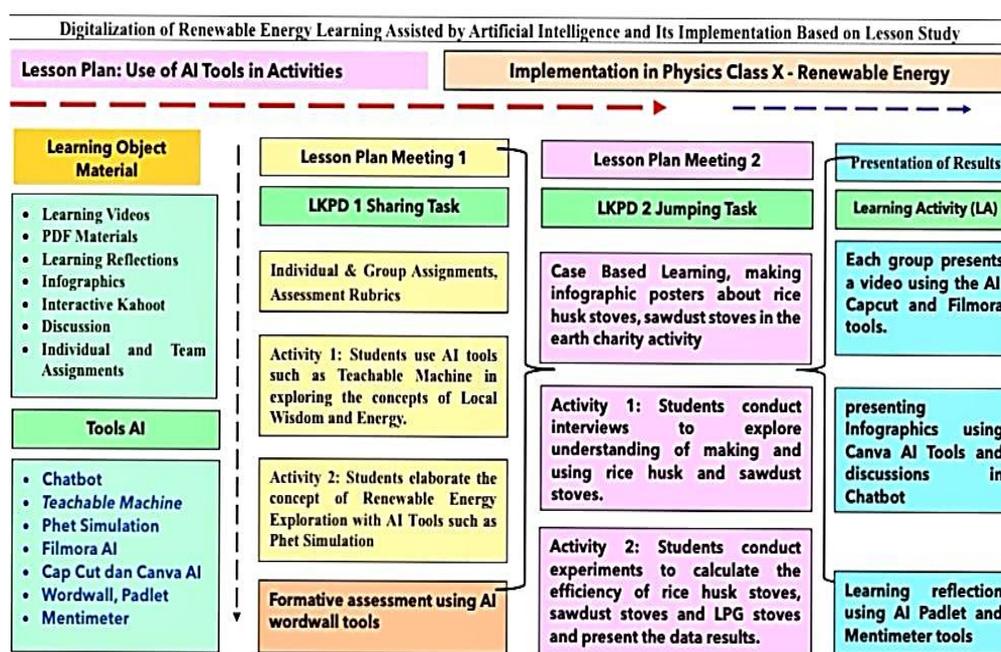
Figure 1. Design of using AI in learning

The conceptual framework of AI integration is presented in Figure 1, while the practical use of AI tools during classroom learning is depicted in Figure 2. These figures illustrate how digital support tools were embedded within the learning process to amplify students' engagement, autonomy, and capacity for critical thinking. By combining CBL with AI-enhanced instruction and iterative development through Lesson Study, the learning design offered students an opportunity to engage deeply with complex socio-scientific issues while developing essential 21st-century competencies.

Canva AI	Phet Simulation	Video Cap Cut AI
Canva AI is used by students to create infographic posters and group presentations of the results of working on the LKPD.	Phet Simulation is used by students to conduct virtual-based experiments and aids students in understanding abstract science material.	Students make a video of each group conducting experiments related to the efficiency comparison test of rice husk stoves, sawdust stoves and LPG stoves.
ChatBot	Kahoot AI	Padlet AI
Chatbot is used by students in each group to discuss on the LMS online.	Kahoot is used as a learning outcome assessment that aims to measure the achievement of learning objectives.	The AI padlet is used as a reflection of learning related to whether they have understood, and student responses related to the learning conducted by the teacher.

Figure 2. The use of AI tools in learning

Data Collection and Instruments

Data collection in this study was carried out using a multi-method approach, integrating both qualitative and quantitative techniques to ensure comprehensive insight into the development, implementation, and impact of the learning tools. The data collection focused on three main areas: the feasibility of the developed LKPD, students' learning barriers, and the development of science process skills and digital literacy (see Table 2).

Table 2. Instruments and Data Analysis

Data	Instrument	Analysis	Participant
Feasibility Test of LKPD	The Expert Validation Questionnaire consists of: Material Validation and Learning Technology Validation	Product feasibility test data was analyzed descriptively quantitatively.	2 experts
Student Learning Barriers	Lesson Study Sharing Task and Jumping Task Observation Sheet	Data findings were analyzed descriptively qualitatively, namely confirmability, member checks and in-depth interviews. The findings are displayed in a table.	120 student
Students' Science Process Skills	Science process skills diagnosis assessment sheet	Data using the Gain-Score test, analyzed descriptively quantitatively and displayed in graphs and tables.	120 student
Student Digital Literacy	Digital literacy assessment observation sheet	Data using the Gain-Score test and quantitative descriptive analysis and displayed in graphs and tables.	120 student

The research product in the form of digital LKPDs is validated using expert review sheets to obtain the first prototype. Next, data on students' learning barriers

related to renewable energy material is diagnosed using tests and observations conducted by observers during lesson study (De Pilli et al., 2024). Furthermore, data on students' scientific process skills and digital literacy is collected using observation sheets. The collected data, including student work, interview results, observation results, video recordings, and reflection results, constitute empirical data (Wallwey & Kajfez, 2023; Wang & Wang, 2024). Data analysis employs two strategies: qualitative descriptive analysis of student learning barriers based on interview results, observations, or documentation, while quantitative descriptive analysis is used for scientific process skills and digital literacy data (Andersen et al., 2024; Wang & Wang, 2024). The LKPD was pilot-tested in a small class, while the implementation of the two-cycle LKPD was pilot-tested in a large class. Subsequently, product validation and feasibility were conducted.

Data Analysis Procedures

The data collected in this study were analyzed using a mixed-method approach, integrating both quantitative and qualitative techniques to evaluate the feasibility, effectiveness, and contextual relevance of the developed learning tools. This dual strategy provided a robust understanding of both student competency development and the pedagogical dynamics that unfolded during lesson implementation.

For quantitative analysis, several techniques were employed. The feasibility of the LKPD (Learner Worksheets) was assessed through scores from the Expert Validation Questionnaire, which were aggregated using a basic mean calculation (Formula 1). These mean scores were then converted into scaled categories based on the interpretation framework outlined in Table 3 that classified the LKPDs into levels ranging from "Very Poor" to "Very Good," depending on how far the scores deviated from the mean using standard deviation criteria.

$$x = \frac{\sum x}{n} \qquad (1)$$

The students' science process skills and digital literacy development were analyzed using the N-Gain formula, which measures the magnitude of learning improvement from pretest to posttest. The resulting scores were classified into gain categories (High, Medium, Low), allowing the researchers to quantify the learning impact of the instructional model. For further interpretation of students' digital literacy, analysis referred to Table 4, which detailed the performance indicators across three main dimensions: technical skills, critical understanding, and social competence. These competencies were then categorized into proficiency levels—Basic, Expert, and Role Model—as described in Table 5.

Table 3. Conversion of Actual Score to Scaled Score 5

Score range (i)	Value	Category
$\chi > \bar{x} + 1.80\ Sbi$	A	Very Good
$\bar{x} + 0.60\ SBi < \chi \leq \bar{x} + 1.80\ Sbi$	B	Good
$\bar{x} - 0.60\ SBi < \chi \leq \bar{x} + 0.60\ Sbi$	C	Fair
$\bar{x} - 1.80\ SBi < \chi \leq \bar{x} - 0.60\ Sbi$	D	Poor
$\chi \leq \bar{x} - 1.80\ Sbi$	E	Very Poor

In parallel, qualitative data were analyzed to deepen the understanding of the learning context and students' experiences. Sources of qualitative data included

observation notes, interview transcripts, video documentation, and student learning artifacts. These data were coded thematically to identify patterns related to learning barriers, engagement with digital tools, and students' responses to the instructional design. The researchers also applied confirmability checks across multiple observers to ensure reliability and member checking with participants to validate interpretations. Triangulation across observation, documentation, and interview sources further strengthened the credibility of the findings.

Table 4. Digital Literacy Competency Levels

Levels of Digital Literacy	Technical Skills			Critical Understanding			Social Competance		
	Unskilled	Skilled	Very Skilled	Understand	Analyze	Evaluate	Communication	Cooperation	Products
Basic	√			√			√		
Expert		√				√		√	
Role model		√	√		√	√		√	√

These qualitative insights were particularly valuable during the SEE and REDESIGN phases of the Lesson Study, as they informed decisions on modifying the instructional tools and strategies. Overall, this comprehensive data analysis approach enabled a multidimensional evaluation of the learning design's implementation and impact.

Table 5. Digital Literacy Competency Levels

Digital Literacy	Basic	Expert	Role model
Technical Skills	1-4	5-8	9-12
Critical Understanding	1-4	5-8	9-12
Social Competence	1-4	5-8	9-12

Ethical Statement

This study was conducted in compliance with ethical standards for educational research involving human participants. Prior to data collection, informed consent was obtained from all participating students and their guardians, and formal permission was secured from the participating schools in the Lubuklinggau city area. All participants were informed of the study's objectives, their voluntary involvement, and their right to withdraw at any stage without any academic consequences.

The involvement of pre-service teachers (PPL students), lecturers, and school-based teachers was based on mutual collaboration and informed agreement, ensuring that the Lesson Study cycles were conducted in a respectful, non-intrusive manner. All data collected, including video recordings, student work, interview responses, and observation notes, were treated with strict confidentiality. Data were anonymized during analysis and reporting to protect participants' identities.

The development and validation of learning materials followed ethical guidelines to ensure non-maleficence, academic fairness, and respect for learners' intellectual and emotional well-being. This research did not involve any experimental manipulation that could pose psychological or physical risk to the participants.

RESULTS AND DISCUSSION

Validation of Learning Tools (LKPD) by Experts

Based on the results of the digital module assessment by the three experts, it was found that designing a case-based renewable energy learning design resulted in the creation of a Lesson Plan (RPP), teacher's guide, and two LKPDs. LKPD 1 and LKPD 2 were then reviewed by experts (expert review) and tested through a one-to-one stage to assess their validity. The revision process resulted in LKPDs that are valid and aligned with the learning objectives outlined in Table 7.

Table 6. Expert validation results

Validator	Average	category	Description
Subject matter expert	0.86	Very Valid	LKPD 1 Sharing
Learning technology expert	0.90	Very Valid	Task and LKPD 2 Jumping Task are
Learning model expert	0.88	Very Valid	suitable for use.

"Highly Valid" category according to the three validators, namely subject matter experts (0.86), learning technology experts (0.90), and learning model experts (0.88). The highest score was given by the learning technology experts, indicating that the integration of technology in the LKPD is considered very good. Additionally, the subject matter expert also stated that LKPD 1 (Sharing Task) and LKPD 2 (Jumping Task) are suitable for use in learning. The consistency of these evaluations indicates that the LKPD has met the aspects of content suitability, model approach, and technological readiness in a balanced manner.

Table 7. Suggestions for Improvement of LKPD from Experts

Aspect	Indicator	Improvement Suggestions
Content Quality	Accuracy, depth, and relevance to renewable energy topics	The material is very accurate, relevant, and complete according to the curriculum according to world global issues
AI Integration in Learning	Use of AI to support learning (e.g. chatbot, simulation, data visualization)	AI was used effectively, interactively such as Chatbot, Canva AI to facilitate students making group presentations, and Phet Simulation.
Case Based Learning	Clarity of case, relevance to real context, and student engagement	Create Cases that are contextualized, and encourage student analysis and problem solving
Strengthening Science Process Skills	Observation, measurement, data analysis, inference,	Include the SPS indicators which are contained in LKPD 1 and 2 so that

Aspect	Indicator	Improvement Suggestions
	communication of results	they facilitate all science process skills properly and structured.
Interactivity and Graphic design of the module	Ease of navigation, visual design, interactive elements	Highly engaging, intuitive and interactive design (videos, simulations, quizzes, Chatbot) include a Barcode or link for access.
Alignment with Learning Objectives	Conformity with objectives and achievement indicators	LKPD 1 Sharing Task and LKPD 2 Jumping Task are arranged in accordance with the learning objectives.
Innovation and Originality	Uniqueness of approach, creativity in delivery	Module is highly innovative and demonstrates an original approach in combining AI and the context of renewable energy

Based on Table 6, the expert validation results for the Student Worksheet (LKPD) that was developed showed excellent scores in two main aspects, namely the quality of the material content and the integration of AI in learning. In terms of material content quality, all three validators (Expert 1, Expert 2, and Expert 3) gave high scores, with the assessment that the material was very accurate, relevant, and comprehensive. The LKPD was found to align with the current curriculum and be consistent with global issues related to renewable energy. This indicates full agreement among the experts regarding the quality of the content. Furthermore, in terms of AI integration in learning, the experts assessed that the use of AI in the LKPD was effective and interactive.

The LKPD was found to incorporate learning technologies such as chatbots, Canva AI for supporting student group presentations, and PhET Simulations to aid conceptual understanding through virtual experiments. Overall, the validation results indicate that this LKPD meets quality standards in terms of content and educational technology innovation and is suitable for use in the context of renewable energy education based on case-based learning. For the integration of case-based learning (CBL) in LKPD 1 and 2, experts provided very positive evaluations of the quality of the approach used in the LKPD. Validators suggested that the cases presented in the LKPD be designed to be more contextual and relevant to real life, and capable of encouraging active student engagement in the analysis and problem-solving process. Based on these validation results, it can be concluded that the LKPD has good quality and is valid for use in renewable energy learning processes that integrate case-based approaches and optimize students' science process skills.

Analysis of Student Learning Barriers During Lesson Study Cycles

Expert validation of the LKPD also covers the aspects of interactivity and graphic design of the module, which were rated very good by all three experts. The validators assessed that the visual appearance of the module was attractive, intuitive, and contained interactive elements such as videos, simulations, quizzes, and chatbots. However, it is recommended that barcodes or links be included that directly lead to these interactive media, making it easier for students to access and use them. In terms

of innovation and originality, the module was found to have a unique and creative approach, particularly in combining Artificial Intelligence (AI) technology with the context of renewable energy education. Overall, these three aspects indicate that the LKPD not only meets pedagogical standards but also excels in terms of technology, integration, and innovation. This reinforces the LKPD's suitability as a modern and adaptive contextual learning medium in line with contemporary developments.

Table 8. Student learning barriers in Lesson Study-based experiments

Learning Barriers	Cycle 1	Cycle 2	Solution
Students' difficulties in understanding the working principle of the stove, namely students often do not understand the principle of indirect combustion or gasification used in rice husk stoves and LPG stoves.	80%	0%	Students explore information from various sources related to the working principles of biomass stoves.
Students have difficulty understanding the working principles of renewable energy because learning is still dominated by theory.	80%	0%	Making LKPD Jumping Task Implementation of renewable energy on biomass stoves so that learning with concrete visualization.
Students' difficulty in measuring the mass of water, the initial temperature and the final temperature of water precisely.	80%	0%	Students are facilitated with LKPD Sharing Task, which adds measurement procedures, and demonstrates how to use and read measuring instruments that are accurate and according to procedures.
Students' difficulty in measuring the warm-up time was not recorded correctly, which affected the estimation of power and efficiency.	70%	0%	Students are given group guidance and divided into tasks by the teacher, some are measuring and some are observing the process, some are recording the measurement results and some are processing the measurement data.
Inaccurate data was found when calculating the heating energy of the biomass stove and the heating energy of the LPG stove produced.	90%	2%	Students are given repeated measurements of 5 repetitions for data collection

Learning Barriers	Cycle 1	Cycle 2	Solution
Confused about using the energy efficiency formula.	90 %	4%	Students asked PPL students for guidance in finding the energy efficiency produced by biomass stoves.
It is difficult to convert energy units from calories to joules, convert temperature from degrees kelvin to degrees centigrade, and convert from grams to kilograms.	92 %	6%	Students are given an explanation in cycle 2 to convert energy units from calories to joules, convert temperature from degrees kelvin to degrees centigrade, and convert from grams to kilograms.
Error in calculating the calorific energy of rice husk (e.g., the calorific value of husk is about 13-15 MJ/kg and calculating the calorific energy of LPG stove).	98 %	28 %	Students were given an explanation in cycle 2 in calculating the chemical energy of rice husk (for example: the calorific value of husk is about 13-15 MJ/kg, calculating the calorific energy of LPG stove.
Not accustomed to reading and interpreting practicum data into quantitative conclusions. As well as difficulty compiling tables or graphs of experimental results, making it difficult to analyze the relationship between variables.	95 %	35 %	Students were given guidance in cycle 2 on how to draw conclusions, interpret measurement data and graph measurement results.

Based on Table 8, the implementation of Lesson Study in the Do stage involved dividing students into four groups of four and asking them to work on the worksheet individually. If students encountered difficulties, they could ask for help from their teammates. An interesting aspect of this discussion was that students with higher abilities guided those with lower abilities who were experiencing difficulties, ensuring that the peer tutoring process ran smoothly. Some of the answers provided by the students aligned with the predictions formulated in the Hypothetical Learning Trajectory (HLT).

Overall, students were able to identify and demonstrate energy efficiency values, although some errors were still present. Students demonstrated the habit of reading and interpreting experimental data into quantitative conclusions. However, challenges were still encountered in organizing tables or graphs of experimental results, which impacted the difficulty in analyzing relationships between variables. Additionally, errors were found in the calculation of thermal energy from rice husks and wood chips. After confirmation, students acknowledged that the errors occurred due to the desire to provide answers even if they were not entirely accurate, and

ultimately recognized their mistakes after the reflection process. Hypothetical Learning Trajectory (HLT) is able to diagnose student learning barriers with Lesson Study(Eccott et al., 2025; Hasan et al., 2021).

Based on the results of observations in three cycles of Lesson Study, a number of student learning barriers were identified in understanding concepts and conducting experiments related to renewable energy learning, particularly in the use of biomass stoves fueled by rice husks. In cycle 1, most students experienced various difficulties with a high percentage of barriers, but there was a significant decrease in cycle 2, and almost all barriers were successfully minimized after the implementation of collaboration-based solutions and teacher reflection (Uştuk & Çomoğlu, 2019; Vígh, 2024). The main obstacle that emerged was students' difficulty in understanding the working principles of the stove, particularly related to the process of indirect combustion or gasification. In the initial cycle, 80% of students experienced this obstacle. However, after being given tasks to gather information from various sources, this obstacle decreased drastically to 0% in Cycle 2. This proves that Lesson Study is able to minimize students' learning obstacles (Kandaga et al., 2021; Putri Damayanti & Sumarni, 2020).

Students also had difficulty understanding the working principles of renewable energy because the learning approach was still too theoretical. To overcome this, teachers developed a Jumping Task-based worksheet that encouraged students to visualize the implementation of renewable energy through biomass stoves. As a result, the obstacles initially experienced by 80% of students decreased dramatically to 0% in cycle 2. In terms of experimental skills, students struggled to measure the mass of water, initial and final temperatures, and accurately record heating times, which affected the accuracy of energy efficiency data. Through Sharing Task worksheets that included measurement procedures and demonstrations of measuring tools by teachers, as well as role distribution in experimental groups, the initial 70-80% of obstacles were reduced to 0% in cycle 2. Issues also arose in terms of heat energy calculations and the use of energy efficiency formulas, where conceptual and technical errors were still found in most students (up to 98% in Cycle 1). As a solution, the teacher repeated the measurements five times, provided intensive guidance through student teachers, and included explicit explanations regarding unit conversion and the calculation of heat values in Cycle 2.

Effectiveness of Case-Based Learning in Improving Scientific Process Skills (SPS)

These challenges (described previously) decreased significantly in subsequent cycles. Additionally, students also faced difficulties in reading, interpreting, and presenting experimental data, such as creating tables and graphs, as well as drawing quantitative conclusions. Initially, 95% of students demonstrated these difficulties, but through direct guidance in cycle 2, they began to develop skills in creating graphs and analyzing relationships between variables, reducing the challenges to 8% in cycle 2. Overall, the Lesson Study approach proved effective in identifying and addressing students' learning challenges through collaborative, reflective, and continuous learning improvements. This aligns with previous research indicating that each cycle provides opportunities for improvement based on real-world classroom needs, which gradually enhance students' conceptual understanding and practical skills significantly. This proves that the Lesson Study strategy is able to diagnose students'

learning disabilities with sharing task and jumping task (Hidayat & Santoso, 2021; Kandaga et al., 2021).

Table 9. Students' SPS achievement in learning

SPS indicator	r count	r table	Category
Observing skills	0.90	0.456	Valid and very high
Classifying skills	0.80	0.456	Valid and high
Measuring skills	0.94	0.456	Valid and very high
Predicting skills	0.78	0.456	Valid and high
Interpreting data	0.77	0.456	Valid and high
Hypothesizing skills	0.76	0.456	Valid and high
Planning experiments Skills	0.96	0.456	Valid and very high
using measuring instruments Skills	1.00	0.456	Valid and very high
applying concepts	0.80	0.456	Valid and high
Communicating skills	0.98	0.456	Valid and very high

Based on Table 9, these results indicate that case-based learning with the lesson study strategy is not only effective in improving conceptual knowledge but also capable of developing aspects of scientific process skills. This aligns with previous research indicating that this success is supported by the use of Lesson Study, which enables teachers to reflect on and improve teaching strategies collaboratively and continuously. The application of Case-Based Learning in the didactic design of renewable energy integrated with SPS shows a positive impact on significantly improving students' SPS achievements, as shown in Table 9 and Figure 3, and is also evident from Figure 4, which illustrates collaborative activities for enhancing digital literacy within groups.
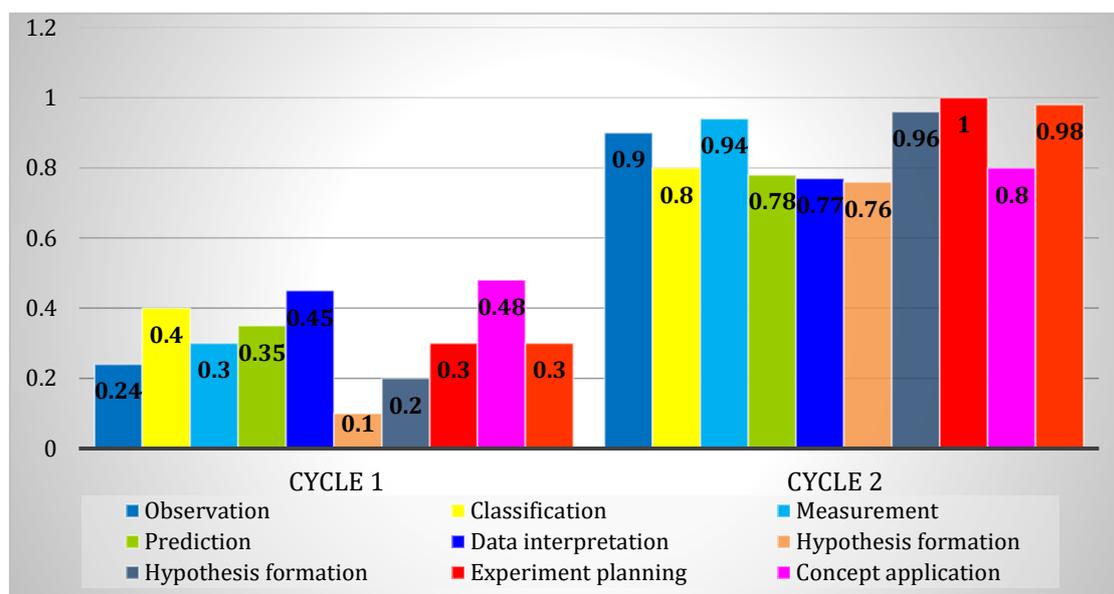
Figure 3. Student Achievement in Sharing Tasks and Jumping Tasks

Observation results indicate that during the Sharing Task phase, students' SPS achievements remain relatively low. For example, only 20% of students demonstrated the skills of classifying, interpreting data, formulating hypotheses, and applying concepts appropriately, this is in line with the opinion of previous research (Ding,

2022; Nasseri et al., 2024; Oberleiter et al., 2023). Similarly, only 30% demonstrated prediction skills and 40% demonstrated observation skills. However, after implementing the Jumping Task, which challenges students to complete complex tasks independently before receiving discussion, there was a significant increase in achievement across all SPS indicators. This is in line with previous research, which is true (Maison et al., 2019).

Skills in using measurement tools increased from 50% to 100%, planning experiments from 50% to 96%, and communicating results from 40% to 98%. Even indicators that were previously very low, such as classifying and applying concepts, saw improvements to 72% and 60%, respectively, aligning with previous research stating that student centered learning can enhance SPS (Kim & Kim, 2021; V. Kumar et al., 2024).

Enhancement of Digital Literacy Through AI-Based Learning

Based on Table 10 the results of the analysis of digital literacy achievement data for all categories of student ability from Cycle 1 to Cycle 2 show that students with low ability experienced the most significant increase in the exemplary category, from 20 to 100. This indicates that the AI-based CBL learning strategy that was implemented successfully encouraged students who previously had limited abilities to achieve the highest level of digital literacy. Meanwhile, in the high-ability group, achievements in the Basic category dropped sharply from 20 to 0, indicating a shift in learning quality toward a better direction, where students are no longer at the basic level. This is in line with previous research related to digital literacy can be improved by giving students the freedom to use technology to achieve learning goals (Gu et al., 2023; Reddy et al., 2023; Ylipulli et al., 2023).

Table 10. Digital Literacy Achievement by Ability Level in each cycle

Category	High Ability		Medium Ability		Low Ability	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2
Basic	20	0	50	10	60	0
Expert	30	50	40	60	40	20
Role model	70	70	20	50	20	100
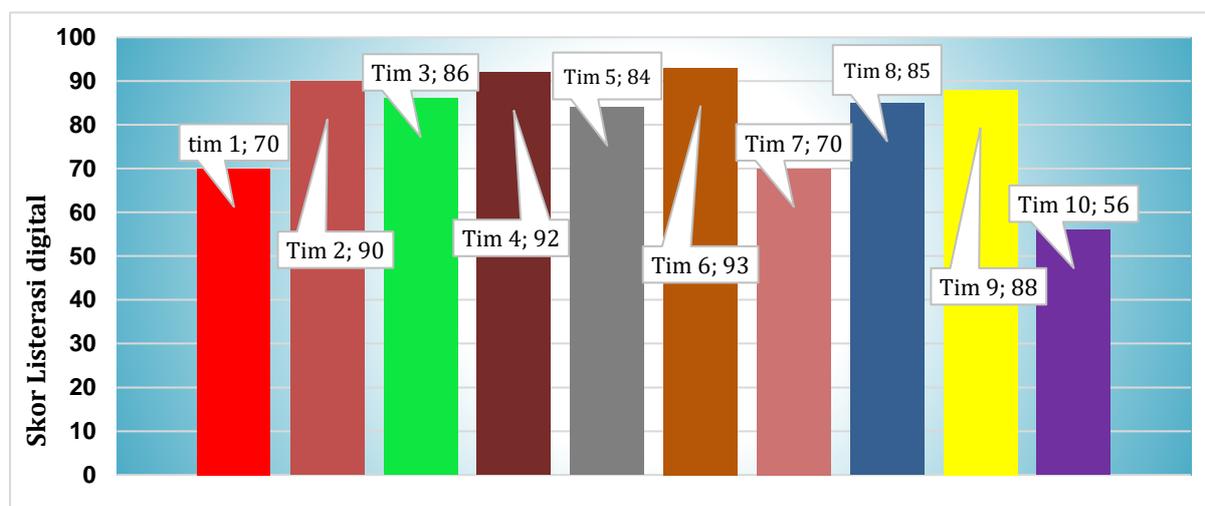
Figure 4. Digital Literacy Outcomes in groups

Although the number of students in the Exemplary category remained unchanged (still 70), the loss of achievement in the Basic category and the increase in the Expert category (from 30 to 50) indicate an improvement in the quality of achievement, not just the quantity. On the other hand, the Basic category as a whole decreased dramatically at all ability levels, even reaching zero in the high and low ability groups in Cycle 2. This indicates a shift in student achievement from the basic level to the expert and exemplary levels. Thus, it can be concluded that the implemented AI-based CBL learning strategy is successful and able to encourage the improvement of digital literacy as a whole, based on previous research is true (Reddy et al., 2023; Zahoor et al., 2023).

Student activities solve jumping task cases for each group.

Students hear the presentation of the group's cases that appear, observers observe the presentation activity

Figure 5. Jumping Task Activity with CBL

Contributions of the Study to Didactic Design and Technology Integration

This study provides a number of positive contributions, including the concept of didactic design through the integration of the Case Based Learning (CBL) approach, science process skills, and the systematic use of Artificial Intelligence (AI) in renewable energy learning as an innovation in teaching, providing teachers and prospective teachers with knowledge in designing case-based teaching scenarios. This aligns with previous research. Additionally, it produces learning materials in the form of AI-integrated worksheets, which serve as an alternative medium for teachers to enhance students' scientific process skills. Another contribution is the use of AI tools such as Padlet, Canva, Phet Simulation, and Kahoot as learning media to foster students' interest in science education, and it is hoped that these can be implemented in other physics topics.

This is demonstrated through the improvement of students' energy literacy and environmental awareness through learning about renewable energy topics, consistent with previous research (Anderson et al., 2024; Daly et al., 2024; de Leng et al., 2024). With AI support, students are also trained to be more independent and active in addressing sustainable energy-related issues in society. This supports the national agenda for digital transformation in education and empowers teachers to create technology-based learning that aligns with the demands of the 21st century (Bai & Zhang, 2025; Halpin, 2025; Holl, 2024). So that AI can improve students' digital literacy, make learning interesting, and improve students' science process skills through case-based learning related to renewable energy.

CONCLUSION

This study provides a number of positive contributions, namely the application of renewable energy learning design based on Case Based Learning can improve students' science process skills by an average of 0.87 in the high category. Furthermore, the use of Artificial Intelligence (AI) in the learning process can improve students' digital literacy with 20 students achieving the expert category and 100 students achieving the exemplary category. Furthermore, the LKPD developed is 0.92 in the highly valid category and suitable for use. This LKPD is capable of addressing students' learning difficulties based on the results of Lesson Study conducted by teachers, researchers, and students. An interesting finding in this study is that students with low abilities experienced a significant increase in digital literacy.

Additionally, the study produced an AI-integrated LKPD as an alternative medium for teachers to enhance students' scientific process skills. Another contribution is the use of AI tools such as Padlet, Canva, Phet Simulation, and Kahoot as learning media to foster students' interest in learning physics, and it is hoped that these can be implemented in other physics topics. This is demonstrated through improvements in environmental literacy and environmental awareness. With AI support, students are also trained to be more independent and active in addressing cases related to sustainable energy in society.

RECOMMENDATIONS

Based on the findings and limitations of this study, several important directions are recommended for future research and educational practice. First, attention must be given to addressing infrastructural limitations that hinder the implementation of AI-assisted learning in schools with restricted access to electricity, internet connectivity, or digital devices. Future studies should investigate the development of offline-capable AI applications or modular digital content that can be deployed in low-resource environments, ensuring equitable access to technology-enhanced education. Additionally, the lack of teacher competence in integrating technology into instructional practice presents a critical challenge. To overcome this, comprehensive professional development programs should be established to enhance teachers' digital literacy and capacity to implement AI-based pedagogies, such as Case-Based Learning (CBL), effectively.

Furthermore, future research should focus on contextualizing AI-assisted learning within local renewable energy systems. One promising example is the use of the Watervank waterfall as a microhydro power plant in village settings, which could serve as a meaningful and relevant context for designing CBL modules that connect science education with students' real-life environments. Finally, ongoing development of AI-integrated learning tools must align with Indonesia's national agenda for digital transformation in education. By doing so, the education system can better support the cultivation of 21st-century competencies and empower educators to innovate with technology in sustainable and inclusive ways.

Author Contributions
YY: Conceptualization, Resources, AF: Writing and Review & Editing, Supervision. WA: Methodology, Formal Analysis, Data Curation, Financial Report, Project Administration. E: Investigation, Writing and Original Draft Preparation. IAP: Software, Validation, Visualization. All authors have read and agreed to the published version of the manuscript.

Conflict of interests
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

REFERENCES

Aas, H. K., Uthus, M., & Løhre, A. (2024). Inclusive education for students with challenging behaviour: development of teachers' beliefs and ideas for adaptations through Lesson Study. *European Journal of Special Needs Education*, *39*(1), 64–78. https://doi.org/10.1080/08856257.2023.2191107

Ali, F., Dawood, A., Hussain, A., Alnasir, M. H., Khan, M. A., Butt, T. M., Janjua, N. K., & Hamid, A. (2024). Fueling the future: biomass applications for green and sustainable energy. *Discover Sustainability*, *5*(1). https://doi.org/10.1007/s43621-024-00309-z

Alzahrani, R. (2024). Studying the effectiveness of self-directed education in learning and teaching the otolaryngology module in an integrated-based curriculum. *Heliyon*, *10*(16), e36010. https://doi.org/10.1016/j.heliyon.2024.e36010

Andersen, L. B., Basballe, D. A., Buus, L., Dindler, C., Hansen, T. I., Hjorth, M., Iversen, O. S., Johannessen, C. M., Kanstrup, K. H., Lorentzen, R. F., Misfeldt, M., Musaeus, L. H., Nielsen, C. B., Petersen, M. G., Schrøder, V., & Slot, M. F. (2024). Infrastructuring digital literacy in K-12 education: A national case study. *International Journal of Child-Computer Interaction*, *42*(October). https://doi.org/10.1016/j.ijcci.2024.100697

Anderson, A., Ahmad, A., & Chang, S. (2024). Case-based learning for cybersecurity leaders: A systematic review and research agenda. *Information and Management*, *61*(7), 104015. https://doi.org/10.1016/j.im.2024.104015

Arab, F., & Saeedi, M. (2024). The effect of the case-based learning approach on the level of satisfactions and learning of nursing students in Iran: A randomized controlled trial. *Heliyon*, *10*(15), e35149. https://doi.org/10.1016/j.heliyon.2024.e35149

Bai, X., & Zhang, X. (2025). Artificial Intelligence-Powered Materials Science. *Nano-Micro Letters*, *17*(1). https://doi.org/10.1007/s40820-024-01634-8

Bintoro, H. S., Zaenuri, & Wardono. (2021). Application of information technology and communication-based lesson study on mathematics problem-solving

ability. *Journal of Physics: Conference Series*, *1918*(4). https://doi.org/10.1088/1742-6596/1918/4/042105

Daly, R., Spooner, M., Offiah, G., Flood, K., & Illing, J. (2024). Protocol for a realist review of case-based learning in undergraduate medical education. *International Journal of Educational Research Open*, *7*(May), 100366. https://doi.org/10.1016/j.ijedro.2024.100366

de Leng, B., Mannil, M., Patel, R., Pawelka, F., Seifarth, H., & Sundermann, B. (2024). Case-Based Collaborative Learning in Undergraduate Radiology Teaching — Are Essential Conditions for Group Discussions Met? *Academic Radiology*, *31*(9), 3853–3863. https://doi.org/10.1016/j.acra.2024.03.043

De Pilli, T., Alessandrino, O., & Baiano, A. (2024). Quantitative descriptive analysis as a strategic tool in research activities relating to innovative meat tenderisation technologies. *Heliyon*, *10*(11). https://doi.org/10.1016/j.heliyon.2024.e32618

Ding, C. (2022). Examining the context of better science literacy outcomes among U.S. schools using visual analytics: A machine learning approach. *International Journal of Educational Research Open*, *3*(August), 100191. https://doi.org/10.1016/j.ijedro.2022.100191

Eccott, L., Moulson, A., Atkinson, K., Livatino, S., Lewis, J., & Cairns, M. (2025). Lessons learned from the digital transformation of physiotherapy education: A phenomenological study. *International Journal of Osteopathic Medicine*, *56*. https://doi.org/10.1016/j.ijosm.2025.100759

Emblen-Perry, K. (2022). Auditing a case study: Enhancing case-based learning in education for sustainability. *Journal of Cleaner Production*, *381*(P1), 134944. https://doi.org/10.1016/j.jclepro.2022.134944

Gökcek Taraç, M., & Nale, T. (2025). Artificial intelligence in pediatric dental trauma: do artificial intelligence chatbots address parental concerns effectively? *BMC Oral Health*, *25*(1). https://doi.org/10.1186/s12903-025-06105-z

Gu, M. M., Huang, C. F., & Lee, C. K. J. (2023). Investigating university students' digital citizenship development through the lens of digital literacy practice: A Translingual and transemiotizing perspective. *Linguistics and Education*, *77*(November 2022), 101226. https://doi.org/10.1016/j.linged.2023.101226

Guan, L., Li, S., & Gu, M. M. (2024). AI in informal digital English learning: A meta-analysis of its effectiveness on proficiency, motivation, and self-regulation. *Computers and Education: Artificial Intelligence*, *7*(August), 100323. https://doi.org/10.1016/j.caeai.2024.100323

Halpin, H. (2025). Artificial intelligence versus collective intelligence. *AI and Society*, *0123456789*. https://doi.org/10.1007/s00146-025-02240-x

Hasan, R., Lukitasari, M., & Ernawati, Y. (2021). Students' achievement and teachers' perception in the implementation of lesson study-based cooperative learning. *Journal of Physics: Conference Series*, *1731*(1). https://doi.org/10.1088/1742-6596/1731/1/012004

Hidayat, T., & Santoso, S. (2021). Lesson study stimulated students critical thinking in Cell Biology courses. *Journal of Physics: Conference Series*, *1731*(1). https://doi.org/10.1088/1742-6596/1731/1/012016

Holl, C. (2024). The content intelligence: an argument against the lethality of artificial intelligence. *Discover Artificial Intelligence*, 4(1). https://doi.org/10.1007/s44163-024-00112-9

Kandaga, T., Dahlan, T., Gardenia, N., Darta, & Saputra, J. (2021). A lesson study to foster prospective teachers' disposition in STEM education. *Journal of Physics: Conference Series*, *1806*(1). https://doi.org/10.1088/1742-6596/1806/1/012107

Kim, S. L., & Kim, D. (2021). English learners' science-literacy practice through explicit writing instruction in invention-based learning. *International Journal of Educational Research Open*, 2. https://doi.org/10.1016/j.ijedro.2020.100029

Kumar, P., Sahani, J., Rawat, N., Debele, S., Tiwari, A., Mendes Emygdio, A. P., Abhijith, K. V., Kukadia, V., Holmes, K., & Pfautsch, S. (2023). Using empirical science education in schools to improve climate change literacy. *Renewable and Sustainable Energy Reviews*, *178*(March), 113232. https://doi.org/10.1016/j.rser.2023.113232

Kumar, V., Choudhary, S. K., & Singh, R. (2024). Environmental socio-scientific issues as contexts in developing scientific literacy in science education: A systematic literature review. In *Social Sciences and Humanities Open* (Vol. 9). Elsevier Ltd. https://doi.org/10.1016/j.ssaho.2023.100765

Liang, D. Y. (Danni), Chen, D. S., Abeysekera, D. R., O'Sullivan, D. H., Bray, D. J., & Keevill-Savage, I. (2024). Examining the adoption of technology-enhanced learning in universities and its effects on student performance, satisfaction, and motivation. *Computers and Education Open*, *7*(February), 100223. https://doi.org/10.1016/j.caeo.2024.100223

Maison, M., Darmaji, D., Kurniawan, D. A., Astalini, A., Dewi, U. P., & Kartina, L. (2019). Analysis of science process skills in physics education students. *Jurnal Penelitian Dan Evaluasi Pendidikan*, *23*(2), 197–205. https://doi.org/10.21831/pep.v23i2.28123

Moon, S., & Chang, S. J. (2024). Comparing the effects of patient safety education using design thinking and case based learning on nursing students' competece and professional socialization: A quasi-experimental design. *Heliyon*, *10*(9), e29942. https://doi.org/10.1016/j.heliyon.2024.e29942

Nasseri, A., Zhou, T., Ha, V., Zhu, J., Wu, D., & Ohyama, H. (2024). Students' perceptions of virtual interactive clinical case-based learning: A comparative study with three different cohorts. *Journal of Dental Sciences*, *19*(3), 1578–1586. https://doi.org/10.1016/j.jds.2023.12.018

Oberleiter, S., Fries, J., Schock, L. S., Steininger, B., & Pietschnig, J. (2023). Predicting cross-national sex differences in large-scale assessments of students' reading literacy, mathematics, and science achievement: Evidence from PIRLS and TIMSS. *Intelligence*, *100*. https://doi.org/10.1016/j.intell.2023.101784

Perea-Moreno, M. A., Samerón-Manzano, E., & Perea-Moreno, A. J. (2019). Biomass as renewable energy: Worldwide research trends. *Sustainability (Switzerland)*, *11*(3). https://doi.org/10.3390/su11030863

Putri Damayanti, L., & Sumarni, S. (2020). *The Effects of Lesson Study on Learning Community to the Learning Quality*.

Reddy, P., Chaudhary, K., & Hussein, S. (2023). A digital literacy model to narrow the digital literacy skills gap. *Heliyon*, *9*(4), e14878. https://doi.org/10.1016/j.heliyon.2023.e14878

Roorda, G., de Vries, S., & Smale-Jacobse, A. E. (2024). Using lesson study to help mathematics teachers enhance students' problem-solving skills with teaching

through problem solving. *Frontiers in Education*, 9. https://doi.org/10.3389/feduc.2024.1331674

Sanusi, I. T., Oyelere, S. S., & Omidiora, J. O. (2022). Exploring teachers' preconceptions of teaching machine learning in high school: A preliminary insight from Africa. *Computers and Education Open*, *3*(December 2021), 100072. https://doi.org/10.1016/j.caeo.2021.100072

Su, Y. (2023). Delving into EFL teachers' digital literacy and professional identity in the pandemic era: Technological Pedagogical Content Knowledge (TPACK) framework. *Heliyon*, *9*(6), e16361. https://doi.org/10.1016/j.heliyon.2023.e16361

Ulfa, Z., Irwandi, I., Syukri, M., Munawir, A., & Halim, A. (2021). Improving ISLE-based STEM learning outcomes for building the 21st century skills and characters through a lesson study: A case study on Torque and Moment of Inertia. *Journal of Physics: Conference Series*, *1882*(1). https://doi.org/10.1088/1742-6596/1882/1/012153

Uştuk, Ö., & Çomoğlu, İ. (2019). Lesson study for professional development of english language teachers: Key takeaways from international practices. *Journal on Efficiency and Responsibility in Education and Science*, *12*(2), 41–50. https://doi.org/10.7160/eriesj.2019.120202

Vígh, T. (2024). Development of research skills through research-focused microteaching lesson study in preservice teacher education. *Teaching and Teacher Education*, *145*. https://doi.org/10.1016/j.tate.2024.104618

Wallwey, C., & Kajfez, R. L. (2023). Quantitative research artifacts as qualitative data collection techniques in a mixed methods research study. *Methods in Psychology*, *8*. https://doi.org/10.1016/j.metip.2023.100115

Walmsley, T. G., Philipp, M., Picón-Núñez, M., Meschede, H., Taylor, M. T., Schlosser, F., & Atkins, M. J. (2023). Hybrid renewable energy utility systems for industrial sites: A review. *Renewable and Sustainable Energy Reviews*, *188*(February). https://doi.org/10.1016/j.rser.2023.113802

Wang, H. H., & Wang, C. H. A. (2024). Teaching design students machine learning to enhance motivation for learning computational thinking skills. *Acta Psychologica*, *251*. https://doi.org/10.1016/j.actpsy.2024.104619

Woranetsudathip, N., Yuenyong, C., & Nguyen, T. T. (2021). The innovative lesson study for enhancing students' mathematical ideas about addition and subtraction through open approach. *Journal of Physics: Conference Series*, *1835*(1). https://doi.org/10.1088/1742-6596/1835/1/012061

Ylipulli, J., Pouke, M., Ehrenberg, N., & Keinonen, T. (2023). Public libraries as a partner in digital innovation project: Designing a virtual reality experience to support digital literacy. *Future Generation Computer Systems*, *149*, 594–605. https://doi.org/10.1016/j.future.2023.08.001

Zahoor, N., Zopiatis, A., Adomako, S., & Lamprinakos, G. (2023). The micro-foundations of digitally transforming SMEs: How digital literacy and technology interact with managerial attributes. *Journal of Business Research*, *159*(February), 113755. https://doi.org/10.1016/j.jbusres.2023.113755