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The Effectiveness of the CERDAS Learning Media in STEAM-Integrated PjBL to Enhance Elementary Students' Critical Thinking and Collaboration Skills

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Abstract. The achievement of the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 7 (Affordable and Clean Energy), requires innovative science learning that develops students' critical thinking and collaboration skills while fostering awareness of renewable energy and environmental sustainability. However, science learning in elementary schools is often dominated by teacher-centered instruction, limiting students' opportunities to engage in authentic problem-solving and collaborative activities. This study aimed to examine the effectiveness of the CERDAS learning media (Creating Eco-Friendly Electronic Devices Powered by Solar Energy), implemented through a STEAM-integrated Project-Based Learning (PjBL) approach, in enhancing the critical thinking and collaboration skills of fifth-grade students. The study employed a pre-experimental one-group pretest-posttest design involving 30 fifth-grade students from SD Negeri Sambiroto 02, Semarang City, Central Java, Indonesia. Data on critical thinking skills were collected through pretests and posttests, while collaboration skills were assessed using observation sheets and project evaluation rubrics. The results revealed that students' critical thinking scores increased from 53.00 to 86.67, with an N-Gain score of 0.72, categorized as high. Students' collaboration scores also improved from 24.33 to 51.50, with an N-Gain score of 0.76, indicating a high level of improvement. Furthermore, the paired sample t-test yielded a significance value of 0.000 ($p < .001$), confirming that the improvements were statistically significant. These findings suggest that the CERDAS learning media is an effective innovation for transforming elementary science education by enhancing students' critical thinking and collaboration skills while supporting renewable energy literacy and sustainability awareness in line with the Sustainable Development Goals.

Keywords: CERDAS; critical thinking; collaboration; STEAM education; renewable energy

INTRODUCTION

Twenty-first-century elementary education can no longer be understood merely as a process of knowledge transmission; rather, it must be positioned as a means of developing learners' capacity to understand real-world problems, make evidence-based decisions, and act collaboratively in response to sustainability challenges. At the global level, SDG 4 emphasizes the importance of "inclusive and equitable quality education" and relevant and effective learning outcomes, while Target 4.7 explicitly requires all learners to acquire the knowledge and skills needed to promote sustainable development. At the same time, SDG 7 highlights access to affordable, reliable, sustainable, and modern energy, including an increased share of renewable energy in the global energy mix. Thus, science learning in elementary schools occupies a strategic position in bringing together learning quality, the development of twenty-first-century competencies, and early renewable energy literacy (Nations, 2015; Partnership for 21st Century Learning, 2019; Patrick Griffin & Esther Care, 2015; UNESCO, 2017).

The Education for Sustainable Development framework further strengthens this argument. UNESCO states that ESD empowers learners through knowledge, skills, values, attitudes, and behaviors so that they can act responsibly toward the environment, the economy, and society. However, UNESCO (2017, 2020) also indicates that the integration of climate and sustainability issues into education remains insufficient: globally, 47% of national curriculum frameworks from 100 countries make no reference to climate change; although approximately 40% of teachers feel confident teaching the cognitive dimension of climate change, only 20% are able to explain well how to take action. These data show that the main challenge is not merely to insert sustainability topics into the curriculum, but also to transform pedagogy so that students learn through action, reflection, and authentic problem-solving (UNESCO, 2017, 2020).

This need becomes even more urgent at the elementary school level. A UNESCO report on science and social science curricula in primary schools shows that, among more than 830 Grade 3 and Grade 6 curricula in 88 countries, 66% mention the environment, sustainability, and climate change at least once; however, the level of emphasis remains low to moderate in most curricula, and in 44% of curricula the emphasis is very low or even absent (Aaron & Marcia, 2026). UNESCO also stresses that early elementary grades require a stronger process of "greening the curriculum." This finding is important for the present article because the topic of solar energy and eco-friendly devices is not merely an additional subject matter but an entry point for contextualizing elementary science within the global sustainability agenda in a concrete and age-appropriate way (Aaron & Marcia, 2026).

From a pedagogical perspective, strengthening critical thinking and collaboration requires learning to move away from expository patterns toward active, open, and problem-based learning experiences (Krajcik & Blumenfeld, 2005; Patrick Griffin & Esther Care, 2015). The SDG 4 progress report shows that global learning outcomes remain a serious concern; from 2012 to 2022, the proportion of students reaching minimum proficiency in reading declined from 59% to 47% and in mathematics from 41% to 36% (United Nations, 2026). Although these data are global in scale, their main message is clear: improving access to education does not automatically produce high-quality learning. In the Indonesian context, a recent national survey of K–12 teachers also shows that classroom technology use is still largely directed toward instructional preparation efficiency, while barriers such as generic outputs, infrastructure gaps, and limited contextual fit continue to hinder pedagogical transformation (Aisyah et al., 2026).

Within this framework, STEAM and project-based learning are highly relevant. Recent literature positions STEAM as an interdisciplinary pedagogy that integrates science, technology, engineering, arts, and mathematics to build creative, contextual, and learner-centered experiences (Henriksen, 2014; Perignat & Katz-Buonincontro, 2019; Quigley et al., 2017). Meanwhile, studies and reviews on Project-Based Learning indicate that PjBL is increasingly viewed as a promising approach for expanding learning experiences, deepening student engagement, and responding to the need for twenty-first-century competencies (Bell, 2010; Chen & Yang, 2019; Kokotsaki et al., 2016; Pearlman & Thomas, 2000; Purnama Yani et al., 2024). Nevertheless, STEAM implementation also faces serious challenges, particularly in relation to teacher competence, rigid curriculum structures, and assessment complexity. Therefore, studies that combine concrete learning media with STEAM-integrated PjBL are needed so that conceptual discourse can be translated into operational classroom practice (Margot & Kettler, 2019; Purnama Yani et al., 2024; Sánchez & Cortés, 2024).

Empirically, several studies offer important insights while also revealing research gaps. Maker activities using IoT lab kits and gamification for energy awareness in European schools have shown positive acceptance among school communities and the potential of data- and artifact-based learning to build energy awareness (DeWaters & Powers, 2013; Mylonas et al., 2018; Zografakis et al., 2008). The STEAM for Social Good program for pre-university students demonstrates how interdisciplinary projects can foster design creativity, problem-solving, and sensitivity to social issues (Manikutty et al., 2022). In terms of collaboration, learning analytics studies indicate that high group performance cannot be explained solely by task division; rather, it depends on the synergy among communication, action, and shared orientation toward goals (Ouyang et al., 2022). Even among elementary students, long-term collaborative programs show that meaningful teamwork can be developed, although it requires consistent scaffolding and support from the learning ecosystem (Zha et al., 2025).

Nevertheless, these studies have not fully addressed the needs of the present article. First, many studies examine STEAM, PjBL, collaboration, or energy awareness separately, rather than as an integrated learning design. Second, most evidence comes from outside the Indonesian elementary school context, so pedagogical transfer cannot be assumed to occur automatically. Third, school-based energy research often focuses on awareness, simulation, or gamification, while few studies have tested concrete media based on simple solar-powered devices as the core of a learning project. Fourth, few studies simultaneously examine critical thinking and collaboration as two main outcomes within a single intervention that also targets renewable energy literacy. From this perspective, the study of the CERDAS learning media has a clear space for contribution: it does not merely add a new instructional medium, but tests a learning design that integrates sustainability, simple engineering, tangible products, and higher-order thinking competencies into a single pedagogical package (Margot & Kettler, 2019; Mejias et al., 2021; Perignat & Katz-Buonincontro, 2019).

The CERDAS learning media is understood as a learning medium/project in the form of Creating Eco-Friendly Electronic Devices Powered by

Solar Energy, namely media that encourages students to design or assemble simple electronic devices that use solar energy and emphasize eco-friendly principles. STEAM-integrated PjBL is defined as project-based learning that integrates science, technology, engineering, arts, and mathematics into real-world problem solving and product creation. Critical thinking is operationally positioned as students' ability to identify problems, analyze information, evaluate evidence, provide reasons, and draw logical conclusions or solutions. Collaboration is understood as the capacity to work together productively through communication, task coordination, shared responsibility, and group decision-making. Renewable energy literacy is understood as students' basic understanding of renewable energy sources - particularly solar energy - their benefits, applications in daily life, and relevance to sustainability (Dillenbourg, 1999; Facione, 1990; Johnson & Johnson, 2009; Mylonas et al., 2018).

Based on these theoretical and empirical considerations, this study aims to examine the effectiveness of the CERDAS media implemented through STEAM-integrated PjBL in improving the critical thinking and collaboration skills of fifth-grade elementary school students. The research questions are as follows: does the implementation of the CERDAS media improve students' critical thinking skills; does the implementation improve students' collaboration skills; and how does the integration of renewable energy issues through concrete media-based projects support more meaningful science learning? Hypothetically, this study expects that: H1, there is a significant improvement in students' critical thinking skills after the intervention; H2, there is a significant improvement in students' collaboration skills after the intervention; and H3, science learning that integrates solar energy projects will show additional pedagogical value in the form of increased relevance, engagement, and sustainability awareness among students. Thus, the novelty of this study lies in its pedagogical contribution (CERDAS media in STEAM-PjBL), empirical contribution (simultaneous measurement of two main outcomes), contextual contribution (Indonesian elementary science learning), and policy contribution (support for greening the curriculum and the implementation of SDG 4 and SDG 7 in elementary education) (Aaron & Marcia, 2026; Purnama Yani et al., 2024).

METHODS

This study employed a quantitative approach with a pre-experimental one-group pretest-posttest design. This design was used because the study aimed to examine the initial effectiveness of the CERDAS learning media (Creating Eco-Friendly Electronic Devices Powered by Solar Energy) in elementary science learning based on STEAM-integrated Project-Based Learning in improving students' critical thinking and collaboration skills. The one-group pretest-posttest design enables researchers to compare students' ability before and after the treatment within the same group, making it relevant for examining changes in learning outcomes resulting from the implementation of instructional innovation in a real classroom context (Campbell et al., 1963; Creswell, 2018).

Table 1. One-Group Pretest-Posttest Research Design

Group	Pretest	Treat.	Posttest
Fifth-grade students	O_1	X	O_2

Notes:
O1 = initial measurement of critical thinking and collaboration skills
X = learning using the CERDAS media based on STEAM-integrated PjBL
O2 = final measurement of critical thinking and collaboration skills

This design was selected because the study was conducted in one intact class, allowing the instructional intervention to take place naturally in accordance with the elementary school context. However, because this design did not involve a control group, the interpretation of the findings is directed toward the initial effectiveness of the CERDAS media in the classroom context under study, rather than toward a causal claim that is completely free from threats to internal validity (Campbell et al., 1963; Creswell, 2018).

The participants of this study were 30 fifth-grade elementary school students. Participants were selected using purposive sampling, namely the selection of subjects based on the suitability of learners' characteristics with the research objectives (Fraenkel et al., 2012). Fifth-grade students were selected because they are at a stage of cognitive development in which they begin to be able to conduct observations, provide simple reasoning, work in groups, solve contextual problems, and produce simple products through project activities.

The participant criteria in this study included active fifth-grade students from SD Negeri Sambiroto 02, Semarang City, Central Java, Indonesia who participated in the full sequence of learning using the CERDAS media, completed both the pretest and posttest, and were involved in group project activities. All students in the class were included so that the learning process could take place ecologically without disrupting the structure of the regular classroom. The use of an intact class in instructional research is considered relevant when researchers seek to examine the effectiveness of an intervention in a real educational setting (Creswell, 2018).

The independent variable in this study was the use of the CERDAS learning media implemented through the STEAM-integrated Project-Based Learning approach. The dependent variables consisted of two aspects: students' critical thinking skills and collaboration skills.

The CERDAS media was designed as project-based learning media that invited students to create simple eco-friendly electronic devices using solar energy. Project-based learning is relevant because it positions students as active subjects involved in planning, investigation, product development, testing, revision, and presentation of results (Bell, 2010; Pearlman & Thomas, 2000). STEAM integration in the project enables students to connect science, technology, engineering, arts, and mathematics concepts in solving real-world problems (Bybee, 2013a; Capraro et al., 2013).

The research procedure was carried out in three main stages: preparation, implementation, and data analysis. In the preparation stage, the researcher developed learning materials, the CERDAS media, student worksheets, critical thinking test instruments, collaboration observation sheets, and project assessment rubrics. Instrument development was based on the theoretical constructs of critical thinking and collaboration so that the indicators measured had a clear conceptual foundation (Facione, 1990; Partnership for 21st Century Learning, 2019).

In the implementation stage, students were first given a pretest to measure their initial critical thinking ability. Initial collaboration skills were observed through simple group activities before the main project was conducted. Students then participated in learning using the CERDAS media through the Project-Based Learning syntax integrated with the STEAM approach. The PjBL model was used because it is characterized by authentic problem-based learning, in-depth investigation, active student engagement, collaboration, reflection, and tangible products (Bell, 2010; Pearlman & Thomas, 2000).

The learning stages began with the presentation of a contextual problem concerning the need for clean and eco-friendly energy. The teacher posed a driving question, for example: how can we make a simple device that uses solar energy to support daily life? This question became the basis for students to design the project. Students then worked in groups to design products, select materials, develop plans, create prototypes of simple solar-powered electronic devices, test the function of the devices, make improvements, and present their project results in front of the class.

STEAM integration was carried out through the elements of science, technology, engineering, arts, and mathematics. The science element was reflected in students' understanding of solar energy and energy transformation. The technology element appeared in the use of solar panels and simple electronic components. The engineering element was evident in the process of designing, assembling, testing, and improving prototypes. The arts element appeared in visual design, neatness, and product creativity. The mathematics element was used in simple measurements, size comparisons, material requirement calculations, and interpretation of test results. This integration is consistent with the view that STEAM can enrich science learning by connecting academic concepts with creativity, design, and real-world problem solving (Bybee, 2013a; Yakman, 2008).

At the end of the learning process, students were given a posttest to measure the improvement in their critical thinking skills. Collaboration skills were assessed using observation sheets and project rubrics during the group work process. Data from the pretest, posttest, observations, and project assessment were then analyzed quantitatively.

The research instruments consisted of a critical thinking skills test, a collaboration skills observation sheet, and a CERDAS project assessment rubric. The critical thinking test was developed in the form of contextual essay questions related to solar energy, renewable energy, the environment, and simple problem solving. Essay questions were used because they allow students to provide reasons, analyze information, evaluate solutions, and draw evidence-based conclusions.

The indicators of critical thinking skills referred to six main aspects: interpretation, analysis, evaluation, inference, explanation, and self-regulation (Ennis, 2011; Facione, 1990). These six indicators were adapted to the characteristics of elementary school students and the context of the CERDAS project.

Table 2. Indicators of Critical Thinking Skills

Indicator	Description
Interpretation	Understand information, images, data, or solar-energy problems
Analysis	Explain relationships among parts of a problem or device design
Evaluation	Assess strengths, weaknesses, and feasibility of a solution
Inference	Draw conclusions from data or observations
Explanation	Explain scientific reasons behind decisions or answers
Self-reflection	Review errors, thinking processes, and improved solutions

Collaboration skills were measured using an observation sheet. In twenty-first-century learning, collaboration is not merely understood as group work, but as the ability to work effectively, respect differences, share responsibility, communicate, and solve problems together (Dillenbourg, 1999; Johnson & Johnson, 2009). Therefore, the collaboration indicators in this study included active participation, communication, responsibility, mutual respect, flexibility, and collaborative problem solving.

Table 3. Indicators of Collaboration Skills

Indicator	Description
Active participation	Involved in discussion, planning, and project work
Communication	Express ideas and respond clearly to peers
Responsibility	Carry out agreed roles and tasks
Mutual respect	Respect peers' opinions, ideas, and contributions
Flexibility	Accept feedback and adjust work strategies
Problem solving	Work together to solve project difficulties

The CERDAS project rubric was used to assess the quality of students' products and work processes. The assessed aspects included the accuracy of science concepts, tool functionality, design creativity, use of eco-friendly materials, group cooperation, and ability to present the product. Project assessment is important in PjBL because learning outcomes are reflected not only in test scores, but also in the process of investigation, product quality, revision ability, and students' argumentation regarding the products they developed (Bell, 2010; Pearlman & Thomas, 2000).

Instrument validity was established through expert judgment by experts in elementary science learning, instructional media, and educational evaluation. Expert validation was used to ensure the alignment of instrument items with the constructs being measured, learning objectives, characteristics of elementary school students, and the context of the CERDAS media. Content validity is an important aspect of instrument development because it indicates the extent to which instrument items represent the competency domain to be measured (Lawshe, 1975).

The validated aspects included content relevance, language clarity, measurability of indicators, contextual appropriateness of the items, and feasibility of the assessment rubrics. Instruments that received feedback from validators were revised before being used in the study. The reliability of the critical thinking test could be examined using Cronbach's alpha if the test items used graded scores. Cronbach's alpha is used to determine the internal consistency among items in an instrument (Cronbach, 1951). Meanwhile, the reliability of observation sheets and project rubrics could be strengthened through inter-rater agreement in order to reduce assessment subjectivity.

The data were analyzed using descriptive and inferential statistics. Descriptive statistics were used to calculate the mean, minimum score, maximum score, and standard deviation of the pretest and posttest results. Improvements in critical thinking and collaboration skills were analyzed using the Normalized Gain (N-Gain) formula. N-Gain was used to determine the degree of improvement in students' scores from before to after the treatment by considering the maximum possible score (Hake, 1998). The N-Gain formula is as follows:

$$\mathrm{N-Gain} = \frac{\text{Posttest Score} - \text{Pretest Score}}{\text{Maximum Score} - \text{Pretest Score}}$$

The interpretation of N-Gain refers to the following categories: an N-Gain value of ≥ 0.70 is categorized as high; $0.30 \leq$ N-Gain < 0.70 is categorized as moderate; and N-Gain < 0.30 is categorized as low (Hake, 1998).

Before hypothesis testing was conducted, the normality of the data was tested using the Shapiro-Wilk test. The normality test was conducted to determine whether the difference scores between the pretest and posttest met the assumption of normal distribution. The Shapiro-Wilk test is relevant for small to medium samples and is frequently used in educational research before determining whether parametric tests should be applied (Shapiro & Wilk, 1965).

If the data were normally distributed, the difference between pretest and posttest scores was tested using the Paired Sample t-Test. This test was used because the data came from the same group measured at two different times, namely before and after the treatment (Cohen, 2013; Creswell, 2018). The decision criterion was that if the significance value was less than 0.05, there was a significant difference between pretest and posttest scores. Conversely, if the significance value was greater than 0.05, there was no significant difference between the scores before and after the treatment.

The effectiveness of the CERDAS media was determined based on three main criteria. First, there was an increase in the mean score from pretest to posttest. Second, the N-Gain value was in the moderate or high category. Third, the Paired Sample t-Test showed a significant difference. In addition to statistical significance, the study could also be strengthened by reporting effect size to indicate the practical strength of the treatment effect in an educational context (Cohen, 2013).

This study was conducted by observing ethical principles in research involving elementary school-aged children. The researcher first obtained permission from the school and classroom teacher. Students' identities were kept confidential by using respondent codes or numbers. All project activities used simple tools and materials that were safe for elementary school students under teacher supervision. Documentation activities were used only for research and academic reporting purposes. The principles of consent, data confidentiality, and participant protection must be carefully observed because the research subjects were children (Creswell, 2018).

RESULTS AND DISCUSSION

Improvement in Students' Critical Thinking Skills

The descriptive analysis results showed an improvement in students' critical thinking skills after participating in learning using the CERDAS media based on STEAM-integrated PjBL. The mean pretest score for students' critical thinking skills was 53.00, while the mean posttest score increased to 86.67. This improvement indicates that, after participating in project-based learning, students were better able to understand problems, analyze information, evaluate solutions, draw conclusions, and explain scientific reasoning more logically.

Table 4. Improvement in Students' Critical Thinking Skills

Var.	Pre	Post	Diff.	N-G	Cat.
CT	53.00	86.67	33.67	0.72	High

Based on Table 4, the N-Gain value of 0.72 indicates that the improvement in students' critical thinking skills was in the high category. This finding suggests that the CERDAS media not only helped students understand the concepts of solar energy and energy transformation, but also encouraged them to use reasoning in solving real-world problems. The activities of designing, making, testing, and improving simple solar-powered electronic devices provided opportunities for students to think analytically and reflectively (Abrami et al., 2015; Dwyer et al., 2014; Facione, 1990).

This improvement can be explained by the characteristics of project-based learning. In PjBL, students do not merely receive information from the teacher; rather, they are involved in the processes of inquiry, decision-making, problem solving, and creation of tangible products. This process is consistent with Bell's (2010) view that PjBL can develop higher-order thinking because students are confronted with authentic problems that require exploration and problem solving, both independently and collaboratively. In addition, critical thinking skills develop when students are given opportunities to interpret information, analyze relationships among variables, evaluate alternative solutions, and draw evidence-based conclusions (Facione, 1990).

In the context of the CERDAS media, students learned that solar energy can be converted into electrical energy through a simple solar panel. However, learning did not stop at concept introduction. Students were asked to design simple devices, test whether the devices functioned, identify the causes of failure, and improve their designs. These activities became meaningful learning experiences because students connected science concepts with technology and engineering. This aligns with the STEAM approach, which emphasizes the integration of science, technology, engineering, arts, and mathematics in real-world problem solving (Bybee, 2013a; Capraro et al., 2013).

Pedagogically, the improvement in critical thinking scores also indicates that elementary school students actually have the potential to be engaged in higher-order thinking activities when learning is designed in a concrete, contextual, and developmentally appropriate manner. In this study, the CERDAS media served as a bridge between abstract concepts of renewable energy and direct experiences that students could observe. Thus, the concept of solar energy was not learned merely as memorized content, but became a basis for designing simple solutions to environmental problems (DeWaters & Powers, 2013; Zografakis et al., 2008).

Improvement in Students' Collaboration Skills

In addition to critical thinking skills, this study also measured students' collaboration skills during the project-based learning process. The analysis showed that the mean collaboration score increased from 24.33 in the initial measurement to 51.50 in the final measurement. The N-Gain value of 0.76 indicates an improvement in the high category.

Table 5. Improvement in Students' Collaboration Skills

Var.	Initial	Final	Diff.	N-G	Cat.
Collab	24.33	51.50	27.17	0.76	High

The improvement in collaboration skills indicates that learning using the CERDAS media successfully created a learning situation that required students to work together actively. In the project process, students could not complete the task individually. They needed to discuss, divide roles, express ideas, respect peers' opinions, resolve differences, and take responsibility for the group's work. Thus, collaboration developed not simply because students were placed in groups, but because the task structure required positive interdependence among group members (Dillenbourg, 1999; Johnson & Johnson, 2009; OECD, 2019).

This finding is consistent with the twenty-first-century skills framework, which positions collaboration as one of the main competencies that should be developed from elementary education onward. Collaboration includes the ability to work effectively in teams, respect diverse opinions, be flexible, share responsibility, and contribute to common goals. In CERDAS learning, these indicators were evident when students designed prototypes, selected materials, tested the devices, and presented the project results.

Project activities also gave students opportunities to experience social negotiation. For example, when a prototype did not function properly, students had to discuss the causes of the problem, identify which part of the circuit needed improvement, and decide on a revision strategy. Such situations encouraged students to learn to listen, express opinions rationally, and accept feedback from peers. In other words, collaboration in this study was not understood merely as working together, but as a socio-cognitive process that supported problem solving (Dillenbourg, 1999; Ouyang et al., 2022).

The improvement in collaboration skills was also closely related to the characteristics of PjBL. According to Pearlman & Thomas (2000), project-based learning enables students to work in investigative situations that require planning, cooperation, and product completion. Through the CERDAS project, students gained more authentic learning experiences because they did not simply answer questions, but produced products that could be tested and presented. This strengthens the role of PjBL as an approach relevant to developing both academic and social competencies.

Effectiveness Test Results of the CERDAS Media

To determine whether the improvements in students' critical thinking and collaboration skills were statistically significant, a Paired Sample t-Test was conducted. This test was used because the data came from the same group measured at two different times, namely before and after the treatment. The test results showed a significance value of 0.000 in the statistical output, which in APA Style reporting is written as $p < .001$. This means that there was a significant difference between the scores before and after learning using the CERDAS media.

Table 6. Results of the Paired Sample t-Test

Variable	Comparison	Sig.	Interpretation
Critical thinking	Pretest-Posttest	0.000	Significant
Collaboration	Initial-Final	0.000	Significant

Based on Table 6, the improvement in students' critical thinking and collaboration skills was not only descriptively observable, but also statistically significant. Thus, the CERDAS media can be considered effective in improving both skills in the classroom context studied. However, because this study used a pre-experimental one-group pretest-posttest design, claims of effectiveness should be stated proportionally. The findings indicate strong initial effectiveness, but further research involving a control group is still needed to strengthen causal conclusions.

Substantively, the effectiveness of the CERDAS media can be explained through three main mechanisms. First, the CERDAS media presents real-world problems closely related to renewable energy and environmental issues (DeWaters & Powers, 2013; UNESCO, 2017, 2020). Second, the STEAM-integrated PjBL approach enables students to integrate science, technology, engineering, arts, and mathematics concepts into a coherent learning activity. Third, the project process requires students to think critically and collaborate at the same time, allowing both skills to develop simultaneously.

Discussion

The findings show that the use of the CERDAS learning media (Creating Eco-Friendly Electronic Devices Powered by Solar Energy), integrated with the STEAM-based Project-Based Learning approach, had a positive impact on improving the critical thinking and collaboration skills of fifth-grade elementary school students. The increase in critical thinking scores from 53.00 to 86.67, with an N-Gain value of 0.72, indicates an improvement in the high category. Meanwhile, collaboration skills increased from 24.33 to 51.50, with an N-Gain value of 0.76, which also falls into the high category. The N-Gain category refers to Hake's interpretation, in which an improvement is categorized as high when the N-Gain value is $\geq$ 0.70 (Hake, 1998). The Paired Sample t-Test showed a significance value of 0.000, which in APA Style should be written as $p < .001$; therefore, it can be stated that there was a significant difference between the pre-treatment and post-treatment conditions.

The improvement in students' critical thinking skills can be explained by the characteristics of the CERDAS media, which positions students as active subjects in learning. Students did not merely receive explanations about solar energy, energy transformation, or renewable energy; instead, they were directly involved in designing, making, testing, evaluating, and improving simple solar-powered electronic devices. These activities are consistent with the concept of critical thinking as the ability to interpret, analyze, evaluate, infer, explain, and self-regulate in making decisions based on reasons and evidence (Facione, 1990).

In the CERDAS learning process, students were faced with real situations, such as when a device did not turn on, when cable connections were inaccurate, when the solar panel position was not optimal, or when sunlight intensity was insufficient. These situations encouraged students to identify problems, find causes, compare alternative solutions, and draw conclusions based on observations. This process shows that critical thinking develops not through memorization of concepts, but through learning experiences that require reasoning, evaluation, and reflection (Ennis, 2011; Facione, 1990).

The effectiveness of the CERDAS media is also closely related to the Project-Based Learning approach. Project-based learning provides students with opportunities to learn through authentic problems, in-depth investigation, group work, product creation, and presentation of results. These characteristics make PjBL relevant for developing students' higher-order thinking and social skills (Bell, 2010; Chen & Yang, 2019; Kokotsaki et al., 2016). In this study, the project of making simple solar-powered devices was not merely a final assignment, but the core of the learning process that connected science concepts with real practice.

From the STEAM perspective, the CERDAS media has strength because it integrates the elements of science, technology, engineering, arts, and mathematics into one learning activity. The science element appeared in students' understanding of solar energy and energy transformation. The technology element emerged through the use of solar panels and simple electronic components. The engineering element was visible when students designed, assembled, tested, and improved prototypes. The arts element appeared in product design, neatness, and creativity. The mathematics element was used when students made simple measurements, compared material sizes, and estimated component needs. This integration is in line with the view that STEAM can help students connect academic concepts with creativity, design, technology, and real-world problem solving (Bybee, 2013b; Capraro et al., 2013; Henriksen, 2014; Perignat & Katz-Buonincontro, 2019).

The improvement in students' collaboration skills also indicates that the CERDAS media successfully created a learning environment that encouraged productive social interaction. In the CERDAS project, students needed to discuss, divide tasks, respect peers' opinions, resolve differences, and take responsibility for group outcomes. Collaboration occurred not merely because students were placed in groups, but because the project structure required positive interdependence among group members. This is consistent with the twenty-first-century skills framework, which defines collaboration as the ability to work effectively in teams, share responsibility, be flexible, and contribute to common goals (Dillenbourg, 1999; Johnson & Johnson, 2009).

Collaboration in CERDAS learning was also authentic because each student had opportunities to contribute according to their respective abilities. Some students were involved in drawing designs, selecting materials, assembling components, testing devices, recording results, and presenting products. Thus, the CERDAS project did not merely train group work formally, but built shared responsibility in solving problems. PjBL is indeed designed to develop cooperation, communication, independence, and problem-solving skills through meaningful project activities (Bell, 2010).

The findings of this study are also relevant to the Sustainable Development Goals agenda, particularly SDG 4 on quality education and SDG 7 on affordable and clean energy. SDG 4 emphasizes the importance of inclusive, quality education that equips learners with the skills needed to support sustainable development. Meanwhile, SDG 7 emphasizes the importance of access to modern, sustainable, and renewable energy. Through the CERDAS media, students not only learned science concepts but also began to understand the use of solar energy as an eco-friendly alternative energy source. Thus, CERDAS learning can be viewed as an early form of education for sustainable development in elementary schools (Nations, 2015; UNESCO, 2017, 2023; United Nations, 2026).

Theoretically, the findings strengthen the argument that critical thinking and collaboration skills are more effectively developed through active, contextual, and problem-based learning. Critical thinking cannot be sufficiently developed through lectures or routine exercises; it requires learning experiences that demand analysis, evaluation, and decision-making. Similarly, collaboration cannot be adequately formed through ordinary group assignments; it requires a work structure that encourages role division, communication, responsibility, and group reflection (Abrami et al., 2015; Dwyer et al., 2014).

Practically, the findings show that elementary school teachers can use the CERDAS media as an alternative innovation in science learning, particularly in the topic of energy and energy transformation. This media can help teachers transform initially abstract learning into more concrete, active, and meaningful learning. Energy learning is no longer delivered only through pictures or verbal explanations, but through direct experiences of making and testing simple solar-powered devices. This is consistent with the principle of PjBL, which emphasizes student involvement in investigation and the production of tangible work (Bell, 2010; Krajcik & Blumenfeld, 2005).

Nevertheless, the findings should be interpreted proportionally because the design used was a pre-experimental one-group pretest-posttest design. This design did not involve a control group, so the improvement in learning outcomes cannot be completely separated from possible external influences such as prior learning experiences, student motivation, teacher effects, or test repetition effects. Therefore, the most appropriate claim is that the CERDAS media demonstrated strong initial effectiveness in the classroom context studied. Future studies are recommended to use quasi-experimental or experimental designs with a control group to strengthen causal evidence (Campbell et al., 1963; Creswell, 2018).

Overall, the CERDAS media based on STEAM-integrated PjBL has proven to be a potential innovation for elementary science learning. This media not only improves students' critical thinking and collaboration skills, but also introduces them to renewable energy and sustainability issues from an early age (DeWaters & Powers, 2013; UNESCO, 2017, 2020, 2023). Thus, CERDAS provides a pedagogical contribution to strengthening science learning that is active, contextual, collaborative, and relevant to twenty-first-century challenges.

CONCLUSION

Based on the findings, it can be concluded that the CERDAS learning media (Creating Eco-Friendly Electronic Devices Powered by Solar

Energy), implemented through the STEAM-integrated Project-Based Learning approach, is effective for use in elementary science learning. This media is able to create learning experiences that are more concrete, contextual, active, and meaningful for students. Through the activities of designing, making, testing, improving, and presenting simple solar-powered devices, students not only understand the concepts of energy and energy transformation, but are also engaged in scientific thinking and real-world problem-solving processes.

The implementation of the CERDAS media has been shown to contribute to the strengthening of students' critical thinking skills. This occurs because learning provides space for students to identify problems, analyze causes, evaluate alternative solutions, draw evidence-based conclusions, and reflect on the work process they undertake. Thus, learning is no longer centered on concept memorization, but moves toward learning that requires reasoning, argumentation, and decision-making.

In addition, the CERDAS media also promotes the improvement of students' collaboration skills. The project work process requires students to discuss, divide roles, respect peers' opinions, take responsibility for group tasks, and solve problems together. The collaboration formed in this learning is authentic because project success depends on the contribution of each group member.

Pedagogically, this study shows that the integration of STEAM and Project-Based Learning can be a relevant strategy for strengthening the quality of elementary science learning. The CERDAS media functions not only as a learning aid, but also as a vehicle for connecting science concepts with technology, engineering, design creativity, simple mathematics, and sustainability issues. Therefore, this media has the potential to support more applicable science learning aligned with the needs of twenty-first-century education.

This study also contributes to strengthening renewable energy literacy and environmental awareness from an early age. Through the use of solar energy in the learning project, students are introduced to the importance of clean energy, eco-friendly technology, and responsibility for sustainability. Thus, the CERDAS media is relevant to efforts to support quality education and sustainable development.

However, this study still has limitations because it was conducted with one group of students without involving a control group. Therefore, future research is recommended to use experimental or quasi-experimental designs with a broader range of participants. Future studies may also add qualitative data, such as student interviews, teacher reflections, in-depth observations, and product analysis, in order to obtain a more comprehensive understanding of the process of developing students' critical thinking and collaboration skills in CERDAS media-based learning.

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