The Effectiveness of SimBucket-Based Interactive E-LKPD with STAD in Enhancing Students' Conceptual Understanding

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Abstract: In order to improve students' conceptual grasp of alternative energy, this study examined the viability and efficacy of integrating a SimBucket-based interactive E-LKPD with the Student Teams Achievement Division (STAD) cooperative learning paradigm. The ADDIE model was used in the research's R&D methodology. Thirty-six senior high school students participated. Expert validation sheets, conceptual comprehension assessments, and student response questionnaires were used to gather data, which were then analyzed using normalized gain (N-Gain) and descriptive statistics. The designed E-LKPD received an 87.14% validation score. indicating that it was highly feasible. Student responses reached 90.76%, demonstrating excellent usability and engagement. Furthermore, the average N-Gain score of 0.83 (high category) indicated substantial improvement in students' conceptual understanding. These findings demonstrate that integrating SimBucket simulations with E-LKPD and the STAD model effectively supports conceptual learning. This study contributes to digital physics education by providing an innovative learning medium that visualizes abstract concepts while promoting active and collaborative learning.

Abstrak: Penelitian ini bertujuan menganalisis kelayakan dan efektivitas E-LKPD interaktif berbasis SimBucket yang diintegrasikan dengan model pembelajaran kooperatif tipe Student Teams Achievement Division (STAD) dalam meningkatkan pemahaman konsep siswa pada materi energi alternatif. Penelitian menggunakan pendekatan Research and Development (R&D) dengan model ADDIE yang meliputi tahap analisis, desain, pengembangan, implementasi, dan evaluasi. Subjek penelitian berjumlah 36 siswa sekolah menengah atas. Data dikumpulkan melalui lembar validasi ahli, tes pemahaman konsep, dan angket respons siswa, kemudian dianalisis menggunakan statistik deskriptif dan analisis normalized gain (N-Gain). Hasil penelitian menunjukkan bahwa E-LKPD yang dikembangkan memperoleh skor validasi sebesar 87,14% dengan kategori sangat layak. Respons siswa mencapai 90,76% dengan kategori sangat baik, yang mencerminkan tingkat keterlibatan, kemudahan penggunaan, dan keberterimaan media yang tinggi. Selain itu, nilai rata-rata N-Gain sebesar 0,83 berada pada kategori tinggi, yang menunjukkan peningkatan signifikan dalam pemahaman konsep siswa. Temuan ini menegaskan bahwa integrasi SimBucket dan model STAD efektif mendukung pembelajaran fisika yang interaktif, kolaboratif, dan berorientasi pada penguatan pemahaman konsep.

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A. Introduction

Recent advances in science and technology have changed education, among other facets of human existence. The Fourth Industrial Revolution's quick growth of digital technology has sped up the incorporation of technology into education, creating opportunities to develop innovative instructional media that support twenty-first-century learning competencies (Arrafi et al., 2025). In science education, digital technologies enable students to understand complex scientific concepts by overcoming limitations of time, space, and direct observation while providing more interactive and meaningful learning experiences (Haleem et al., 2022). Consequently, educational practices are shifting from teacher-centered instruction toward technology-enhanced, student-centered learning environments that promote active participation and conceptual understanding (Sailer & Homner, 2021). Nevertheless, despite these technological advances, physics education in Indonesian senior high schools continues to face significant challenges in facilitating meaningful conceptual learning (Purwana et al., 2025).

Physics plays a fundamental role in developing students' critical, logical, and systematic thinking skills because it explains natural phenomena through scientific concepts and reasoning (Fitriani et al., 2021). However, many physics topics remain difficult for students because they involve abstract concepts that cannot be directly observed, particularly topics related to alternative energy and energy transformation (Sari & Rahayu, 2022). Conventional instructional approaches that rely primarily on lectures and printed textbooks often fail to bridge the gap between theoretical knowledge and authentic scientific phenomena. As a result, students frequently memorize formulas without developing a deep conceptual understanding of the underlying principles.

Conceptual understanding is widely recognized as one of the primary goals of science education because it enables learners to interpret, organize, and apply scientific knowledge in various contexts. Schneider & Stern (2021) define conceptual understanding as learners' ability to construct meaningful knowledge through cognitive processes that involve interpreting, integrating, and applying information. Similarly, Nikat et al (2022) describe conceptual understanding as the ability to comprehend, classify, analyze, and explain scientific phenomena, while Sun & Nancy (2025) emphasize that conceptual understanding provides the foundation for developing mental models and solving physics problems effectively. According to the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001), Seven cognitive processes—interpreting, exemplifying, categorizing, summarizing, inferring, comparing, and explaining—can be used to evaluate conceptual comprehension. These indicators reflect students' ability to construct meaningful knowledge rather than simply recalling information. Therefore, improving conceptual understanding requires learning environments that actively engage students in exploring, discussing, and visualizing scientific concepts.

One promising approach for addressing this challenge is the use of digital simulation technology. Interactive simulations allow students to visualize invisible or abstract physical phenomena, manipulate variables, and immediately observe the consequences of their

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actions, thereby promoting deeper conceptual learning (Ula et al., 2025). Previous studies have consistently demonstrated that simulation-based learning enhances students' motivation, engagement, and learning outcomes (Kristanto & Dewi, 2024). Among various simulation platforms, SimBucket provides virtual experiments in physics and astronomy that enable students to explore scientific concepts interactively through web-based simulations (Martinez et al., 2021). Because SimBucket is easily accessible through digital devices, it offers considerable potential for supporting physics learning in schools with different levels of technological infrastructure.

However, digital simulations alone cannot maximize learning outcomes without an instructional strategy that actively engages students in collaborative knowledge construction. Cooperative learning, particularly the Student Teams Achievement Division (STAD) model, encourages students to learn through structured teamwork, peer discussion, and shared responsibility for achieving learning goals (Wulandari, 2022). Previous studies have shown that STAD significantly improves academic achievement, collaboration, and student participation (Freeman et al., 2014). Likewise, integrating simulation media with cooperative learning has been reported to increase students' learning outcomes and classroom engagement (Dwiantari et al., 2024). These findings suggest that combining interactive digital simulations with cooperative learning may provide a more comprehensive learning environment that simultaneously supports cognitive development and social interaction.

Despite these promising findings, several important research gaps remain. First, previous studies have generally examined digital simulations and cooperative learning as separate instructional approaches, with limited attention to their integrated implementation. Second, studies investigating interactive E-LKPD have largely focused on digital worksheets or simulation-based learning independently, rather than embedding web-based simulations within structured collaborative learning activities. Third, relatively few studies have explored this integrated approach in teaching alternative energy, a topic that requires students to visualize complex energy transformation processes and develop higher levels of conceptual understanding (Hoque et al., 2022; Banda & Nzabahimana, 2021). In addition to these theoretical gaps, a preliminary needs analysis conducted at State Senior High School 6 Bengkulu City revealed that 89.05% of students expressed the need for more engaging and technologically assisted educational materials to improve their comprehension of alternative energy concepts. These findings demonstrate both a practical need and a clear opportunity for developing more effective digital learning resources.

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To address these gaps, this study developed an interactive E-LKPD integrating SimBucket simulations with the STAD cooperative learning model. The novelty of this study lies not merely in combining these instructional components, but in designing an integrated digital learning environment in which interactive simulations, structured electronic worksheets, and collaborative learning activities function synergistically to enhance students' conceptual understanding of alternative energy. This integrated framework simultaneously supports scientific visualization, guided inquiry, collaborative problem-solving, and conceptual knowledge construction, thereby extending previous studies that have examined these components independently. Consequently, this study contributes both theoretically by enriching the literature on technology-enhanced cooperative learning and practically by providing an innovative instructional medium for physics education.

Considering the recognized research gaps and the suggested instructional innovation, The purpose of this project is to create an interactive E-LKPD based on SimBucket that is connected with the STAD cooperative learning paradigm and to assess its viability and efficacy in improving students' conceptual comprehension. of alternative energy, and students' responses to its implementation. Through this investigation, the study seeks to provide empirical evidence supporting the integration of digital simulations, interactive worksheets, and cooperative learning in physics education.

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B. Method

The five systematic steps of the ADDIE instructional design model—analysis, design, development, implementation, and evaluation—were used in this study's R&D methodology. The ADDIE paradigm was chosen because it offers a systematic, iterative framework for creating, validating, implementing, and evaluating educational products, thereby ensuring that the developed instructional media meet pedagogical, technical, and learning requirements (Branch, 2009). Additionally, because of its adaptability, the model has been frequently used in studies on educational development in accommodating continuous revisions throughout the development process and its effectiveness in producing learning media that align with users' needs (Kustandi et al., 2021; Hasan & Larumbia, 2021). The R&D approach was considered appropriate because this study not only developed an interactive E-LKPD but also evaluated its feasibility and effectiveness in enhancing students' conceptual understanding of alternative energy (Sugiyono, 2013). Throughout the development process, formative evaluation was conducted at each ADDIE phase to ensure continuous product refinement prior to classroom implementation. The overall research flow based on the ADDIE model is illustrated in Figure 1.

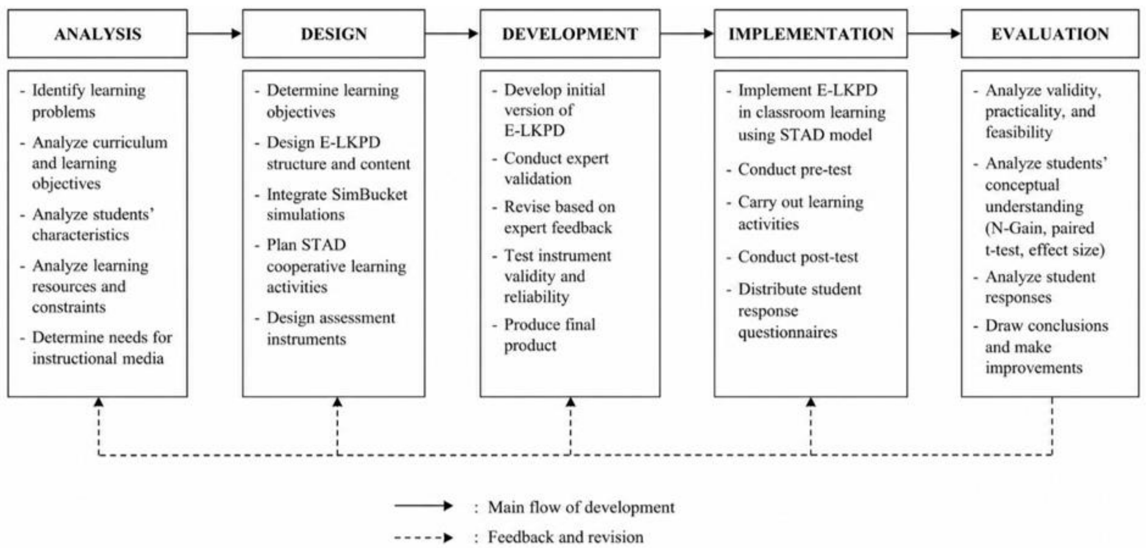

Figure 1. Research Flow Based on the ADDIE Model

Figure 1 illustrates the systematic development process adopted in this study. The research began with identifying instructional needs and learning problems, followed by designing the interactive E-LKPD, developing and validating the product, implementing it in classroom learning, and conducting formative and summative evaluations to ensure The developed learning media's viability, usefulness, and efficiency.

The study was conducted at State Senior High School 6 Bengkulu City during the second semester of the school year 2025–2026. 36 Grade 10 students made up the participants; they were chosen using a straightforward random sampling method. One class was randomly selected from the population of Grade 10 students because all classes

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followed the same curriculum, learning objectives, and instructional schedule, thereby providing comparable learning conditions. Prior to data collection, permission was obtained from the school, and all participants voluntarily participated in the study while maintaining the confidentiality of their personal information throughout the research process.

Three research instruments were employed to evaluate the developed product. The first instrument was an expert validation sheet completed by subject-matter and instructional media specialists to evaluate the interactive E-LKPD's media usability, instructional design, presentation quality, language appropriateness, and material correctness. In order to assess students' performance across the seven conceptual understanding indicators—interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining—proposed by Anderson & Krathwohl (2001), the second tool was a conceptual understanding test that was given as a pre-test and post-test. A student response questionnaire with a five-point Likert scale was the third tool used to assess students' perceptions regarding the attractiveness, usability, interactivity, and overall learning experience provided by the developed E-LKPD.

Internal consistency reliability was assessed using Cronbach's Alpha prior to classroom deployment, while content validity of the research instruments was assessed using Aiken's V to make sure each question appropriately reflected the desired concept. Descriptive statistics were then used to examine the data in order to ascertain the viability of the product and the reactions of the pupils. Students' pre-test and post-test scores were compared using normalized gain (N-Gain) analysis to look for gains in conceptual comprehension. Before conducting inferential analysis, the data were tested for normality to verify statistical assumptions. The statistical significance of the observed improvement was then assessed using a paired-samples t-test, and the size of the instructional impact was determined using Cohen's d. When taken as a whole, these analyses provide thorough proof of the viability, efficacy, and educational impact of the SimBucket-based interactive E-LKPD combined with the Student Teams Achievement Division (STAD) cooperative learning paradigm.

C. Result

Preliminary Analysis

The preliminary analysis was carried out to determine the learning requirements of the children and curriculum requirements as the basis for developing the SimBucket-based interactive E-LKPD. Classroom observations, physics instructor interviews, and a needs analysis were used to collect data analysis questionnaire administered to Grade 10 students at State Senior High School 6 Bengkulu City. The analysis focused on current learning practices, the use of instructional media, and students' expectations for technology-supported learning.

a. Needs Analysis

The needs analysis showed that lectures and printed teaching materials continued to be the main methods of physics instruction, limiting students' opportunities to actively explore concepts and visualize abstract phenomena. As a result, students experienced difficulties in understanding alternative energy concepts and required more interactive learning media.

Table 1. Results of the Analysis of Learners' Needs

No	Aspect	Percentage (%)
1	Physics Learning Conditions	87.90
2	Current Use of Teaching Materials	88.13
3	Need for Interactive Media	89.80
4	Accessibility & Flexibility Requirements	90.00
5	Learning Experience & Collaboration Needs	89.43
Average		**89.05**

As shown in Table 1, all aspects obtained percentages above 87%, with an average score of 89.05%, indicating a high demand for interactive digital learning media. The highest score was found in accessibility and flexibility (90.00%), followed by the need for interactive media (89.80%). These findings demonstrate that students expect learning resources that are accessible, interactive, and capable of supporting collaborative learning while facilitating conceptual understanding.

b. Curriculum Analysis

The curriculum analysis showed that the Merdeka Curriculum emphasizes student-centered learning, collaboration, inquiry, and the integration of digital technology into classroom instruction. However, classroom observations revealed that physics learning remained largely teacher-centered and relied mainly on textbooks, making it difficult for students to understand abstract concepts such as alternative energy. Therefore, the development of a SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model was considered appropriate to support curriculum implementation by providing interactive visualization, collaborative learning activities, and technology-enhanced instruction aimed at improving students' conceptual understanding

Development of the SimBucket-Based Interactive E-LKPD

a. Product Design

Based on the results of the preliminary analysis, a SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model was designed to facilitate students' conceptual understanding of alternative energy. The product was structured to align with the learning outcomes of the Merdeka Curriculum and the indicators of conceptual understanding. The E-LKPD consists of three main sections: the introductory

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section, the core learning activities, and the closing section. The introductory section includes the cover, learning objectives, instructions for use, and student identity. The core section contains concept explanations, SimBucket simulation activities, collaborative learning tasks based on the STAD model, and guided exercises. The closing section provides evaluation activities, learning reflection, and feedback to assess students' conceptual understanding. The overall structure of the developed interactive E-LKPD is presented in Figure 2.

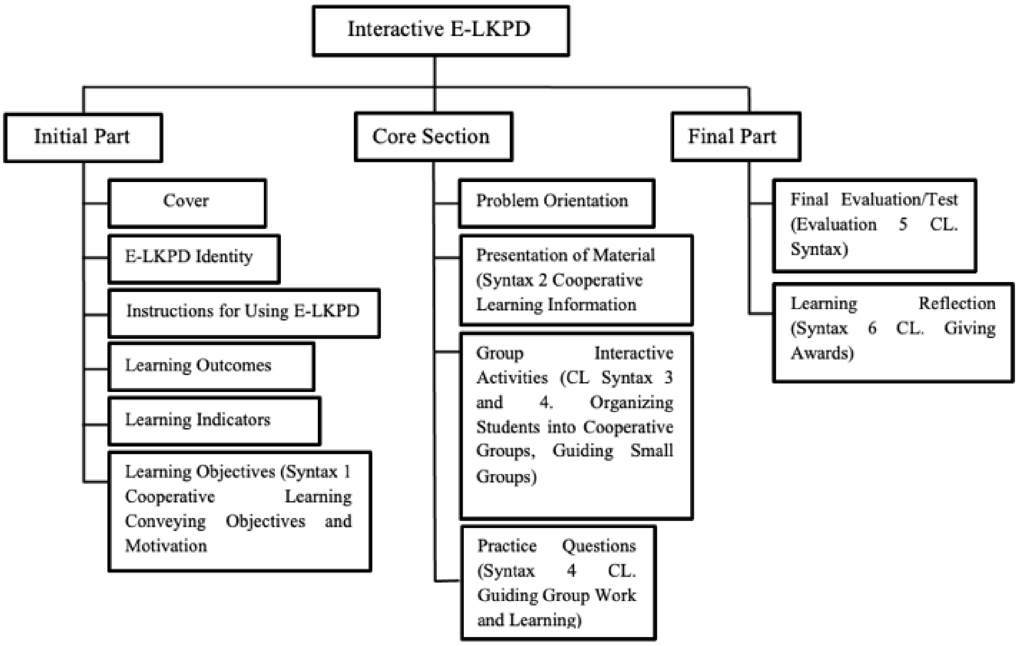

Figure 2. Design of the SimBucket-Based Interactive E-LKPD

Figure 2 illustrates the overall structure of the interactive E-LKPD, showing the sequence of learning activities from introduction to evaluation. The design integrates SimBucket simulations with STAD cooperative learning syntax, enabling students to explore concepts interactively, collaborate with peers, and construct conceptual understanding through structured learning activities.

b. Product Development

The product was developed using the Liveworksheets platform to create a web-based interactive E-LKPD that could be accessed through computers and mobile devices. SimBucket simulations were embedded into the learning activities to provide dynamic visualization of alternative energy concepts, allowing students to observe scientific phenomena and interact directly with simulation-based tasks. The developed E-LKPD also incorporates collaborative discussion activities, practice exercises, and formative assessments designed according to the STAD cooperative learning model. As a result, the learning media combines digital visualization, interactive worksheets, and cooperative

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learning within a single instructional environment. The interface of the developed E-LKPD is presented in Figure 3.

Figure 3. Interface of the Developed SimBucket-Based Interactive E-LKPD

Figure 3 presents several interface components of the developed interactive E-LKPD, including the cover page, learning activities, and evaluation section. The interface was designed to be simple, attractive, and easy to navigate, enabling students to access learning materials, complete simulation-based activities, and participate in collaborative learning more effectively.

Product Validation

a. Expert Validation

The feasibility of the developed SimBucket-based interactive E-LKPD was evaluated through expert validation involving three validators with expertise in physics education, instructional media, and educational technology. The validation process assessed three main aspects, namely content suitability, language quality, and media design. The experts' recommendations were subsequently utilized to edit and improve the work before to its deployment in classrooms.

Table 2. Expert Validation Results

Validator	Percentage (%)	Category
Validator 1	84.29	Highly Feasible
Validator 2	82.86	Feasible
Validator 3	95.71	Highly Feasible
Average	**87.14**	**Highly Feasible**

As presented in Table 2, the developed interactive E-LKPD achieved an average validation score of 87.14%, indicating that the product falls within the Highly Feasible

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category. Although slight differences were observed among the validators, all evaluation scores exceeded the minimum feasibility criterion, demonstrating a high level of agreement regarding the quality of the developed learning media. These findings indicate that the E-LKPD satisfies the essential requirements related to instructional content, language clarity, and media design, thereby confirming its suitability for implementation in physics learning. To provide a more detailed evaluation, the validation results for each assessment aspect are presented in Table 3.

Table 3. Validation Results by Assessment Aspect

Aspect	Percentage (%)	Category
Content Suitability	83.33	Feasible
Language	86.67	Highly Feasible
Media Design	90.48	Highly Feasible

The results indicate that media design received the highest validation score (90.48%), indicating that the interface, navigation, and integration of SimBucket simulations were considered appropriate for supporting classroom learning. Meanwhile, the language aspect achieved a score of 86.67%, indicating that the instructions and learning materials were clear and easy to understand. The content suitability aspect obtained the lowest score (83.33%), although it still met the feasibility criteria, indicating that minor revisions were required to improve the alignment between learning materials, learning objectives, and conceptual understanding indicators.

b. Product Revision

The expert validation process also generated several recommendations for improving the quality of the developed E-LKPD. These suggestions were accommodated through product revisions before the implementation stage to ensure ensured the educational materials fulfilled both technical and pedagogical requirements.

Table 4. Product Revisions Based on Expert Suggestions

No	Expert Suggestions	Revisions Made
1	Improve the consistency of learning objectives with the conceptual understanding indicators.	Learning objectives and activity instructions were revised to align with all conceptual understanding indicators.
2	Simplify several instructional sentences to improve readability.	Several explanations and activity instructions were rewritten using clearer and more concise language.
3	Improve the layout and consistency of fonts, spacing, and visual elements.	The interface was redesigned by standardizing typography, spacing, and page layout to enhance readability.
4	Strengthen the integration between SimBucket simulations and worksheet activities.	Simulation links and guiding questions were revised to better support students' exploration and discussion activities.

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The revisions improved both the pedagogical quality and usability of the developed E-LKPD. In particular, the refinement of instructional content, language, and interface design enhanced the coherence between learning objectives, simulation activities, and collaborative learning tasks. Consequently, the final version of the interactive E-LKPD was considered appropriate for classroom implementation and subsequent effectiveness testing.

Student Responses

Students were requested to fill out a response form in order to assess the usefulness and practicality of the created educational materials after participating in the learning activities using the SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model. The questionnaire assessed three aspects, namely presentation, content, and usefulness of the developed learning media. Table 5 displays the findings of the study of student responses.

Table 5. Results of the Student Response Questionnaire

No	Aspect	Percentage (%)
1	Presentation	91.11
2	Content	90.42
3	Usefulness	90.76
Average	**90.76**	**Very Good**

As presented in Table 5, the developed interactive E-LKPD received an average student response score of 90.76%, indicating a Very Good level of acceptance. The presentation aspect received the best rating (91.11%), indicating that students perceived the interface, layout, andorganization of learning activities as attractive and easy to follow. The content aspect also achieved a high score (90.42%), indicating that the learning materials were relevant, understandable, and supported conceptual learning. Furthermore, the usefulness aspect reached 90.76%, demonstrating that students considered the developed E-LKPD beneficial for understanding alternative energy concepts and facilitating collaborative learning. Overall, these results show that the created educational materials are useful, user-friendly, and well accepted by students during classroom implementation.

Effectiveness of the Developed E-LKPD

By comparing students' conceptual comprehension before to and during the use of the learning materials, the efficacy of the created interactive E-LKPD was assessed. Prior to the learning activities, students took a pre-test, and following the instructional intervention, they took a post-test. Normalized gain (N-Gain) and descriptive statistics were used to examine the increase in conceptual comprehension.

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a. Pre-test and Post-test Results

Table 6 shows a comparison of students' pre-test and post-test results for each conceptual knowledge indicator.

Table 6. Students' Pre-test and Post-test Scores

Indicator	Pre-test	Post-test
Interpreting	52.22	95.00
Inferring	50.56	95.56
Exemplifying	50.56	89.44
Summarizing	47.22	94.44
Classifying	41.11	88.33
Comparing	44.44	88.33
Explaining	36.11	86.67
Average	**46.03**	**91.11**

The results presented in Table 6 indicate a substantial improvement in students' conceptual understanding after using the developed interactive E-LKPD. The average score increased from 46.03 in the pre-test to 91.11 in the post-test, representing an increase of 45.08 points. Improvements were observed across all conceptual understanding indicators, indicating that the developed learning media effectively supported students in constructing a deeper understanding of alternative energy concepts.

N-Gain Analysis

To determine the magnitude of learning improvement, the pre-test and post-test scores were analyzed using the normalized gain (N-Gain). The results are presented in Table 7.

Table 7. N-Gain Analysis Results

Indicator	N-Gain	Category
Interpreting	0.89	High
Inferring	0.91	High
Exemplifying	0.78	High
Summarizing	0.89	High
Classifying	0.80	High
Comparing	0.78	High
Explaining	0.79	High
Average	**0.83**	**High**

As shown in Table 7, The average N-Gain score was 0.83, which is in the High range. The highest improvement was observed in the inferring indicator (0.91), while all remaining indicators also demonstrated high levels of improvement. These findings indicate that the developed interactive E-LKPD effectively enhanced students' conceptual understanding

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across all measured cognitive indicators rather than improving only specific aspects of learning. Overall, the consistently high N-Gain values demonstrate the effectiveness of integrating SimBucket simulations with the STAD cooperative learning model in supporting conceptual learning.

Normality Test

The pre-test and post-test scores were tested for normality using the Shapiro-Wilk test before the inferential analysis was carried out. The Shapiro-Wilk test was deemed suitable for evaluating the normality assumption because the sample size was less than 50 individuals (n = 36). Table 8 displays the normalcy test results.

Table 8. Shapiro–Wilk Normality Test Results

Variable	N	Shapiro–Wilk (W)	Sig. (p)	Interpretation
Pre-test	36	0.972	0.382	Normally distributed
Post-test	36	0.981	0.691	Normally distributed

As shown in Table 8, The pre-test (p = 0.382) and post-test (p = 0.691) significant values were both higher than the significance threshold of 0.05. These findings show that both datasets were normally distributed and satisfied the assumption of normality. Therefore, the pre-test and post-test scores were considered suitable for further analysis using the paired sample t-test to assess the statistical significance of the pupils' conceptual comprehension development.

Paired Sample t-Test

Following confirmation that the data were normally distributed, a paired sample t-test was used to determine whether students' conceptual understanding improved significantly after using the SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model was statistically significant. The results of Table 9 displays the results of the paired sample t-test.

Table 9. Paired Sample t-Test Results

Variable	Mean Difference	*t*	*df*	Sig. (2-tailed)	Interpretation
Pre-test – Post-test	-45.08	-22.746	35	<0.001	Significant

The paired sample t-test showed a statistically significant difference between students' pre-test and post-test scores ($t(35) = -22.746$, $p < 0.001$), as shown in Table 9. After the designed interactive E-LKPD was implemented, students' conceptual comprehension significantly increased, as indicated by the mean difference of 45.08. The null hypothesis was rejected since the significance value was less than the 0.05 cutoff, confirming that the

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SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model significantly improved students' conceptual understanding of alternative energy.

Effect Size (Cohen's d)

To complement the statistical significance analysis, To ascertain the extent of the instructional impact, Cohen's d was computed of the developed SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model. Unlike significance testing, which only indicates whether a difference exists, effect size provides information about the practical importance of the intervention. Table 10 displays the impact size analysis's findings.

Table 10. Effect Size (Cohen's d) Results

Comparison	Cohen's d	Effect Size Category	Interpretation
Pre-test – Post-test	2.35*	Large	Strong instructional effect

As presented in Table 10, the calculated Cohen's d shows a high effect size, indicating that students' conceptual comprehension significantly improved when the SimBucket-based interactive E-LKPD was combined with the STAD cooperative learning approach. This finding complements the paired sample t-test results by demonstrating that the observed learning gains were not only statistically significant but also educationally meaningful. Therefore, the developed learning media can be considered highly effective in supporting students' conceptual understanding of alternative energy through interactive visualization and collaborative learning activities.

Overall, the findings demonstrate that the SimBucket-based interactive E-LKPD integrated with the STAD cooperative learning model is feasible, practical, and effective for physics learning on the topic of alternative energy. The expert validation confirmed that the created educational materials that satisfied the necessary quality requirements, while the student response questionnaire indicated a high level of acceptance and usability. Furthermore, the substantial improvement in pre-test and post-test scores, supported by a high average N-Gain value, provides empirical evidence that the developed E-LKPD effectively enhances students' conceptual understanding. Collectively, these findings indicate that integrating interactive digital worksheets, simulation-based learning, and cooperative learning offers a comprehensive instructional approach that supports meaningful and technology-enhanced physics learning.

D. Discussion

The findings demonstrate that the SimBucket-based interactive E-LKPD integrated with the Student Teams Achievement Division (STAD) cooperative learning model is a feasible, practical, and effective instructional medium for teaching alternative energy in

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senior high school physics. The expert validation score of 87.14% confirms that the developed product

satisfies the required standards regarding content quality, language clarity, instructional design, and media presentation. This high level of feasibility reflects the effectiveness of The ADDIE model is a methodical development process that involves iterative analysis, design, development, implementation, and evaluation ensured continuous product refinement before classroom application. Consequently, the developed E-LKPD was not merely designed as a digital worksheet but as an integrated learning environment that aligns instructional objectives, interactive learning activities, assessment, and collaborative learning to facilitate conceptual understanding.

The high feasibility of the developed learning media can be explained by the systematic characteristics of the ADDIE instructional design model. Students' learning needs and curricular requirements were meticulously determined throughout the analysis phase to ensure that the product addressed authentic classroom problems. Subsequently, the design and development stages transformed these needs into structured learning activities supported by SimBucket simulations and the STAD cooperative learning model. Continuous expert validation further improved the instructional quality of the product by refining its content, language, and interface. This finding supports instructional design theory, which argues that systematic development enhances the validity, usability, and instructional quality of educational products by ensuring alignment among learning objectives, learner characteristics, instructional strategies, and assessment. Accordingly, the present finding is consistent with the study of Laily & Wiyatmo (2025), who reported that expert validation significantly improves the pedagogical quality and usability of digital learning media.

Beyond confirming its feasibility, the developed E-LKPD proved highly effective in improving students' conceptual understanding of alternative energy. The substantial increase in students' learning achievement, reflected by an average N-Gain of 0.83, indicates that the instructional intervention successfully promoted meaningful conceptual learning. This The complimentary integration is responsible for the improvement of three instructional components. First, the interactive E-LKPD guided students through structured learning activities that encouraged active exploration instead of passive information reception. Second, SimBucket simulations transformed abstract concepts of energy transformation into observable visual representations, enabling students to construct more accurate mental models. Third, the STAD cooperative learning model facilitated collaborative discussion and peer interaction, allowing students to negotiate ideas, justify scientific reasoning, and solve conceptual problems collectively. These complementary instructional components created meaningful learning experiences that supported deeper cognitive processing and conceptual knowledge construction.

The effectiveness of this instructional integration can be explained According to constructivist learning theory, knowledge is actively created through interaction with learning experiences and social environments. Rather than memorizing scientific facts,

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students actively explored simulation results, discussed alternative explanations, and reconstructed their understanding through collaborative inquiry. In addition, the findings are strongly supported by According to Mayer's Cognitive Theory of Multimedia Learning (Mayer, 2021), meaningful learning takes place when verbal explanations are integrated with relevant visual representations. The dynamic visualizations provided by SimBucket reduced cognitive load while helping students organize information into coherent mental models, thereby facilitating conceptual understanding and long-term knowledge retention. These theoretical perspectives explain why integrating interactive worksheets, digital simulations, and collaborative learning produced greater conceptual gains than conventional instruction.

Additionally, the current results support earlier research showing the efficacy of simulation-based and cooperative learning. Jullyantama et al (2024) and Damayanti et al (2025) concluded that integrating simulation media with cooperative learning significantly improves conceptual understanding and learning outcomes, as well as fostering student collaboration and creativity (Zaqiah et al., 2022). Similarly, Sari & Hidayat (2022) reported that technology-supported interactive learning media promote meaningful learning by encouraging students' active participation and conceptual engagement. However, the present study extends the existing literature by integrating interactive E-LKPD, SimBucket simulations, and the STAD cooperative learning model into a unified instructional framework rather than applying these instructional strategies independently. This integrated approach simultaneously supports scientific visualization, guided inquiry, collaborative knowledge construction, and structured learning activities, thereby providing broader instructional support for conceptual learning than previously reported.

The created educational materials' efficacy is further supported by improvements across all seven conceptual understanding indicators, Specifically, analyzing, illustrating, categorizing, summarizing, deducing, contrasting, and elucidating. The consistently high N-Gain values indicate that the instructional intervention strengthened multiple dimensions of conceptual understanding rather than isolated cognitive skills. Students demonstrated greater ability to interpret scientific information, classify alternative energy sources, summarize scientific principles, infer logical conclusions, compare energy technologies, and explain energy conversion processes. These improvements indicate that conceptual learning occurred comprehensively through the interaction of visualization, inquiry, and collaborative discussion. Such findings reinforce the argument that conceptual understanding develops most effectively when students actively construct knowledge through multiple forms of cognitive engagement rather than relying solely on teacher explanations.

Students also expressed highly positive perceptions of the developed learning media, as reflected by an average response score of 90.76%. This finding indicates that the interactive E-LKPD was perceived as attractive, easy to use, and beneficial for learning physics. The positive responses suggest that combining simulation-based activities with cooperative learning successfully created an engaging, student-centered learning

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environment. These findings can be interpreted through Self-Determination Theory (Ryan & Deci, 2020), which proposes that learning motivation increases when instructional environments support learners' autonomy, competence, and social relatedness. The interactive E-LKPD enabled students to learn independently through guided simulations while simultaneously encouraging collaboration through STAD activities. Consequently, students experienced greater engagement, confidence, and satisfaction during the learning process, which likely contributed to the observed improvement in conceptual understanding.

Overall, this study adds to the expanding corpus of research on technology-enhanced physics instruction by showing that the effectiveness of digital learning depends not only on the adoption of technology but also on its systematic integration within sound pedagogical frameworks. Unlike previous studies that emphasized simulations, digital worksheets, or cooperative learning separately, the present study integrates these components into a coherent instructional model that simultaneously supports cognitive, social, and technological dimensions of learning. Therefore, the findings provide empirical evidence that the integration of SimBucket simulations, interactive E-LKPD, and the STAD cooperative learning model represents an effective instructional approach for improving students' conceptual understanding of alternative energy while enriching the literature on digital and collaborative physics learning.

E. Implication

The findings of this study have both theoretical and practical implications for physics education. Theoretically, this study enriches the literature on technology-enhanced learning by demonstrating that integrating interactive E-LKPD, SimBucket simulations, and the STAD cooperative learning model provides a comprehensive instructional framework for improving students' conceptual understanding. Practically, the developed learning media offers an effective and feasible alternative for physics teachers to facilitate student-centered, collaborative, and technology-supported learning, particularly when teaching abstract topics such as alternative energy. These findings also provide a resource for educators and instructional designers creating cutting-edge digital learning materials that meet the needs of education in the twenty-first century.

F. Limitation and Suggestion for Future Research

There are a number of limitations to this study that should be noted. First, the study only included a limited sample from one senior high school, which may restrict how broadly the results may be applied to other educational settings. Second, the efficiency of the created interactive E-LKPD was evaluated only in terms of students' conceptual understanding of alternative energy, without examining its long-term impact on learning retention, higher-order thinking skills, or other learning outcomes.

Future research is advised to increase the generalizability by using larger and more varied samples from various educational contexts of the findings. Further studies may also investigate the integration of SimBucket-based interactive E-LKPD with other instructional models or emerging digital technologies and examine its effects on additional learning outcomes, such as critical thinking, problem-solving, scientific reasoning, and learning motivation. Such investigations would provide a more comprehensive understanding of the role of interactive digital learning media in physics education.

G. Conclusion

According to the study's findings, enhancing students' conceptual grasp of alternative energy with the SimBucket-based interactive E-LKPD combined with the STAD cooperative learning approach is very doable, useful, and successful. The developed learning media achieved a high expert validation score, received very positive responses from students, and significantly enhanced conceptual understanding, as indicated by the high N-Gain value. These results show that the incorporation of interactive digital worksheets, simulation-based learning, and cooperative learning provides a meaningful instructional approach that supports active participation, conceptual knowledge construction, and collaborative learning. Therefore, the developed E-LKPD can serve as an innovative instructional medium for physics learning and contribute to the advancement of technology-enhanced science education.

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