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Development of Physics E-LKPD Using Augmented Reality (AR) Based LOK-R Model on Students' Critical Thinking Skills

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Abstract
This study was conducted to develop an Electronic Student Worksheet (E-LKPD) based on Augmented Reality (AR) with the LOK-R (Literacy, Orientation, Collaboration, Reflection) model for Physics on thermodynamics material for grade XI students and to test its effectiveness in improving students' critical thinking skills. The research method used was Research and Development (R&D) with the 4D development model, but limited to the development stage (3D). Data collection methods involved non-test instruments (observation sheets and questionnaires) and a 10-item essay test. The results of the study indicate that: (1) The AR-based Physics E-LKPD with the LOK-R model is highly suitable for use in thermodynamics learning for high school students with a "Very Good" category based on expert validation; (2) The developed E-LKPD can improve students' critical thinking skills (N-gain = 0.73) with a "High" category; and (3) This E-LKPD is effective for learning thermodynamics topics regarding students' critical thinking skills.
Keywords: Augmented Reality (AR); Critical Thinking; E-LKPD; LOK-R Model, Thermodynamics.

INTRODUCTION

Education plays a vital role in shaping quality students who are able to adapt to the times. In implementing learning, educators are required to design learning plans, establish appropriate teaching strategies, and prepare supporting tools in the form of teaching materials, modules, and learning media. (Anggraini Hanifah Lubis, 2024)Teaching materials play a crucial role in supporting the learning process, both for educators and students. For educators, teaching materials are useful as a means of facilitating the delivery of material and increasing the effectiveness of learning in order to achieve goals optimally (Sani & Sani, 2014). Meanwhile, for students, teaching materials play a role in fostering learning motivation, increasing independence, and helping them understand and master learning concepts in detail (Adip, 20224). Student Worksheets, often referred to as LKPD, are considered an effective form of teaching material to support the learning process (Cahyadi, 2019).

LKPD is a guide for students to carry out learning activities actively, independently, and in a directed manner as the learning objectives are designed (Tur Rosidah et al., 2021). Along with the advancement of digital technology, LKPD has undergone a transformation into E-LKPD (Electronic Student Worksheet) which integrates various interactive multimedia elements (Ahmad et al., 2021). The use of E-LKPD enables the learning process to be more interesting, participatory, and interactive, in order to be able to increase student involvement and understanding of concepts (Kadek Aprilia Sri Wulandari & Putu Ari Dharmayanti, 2024). E-LKPD plays an important role in building interactions between educators and students, thus encouraging the creation of activity-centered learning and direct student involvement (Hidayat & Aripin, 2023; Ranti & Usmeldi, 2019). E-LKPD plays a role in supporting the implementation of 21st-century learning, oriented towards the development of digital literacy competencies, collaboration, creativity, effective communication, and critical thinking skills of students (Hidayat & Aripin, 2023). One of the learning models that is relevant to the characteristics of E-LKPD is LOK-R (Literacy, Orientation, Collaboration, and Reflection) (Latifah et al., 2024).

This model emphasizes a systematic learning process through four main stages, namely: (1) *Literacy* , where students read and identify the phenomena being studied; (2) *Orientation* , students are directed to understand the context of the problems faced; (3) *Collaboration* , students work together to discuss and solve problems; and (4) *Reflection* , students review the learning process and results to deepen their understanding of concepts (Anggraini Hanifah Lubis, 2024; Khasanah & Sholihah, 2024). The LOK-R model has been proven effective in increasing active student participation and developing higher-order thinking skills through learning that emphasizes literacy, orientation, collaboration, and reflection (Ansori et al., 2024). The application of AR in physics learning can provide a more interactive, realistic learning experience, tailored to everyday contexts . (Al-Ansi et al., 2023)AR technology integrates virtual objects into the real environment in *real time* , making the visualization easier for students to understand abstract physics concepts in a more realistic and meaningful way (Sanjaya, 2023).

Several previous studies have extensively examined the application of *Augmented Reality* (AR) as a medium for learning Physics (Javaheri et al., 2022; Volioti et al., 2022). The author's analysis of research distribution using *VosViewer* shows that topics related to Augmented Reality (AR) experienced a significant increase and reached a peak in 2022–2023. However, the results of the literature review indicate that no recent research has been found that specifically integrates the LOK-R model with Augmented Reality (AR) technology in the form of interactive E-LKPD for Thermodynamics material.

Several studies have shown that the application of AR in learning has the potential to increase learning motivation, strengthen concept retention, and develop students' critical thinking skills through interactive and contextual learning (Villegas & Sanchez Vianey Guadalupe Cruz, 2024; Yun et al., 2023; Yusa et al., 2023). Critical thinking skills are an essential competency that must be developed in Physics learning. However, various research results show that this ability is still relatively low, namely in analyzing, evaluating, and integrating Physics concepts in depth (Sundari & Sarkity, 2021). The results of the study reported that high school students in temperature and heat material showed low critical thinking skills, especially in the aspect of the ability to draw conclusions and provide further explanations for a phenomenon or concept being studied. The study (Ardiyanti & Nuroso, 2021)shows that the development of indicators of students' critical thinking skills is not optimal. This finding is in line with the results of the survey (Programme, Assessment, and Tables 2018) , which revealed that the critical thinking skills of students in Indonesia are below the international average (Setiani et al., 2024).

Physics learning in the Independent Curriculum should be oriented toward developing critical thinking skills through exploratory, collaborative, and scientific inquiry-based activities (Luturmas et al., 2022). However, the reality is that the learning process is still dominated by the teacher, using conventional lecture and practice approaches (Fiteriani 2021) . Visualization of abstract concepts is still limited, while the use of interactive technology has not been optimal (Yusa et al., 2023). This situation impacts students' low ability to connect Physics concepts to real-world phenomena, as well as their lack of training in critical and reflective thinking (OECD, 2019).

Various previous studies have highlighted efforts to improve critical thinking skills through the application of innovative models. The phenomenon-based learning model is a widely used approach , which has been proven effective in improving Physics learning outcomes and making it easier for students to understand concepts through their connection to real phenomena in the surrounding environment (Asfa & Herudin, 2023). The application of the guided inquiry model combined with PhET Interactive Simulations also shows a significant increase in critical thinking skills. The integration of interactive simulations into the learning process allows students to explore concepts independently and in depth, thereby encouraging the development of analytical skills and scientific reasoning (Mardiyanti & Jatmiko, 2022). In addition, the implementation of Project-Based Learning (PjBL) integrated with STEM based on *design thinking* has also been shown to improve students' critical thinking skills and collaborative abilities. This approach encourages students to design creative solutions to contextual problems through scientific thinking processes, team collaboration, and reflection on work results (Anggraini Hanifah Lubis, 2024). The Numbered Heads Together (NHT) cooperative learning model has also been proven effective in improving students' clarification and reasoning skills. Through structured group discussions, this model encourages each member to actively participate in expressing opinions, checking conceptual understanding, and developing logical and argumentative thinking skills (Anjariamsa & Sugianto, 2024). Although various previous studies have contributed to improving critical thinking skills through the implementation of innovative models and media, most of them have not integrated the LOK-R learning model with Augmented Reality (AR) technology in the form of interactive E-LKPD. The novelty of this research is the development of Physics E-LKPD based on the AR-integrated LOK-R model, which allows students to visualize Thermodynamic concepts in a realistic, contextual, and interactive manner. This innovation is expected to strengthen students' critical thinking skills through meaningful learning experiences based on digital exploration. Based on the description, this study aims to: (1) develop a Physics E-LKPD based on the LOK-R model integrated with Augmented Reality (AR) on the topic of Thermodynamics for class XI; and (2) analyze the effectiveness of the E-LKPD in improving students' critical thinking skills.

METHODS

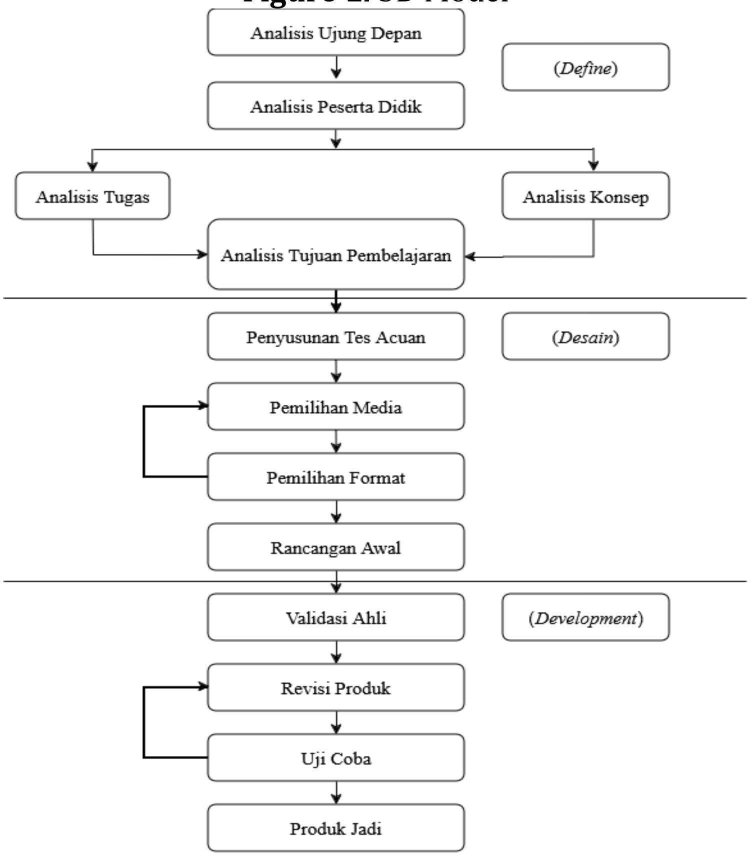
This study adopts the Research and Development (R&D) method with a focus on product development and validation, specifically following the Thiagarajan 4D model, which consists of four stages: define, design, develop, and disseminate (Fiteriani et al., 2021; Yuberti & Saregar, 2020). The goal is to develop an Augmented Reality (AR)-based Physics E-LKPD (Electronic Student Worksheets) utilizing the LOK-R model for teaching Thermodynamics material to grade XI students. However, the scope of this research is confined to the first three stages—define, design, and develop covering product validation, evaluation, and necessary revisions (Latifah et al., 2020). These stages aim to create a product that meets educational needs and fosters critical thinking in students. The model used in this study is supported by the works of previous studies in the field of AR and learning, such as the work by Bower et al. (2017), which highlights the efficacy of AR in enhancing learning engagement and critical thinking.

The Define stage identifies the learning needs and the specific challenges students face in developing critical thinking skills related to Thermodynamics. This stage involves gathering data on student difficulties and areas where critical thinking can be integrated into learning materials. In the Design stage, the initial version of the AR-based E-LKPD is developed, along with the research instruments required for validation and data collection. The design process also involves creating a structure that aligns with the LOK-R model, ensuring that students can engage with both the content and the technology. The integration of AR into the learning process is based on research by Martín-Gutiérrez et al. (2017), which emphasizes the potential of AR to improve learning outcomes in complex subjects like physics. In the Develop stage, the final product is produced through expert validation from material and media specialists, followed by limited trials with students to assess its effectiveness.

To evaluate the developed product, a combination of test and non-test instruments are employed. The test instruments consist of pretest and posttest assessments, measuring students' critical thinking skills through essay questions on Thermodynamics. The non-test instruments include validation sheets completed by subject matter experts and media experts, as well as questionnaires to gather feedback from students and educators on the usability and effectiveness of the E-LKPD. All instruments are carefully validated to ensure the accuracy and relevance of the data collected. Data analysis is performed by calculating the average validation score, the percentage of positive responses from questionnaires, and the N-gain score, which reflects the improvement in students' critical thinking skills between pretest and posttest

(Nurdin & Hartati, 2019). This method of evaluation is aligned with the approach used by Ramasamy et al. (2019), who applied similar data analysis techniques to assess the effectiveness of educational technologies in improving student outcomes.

Figure 1. 3D Model

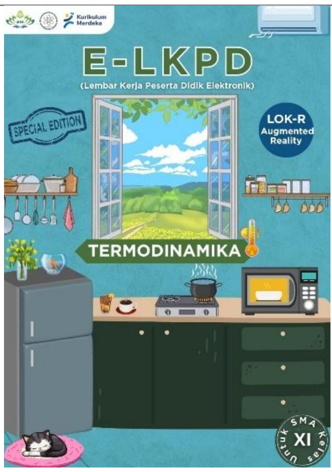
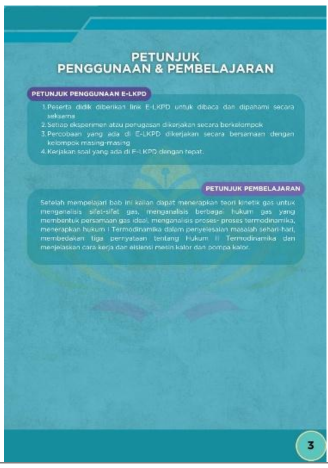


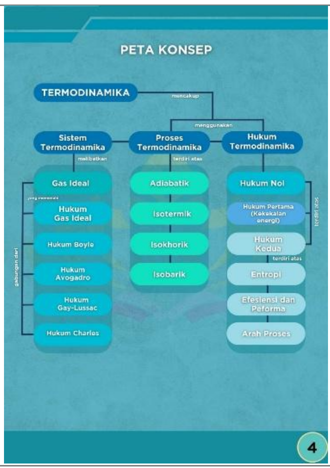
RESULT AND DISCUSSION

The development of Augmented Reality (AR) based Physics E-LKPD using the LOK-R model was developed through four stages according to the 4D model (Thiagarajan 1976) , namely *define, design, develop* , and *disseminate , although the research was limited to the develop* stage . The product was developed for thermodynamics material for grade XI high school with the main objective of improving students' critical thinking skills through the stages of *Literacy, Problem Orientation, Collaboration* , and *Reflection, design* phase focuses on adapting the E-LKPD format to the characteristics of interactive digital media. The initial design includes a cover, foreword, table of contents, content standards, usage and learning instructions, concept maps, the LOK-R learning model, learning activities, summary, reference, and developer profile.

Table 1. Design Stages of Physics E-LKPD Using the Augmented Reality (AR) Based LOK-R Model

Part	Description
Cover	Determine the front cover that is made with full color and images. Dominated by dark turquoise, the logo of UIN Raden Intan Lampung, the physics logo is us, and the independent curriculum logo are at the top left, the images presented on *the cover* are adjusted to the phenomenon of thermodynamic material, the title is in the middle, the class and semester are at the bottom right.

	
Foreword, Table of Contents, Content Standards 	Determine the foreword, table of contents and content standards according to Learning Achievements (CP), Learning Objectives (TP) and Learning Objectives Flow (ATP). The foreword contains an expression of gratitude, the reasons for developing E-LKPD, an explanation of the applied learning model, the benefits of E-LKPD for readers, and thanks from the author to all parties who contributed to the process of compiling E-LKPD. Table of contents of E-LKPD. The content standards include Learning Outcomes (CP), Learning Objectives (TP), and Learning Flow (ATP) .
Instructions for Use & Learning 	Determines the user manual, includes instructions for using the E-LKPD and the features available in the E-LKPD, and the Learning Instructions explain the flow of learning activities that students will undertake during the learning process. This section guides students through the steps from start to finish, including the activities that must be completed at each stage.
Concept maps	Determine the concept map containing the structure of the learning material



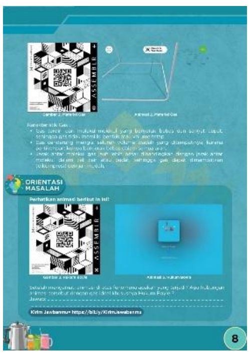
LOK-R Learning Model

Explanation of the LOK-R Model

- Literacy
- Orientation
- Collaboration
- Reflection

and the objectives of the LOK-R learning model

Learning Activities



Student activities using the LOK-R model:

1. Literacy: Literacy in LOK-R learning is reading, understanding, analyzing, and using information critically.

Activities: Students read, understand, analyze, and use information critically with *the Augmented Reality* (AR) provided.

2. Orientation: Orientation refers to the initial stage of learning.
   - Activities: Students are introduced to the objectives, concepts, and structure of the learning process. In this problem-oriented section, students are also given reasoning exercises by observing phenomena in *Augmented Reality* (AR).
3. Collaboration: Collaboration emphasizes cooperation between students in the learning process, whether in discussions, group assignments, or joint problem solving.
   - Activities: Students will observe *Augmented Reality* (AR) and discuss and solve the problems given.

	4. Reflection: Reflection is a process of self-evaluation of learning experiences that have been carried out. • Activities: Students will carry out a self-evaluation process by working on questions.
Summary 	Contains a summary of the material that has been studied, containing important information and core concepts so that students can more easily understand, remember, and review the learning.
References 	Contains a list of references in compiling E-LKPD
Developer profile 	Contains a section that includes brief information about the identity and background of the person who developed the learning product.

The integration of Augmented Reality (AR) in E-LKPD is designed to visualize abstract thermodynamic concepts, such as isobaric, isothermic, and Carnot engine cycle processes, into interactive 3D objects. This aims to reduce misconceptions and improve contextual understanding. An example of the E-LKPD display, specifically the integration of the LOK-R model and Augmented Reality (AR) animation, can be seen in

Figure 2. Physics E-LKPD Using the Augmented Reality-Based LOK-R Model:

Model		**E-LKPD Section**
LOK-R Integration	**(L)**	**Literasi (Membaca dan memahami informasi awal sebagai dasar pembelajaran).** 
	(O)	**Orientasi (Mengidentifikasi tujuan, masalah, dan arah pembelajaran).** 
	(K)	**Kolaborasi (Bekerja sama, berdiskusi, dan bertukar ide dengan teman).** 

(R)


keadaan awal. Semua proses alami bersifat ireversibel dan, menurut Hukum Kedua Termodinamika, proses ini berhubungan dengan sifat spontanitas.

REFLEKSI

Diskusikanlah pertanyaan-pertanyaan berikut ini dengan teman sekelompkmu !

1. Apa yang dimaksud dengan sistem dalam termodinamika? Jelaskan perbedaannya antara sistem terbuka, tertutup, dan terisolasi.
Jawaban:

2. Jelaskan perbedaan antara sifat intrinsik dan ekstrinsik dalam konteks termodinamika. Berikan masing-masing contoh sifatnya !
Jawaban:

3. Apakah yang dimaksud dengan proses adiabatik? Berikan contoh proses adiabatik dalam kehidupan sehari-hari dan jelaskan mengapa kalor tidak berpindah pada proses tersebut
Jawaban:

4. Sebuah sistem berada dalam wadah tertutup dan tidak ada perubahan sifat fisik seperti tekanan, suhu, dan volume. Apa yang bisa kamu simpulkan mengenai keadaan sistem tersebut?
Jawaban:

5. Jika dua sistem digabungkan, dan tekanan serta suhu tetap sama, tetapi massa dan volume menjadi dua kali lipat, jenis sifat apa yang berubah dan mengapa?
Jawaban:

Kirim Jawbanmu= https://bit.ly/KirimJawabanmu

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Refleksi (Meninjau kembali hasil belajar serta menyimpulkan pemahaman).

At the literacy stage, it aims to build an initial understanding of students' basic literacy skills regarding thermodynamics material, students read, observe, and identify information from Augmented Reality (AR) animations. The orientation stage focuses on formulating problems or challenging statements based on the initial understanding that has been obtained, students formulate questions, make hypotheses or determine learning objectives or experiments with Augmented Reality (AR). The collaboration stage, students work together to interact directly with Augmented Reality (AR) animations in E-LKPD, students observe and analyze group results. The reflection stage aims to evaluate and conclude the learning outcomes obtained by working on the questions in E-LKPD.

The research instruments, both tests (pretest and posttest) and non-tests (expert validation and questionnaire responses), were validated before use. The following is a summary of the validation results:

Material Expert Validation Results

Based on the validation results by material experts, an average score of 87.75% was obtained, categorized as Very Appropriate. This result indicates that the feasibility and depth of the material in the Augmented Reality (AR)-based Physics E-LKPD with the LOK-R model is very adequate for use in learning.

Table 2. Results of Material Expert Validation

Rated aspect	Percentage	Category
Presentation Eligibility	89%	Very Worthy
Content Eligibility	84%	Very Worthy
Language Eligibility	85%	Very Worthy
LOK-R Implementation	93%	Very Worthy
Average Total	87.75%	Very Worthy

Based on the validation results in Table 1, all aspects obtained a *very feasible category* , with an average score of 87.75%. The aspect with the highest score was *LOK-R Implementation* at 93%, indicating that the integration of LOK-R syntax in E-LKPD has been in accordance with the characteristics of reflection-based and collaboration-based learning. These results confirm that the E-LKPD product has met the standards of feasibility of content, presentation, and language to be implemented in Augmented Reality (AR)-based physics learning.

Media Expert Validation Results

The media expert validation results showed an average score of 90.2%, categorized as Very Suitable. This high score indicates that the visual design, media size, ease of use, and AR feature integration were deemed excellent and functional.

Table 3. Media Expert Validation Results

Assessment Indicators	Percentage	Category
Media Size	88%	Very Worthy
Overall Design	90%	Very Worthy
Media Cover Design	89%	Very Worthy
Additional information	88%	Very Worthy
Media Content Design	92%	Very Worthy
Ease of Use	94%	Very Worthy
Average Total	90.2%	Very Worthy

Based on the results of media expert validation (Table 2), all assessment indicators showed a *very feasible category* with an average of 90.2%. The aspect with the highest score was *Ease of Use* (94%), which indicates that the E-LKPD is easy to operate and responsive to user needs. Meanwhile, *Media Content Design* obtained a score of 92%, indicating that the product's visual appearance and layout are attractive and facilitate the understanding of physics concepts effectively. These results confirm that the AR-based Physics E-LKPD with the LOK-R model has excellent design advantages and is suitable for implementation in the learning process. These findings support Riduwan (2020), namely, learning media is considered *very feasible* if it obtains a feasibility score above 80%. Thus, the media development has met the validity and feasibility standards for implementation at the limited field trial stage.

Item Validation Results

The validation of the critical thinking skills items (10 descriptive questions) achieved an average score of 87%, categorized as Very Adequate. This ensures that the test instrument used is valid and capable of measuring the critical thinking indicators targeted in thermodynamics.

Table 4. Item Validation Results

Assessment Indicators	Percentage	Category
Question Construction	87%	Very Worthy
Language Eligibility	86%	Very Worthy
Eligibility of Question Item Material	88%	Very Worthy
Average Total	87%	Very Worthy

Overall, the very good results from the validation by material, media, and instrument experts confirm that the AR-based Physics E-LKPD with the LOK-R model has met the standards of pedagogical, content, and technical feasibility for testing in learning. This finding is in line with (Yusa et al., 2023)the statement that the integration of Augmented Reality (AR) in physics learning effectively improves the understanding of abstract concepts and critical thinking skills, which are the foundation of this product's feasibility.

Results of Student and Educator Responses to E-LKPD

The questionnaire responses showed very positive user reception. Student responses averaged 92.5%, categorized as Very Interesting (Excellent), while educator responses were 90%, categorized as Very Interesting.

Table 5. Results of Student and Educator Responses

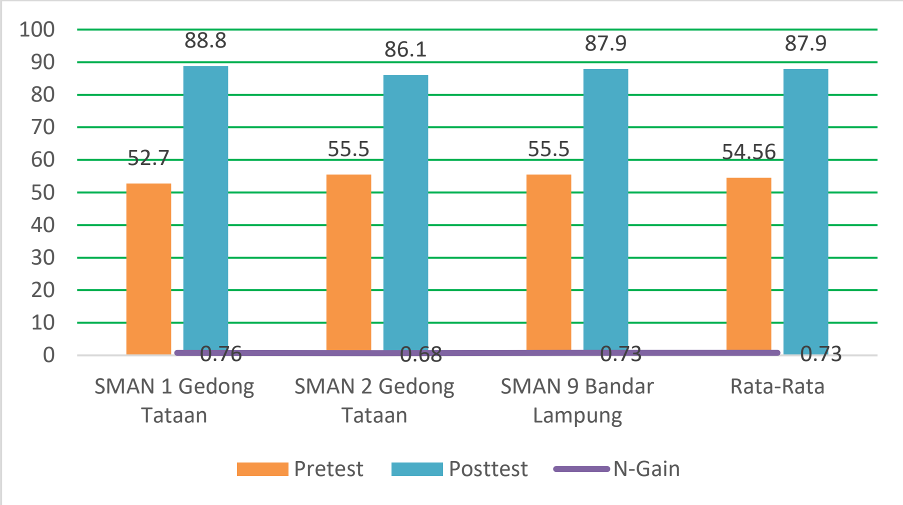
Respondents	Aspect	Percentage (%)	Category
Learners	Content Quality	90%	Very interesting
	Language Eligibility	93%	Very interesting
	E-LKPD Contents	92%	Very interesting
	LOK-R Implementation	92%	Very interesting
	Critical Thinking Skills	94%	Very interesting
	E-LKPD Display	94%	Very interesting
	Average	**92.5%**	**Very interesting**
Educator	Content Quality	92%	Very interesting
	Language Eligibility	93%	Very interesting
	E-LKPD Contents	89%	Very interesting
	LOK-R Implementation	86%	Very interesting
	Critical Thinking Skills	90%	Very interesting
	E-LKPD Display	93%	Very interesting
	Average	**90%**	**Very interesting**

The high response rate, particularly for *the E-LKPD Display* and *Critical Thinking Skills aspects* , demonstrates that AR integration has successfully created an immersive and contextual learning experience, thereby increasing student motivation and engagement. Educators also provided positive responses, particularly regarding the appropriateness of the content and language, confirming the practicality of this medium for implementation in the curriculum.

Results of Improving Students' Critical Thinking Skills

the pretest and *posttest* results showed a significant increase in students' critical thinking skills after using the Augmented Reality (AR)-based E-LKPD with the LOK-R model. The average *pretest score* of 54.56 increased drastically to 87.9 in *the posttest* . The N-gain calculation resulted in a score of 0.73, which is in the High category (Figure 2).

Figure 3. N-Gain Improvement Data for Critical Thinking Skills



This high increase (N-gain = 0.73) can be concluded that the use of Augmented Reality (AR)-based E-LKPD with the LOK-R model is effective in improving students' critical thinking skills. This effectiveness is supported by the systematic integration between AR technology and the LOK-R learning model.

Discussion (In-depth Discussion)

The findings of this study are consistent with previous research, which confirms that the use of interactive digital worksheets and immersive technology significantly contributes to encouraging learning engagement and strengthening students' higher-order thinking skills. Research (Fitri et al., 2025)shows that visual technology-assisted worksheets can improve analytical skills by presenting more concrete conceptual representations. Similarly, (Radu et al., 2023)it confirms that 3D visual media and augmented reality are effective in reducing misconceptions on abstract science topics.

The power of utilizing interactive digital media in improving students' thinking processes is also supported by research that shows that interactive platform-based E-LKPD significantly improves scientific analysis and argumentation skills, because it provides visual exploration space and contextual problem stimuli (Triwahyudianto et al., 2024). In addition, studies and research on Augmented Reality (AR) confirm that the integration of 3-dimensional visual technology in teaching tools functions as *cognitive scaffolding* , making it easier for students to represent and interpret abstract concepts, in turn increasing cognitive activity and the quality of scientific responses, especially when combined with structured problem-solving activities (Garzón & Acevedo, 2019; Ibáñez & Delgado-Kloos, 2018).

The results of this study are supported by (Abd Rahman & Abd Halim, 2025)those stating that Augmented Reality (AR)-assisted learning is able to improve *scientific reasoning* by providing *cognitive scaffolding* that helps students interpret abstract and non-visual concepts, such as energy flow and thermodynamic processes. In addition, (Abd Rahman & Abd Halim, 2025)it confirms that collaborative syntax in structured learning models contributes significantly to strengthening critical thinking skills, especially in the ability to evaluate arguments and make decisions with evidence (*evidence-based decision making*). This finding is in line with (Nirmala et al., 2025)those revealing that reflective activities in LKPD encourage students to carry out inference processes, build cause-effect relationships, and compile scientific explanations in a coherent and logical manner. Thus, the integration of AR in E-LKPD based on the LOK-R model not only supports concept visualization, but also facilitates the development of higher-order thinking skills systematically and meaningfully. The consistent high N-gain results in three trial locations strengthen that the AR-assisted LOK-R (Literacy, Orientation, Collaboration, Reflection) model is not only effective in one class condition, but is adaptive and stable in improving critical thinking skills as a whole. Through the flow: (1) *Literacy-Orientation* that activates interpretation and analysis; (2) *Collaboration* that demands argumentative evaluation; and (3) *Reflection* that stimulates inference and explanation, this model has been proven to accommodate all critical thinking indicators in a structured manner.

CONCLUSION

Based on the research results and discussion, it is concluded that this study shows that the Augmented Reality (AR)-based Physics E-LKPD with the LOK-R model developed has good feasibility and effectiveness in learning thermodynamics for grade XI. This is proven through the results of expert validation and the improvement of students' critical thinking skills which reached the high N-gain category. Positive responses from students and educators also strengthen that this media is practical and interesting to use in the learning process. However, this study still has limitations, especially related to the limited number of samples, the relatively short implementation time, and the technical constraints on the devices used. Therefore, further research needs to involve more diverse participants, review long-term learning outcomes, develop Augmented Reality-based E-LKPD on other physics materials, and improve the optimization of Augmented Reality for devices with low specifications to expand access and effectiveness of its use.

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