



Analysis of the Need for Developing Palm Oil Industry–Based Augmented Reality Media to Improve Energy Literacy and Physics Concept Understanding in Vocational Schools

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Abstract: This study aims to analyze the need for the development of augmented reality (AR)-based learning media in the context of the palm oil industry to improve students' energy literacy and understanding of physics concepts at vocational high schools. The study used a survey method with a descriptive quantitative approach. The research subjects consisted of 62 tenth-grade students at the Sembawa State Agricultural Vocational High School, who were selected using purposive sampling. The research instrument was a five-point Likert scale questionnaire that had been tested for content validity using Aiken's V index and for reliability using Cronbach's Alpha. The results showed that students had a high interest in learning physics, but their understanding of concepts and energy literacy was still in the moderate category. In addition, the learning media used were not yet able to optimally visualize physics processes in the context of the palm oil industry. These findings indicate the need to develop contextual, interactive, and relevant AR-based physics learning media for vocational education. This research provides practical implications in the form of recommendations for the design specifications of palm oil industry-based AR media.

Keywords: Augmented reality; Energy literacy; Palm oil industry; Physics learning; Vocational high school

Introduction

21st century science education requires learning that is not only oriented towards mastery of theoretical concepts, but also towards the development of critical thinking skills, problem solving, creativity, collaboration, and awareness of global issues such as energy sustainability and industrial transformation (Muhali et al., 2025). These competencies are crucial in vocational education, especially in vocational high schools (SMK), as graduates are expected to be able to relate scientific knowledge to real-world work practices in industry (Elliyani et al., 2024; Nisyah et al., 2022; Supena et al., 2021; Tang et al., 2020). In the context of vocational education, energy literacy is a key competency that students must possess (Kellberg et al., 2025; Majid et al., 2025; Santillán & Cedano, 2023).

Energy literacy encompasses the ability to understand energy concepts, evaluate their impact, and apply this knowledge contextually in daily life and industrial environments (Castañeda-Garza et al., 2025; Frings et al., 2024; Remolar et al., 2021). However, various studies show that the energy literacy of vocational education students is still in the moderate to low category, especially in terms of conceptual understanding and technical application of renewable energy (Mustain & Herlina, 2019; O'Connor & Mahony, 2023a; Rohmatulloh et al., 2022; Widiyatmoko et al., 2023).

This problem is exacerbated by the characteristics of physics learning in vocational schools, which are still dominated by conventional media such as textbooks and verbal explanations from teachers (Cerović et al., 2024). These media are unable to visualize abstract physics concepts, such as heat transfer, fluid flow, and energy

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conversion, which are important foundations in the context of the energy industry (Anggraini et al., 2024; Murwitaningsih & Maesaroh, 2023; Novita, 2023). As a result, even though students have a high interest in learning physics, their conceptual understanding is still low and they find it difficult to relate theory to industrial practice (Derasid et al., 2021; Giyarsih et al., 2024).

In Indonesia, the palm oil industry is a strategic sector with great potential as a source of renewable energy, such as biogas from palm oil mill effluent (POME), biomass from shells, and empty palm fruit bunches. The palm oil industry context is highly relevant as an authentic learning resource in vocational physics education because it is close to the students' environment and aligned with the needs of the workplace (Yusro et al., 2023). The integration of local-industrial contexts in learning has been proven to increase relevance, motivation, and conceptual understanding among students (Ellianawati et al., 2025; Susetyo et al., 2024).

One technological approach that has the potential to address these issues is the use of Augmented Reality (AR)-based learning media (Ansori et al., 2025). AR enables the visualization of objects and physical processes in three dimensions, interactively and contextually, thereby helping students to understand phenomena that cannot be observed directly (Fanmita & Guspatni, 2023; Komarudin et al., 2025). A number of studies in the last five years have shown that AR is effective in improving students' conceptual understanding, higher-order thinking skills, and learning engagement in science and vocational education (Asyhari et al., 2024; Saidin et al., 2024; Setiawaty et al., 2024).

Although various studies have reported the effectiveness of Augmented Reality in improving students' conceptual understanding and thinking skills, most of these studies still focus on the context of general education and abstract physics material without direct relevance to the industrial world (Asrizal et al., 2024; Buditjahjanto & Irfansyah, 2023). Research on the development of AR media that specifically integrates the local industrial context, particularly the palm oil industry, into physics education in vocational schools is still very limited. In fact, needs analysis is a crucial stage as the basis for designing learning media that are relevant, contextual, and in line with the characteristics of vocational students (Alawyah et al., 2024; Rejekiningsih et al., 2023).

Therefore, this study aims to analyze the need for the development of industry-based Augmented Reality (AR) media for the palm oil industry to improve energy literacy and students' understanding of physics concepts in vocational high schools. The results of this study are expected to serve as an empirical basis for the

development of contextual physics AR media, support vocational learning, and align with the demands of 21st-century education and sustainable industrial transformation.

Method

This study employed a descriptive quantitative survey design to analyze the need for developing palm oil industry-based Augmented Reality (AR) learning media in vocational physics education. The survey design was selected to systematically capture students' learning conditions, technological readiness, and media content needs as a foundation for designing contextual and industry-relevant AR media.

The research was conducted at Sembawa State Agricultural Vocational School, South Sumatra, which implements industry-oriented vocational learning with a focus on oil palm agriculture. The research subjects consisted of 62 tenth-grade students from two classes selected through purposive sampling. The selection criteria included: students who had studied renewable energy and palm oil bioenergy topics, students with learning or practical exposure related to the palm oil industry, and students with relatively balanced academic abilities. These criteria ensured the relevance of the data to the needs analysis, while acknowledging that the findings were context-specific and not intended for broad generalization.

The data were collected using a closed-ended questionnaire developed to measure students' perceptions and learning needs, rather than direct cognitive mastery. The instrument consisted of five indicators representing core components of AR media development needs: characteristics and barriers to physics learning, energy literacy-related awareness and attitudes, readiness of technology and learning media, students' perceived understanding of physics concepts and interest in energy topics, and AR media content requirements and independent learning patterns. All items were measured using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree).

The content validity of the questionnaire was evaluated by two experts (a physics education expert and a learning technology expert) using Aiken's V , resulting in an average coefficient of 0.83, indicating good content validity. Reliability testing using Cronbach's Alpha yielded a coefficient of $\alpha = 0.87$, demonstrating high internal consistency. A pilot test involving 12 students from schools with similar characteristics was conducted solely to assess item clarity and readability, not for statistical reliability estimation.

Data collection was carried out during physics lessons using Google Forms. Although the questionnaire

was completed independently by students, the participants had been pre-selected based on the established purposive sampling criteria. Data analysis was conducted descriptively by calculating mean scores, percentages, and frequency distributions for each indicator. The scores were converted into a 0–100 scale to facilitate interpretation of the level of need. The results were presented in tables and diagrams and used as the basis for determining the design specifications of palm oil industry-based AR learning media.

$$Value = \frac{Obtained\ score}{Maximum\ score} \times 100\% \tag{1}$$

Result and Discussion

Research related to the analysis of the need for the development of Augmented Reality (AR)-based learning media in the context of the palm oil industry to

improve the energy literacy of vocational students has been conducted. The research results are presented descriptively to illustrate the conditions of physics learning, energy literacy levels, understanding of physics concepts, and student needs for the development of Augmented Reality-based learning media (Rohmatulloh et al., 2022). The presentation of the results focuses on the average scores and percentages of each indicator without accompanying in-depth theoretical interpretations.

Characteristics & Obstacles in Physics Learning

Preliminary information was obtained regarding students' views on physics learning in a vocational context. This information covers three aspects: interest in learning physics, preferred learning methods, and difficulties encountered. The results are shown in Figure 1.

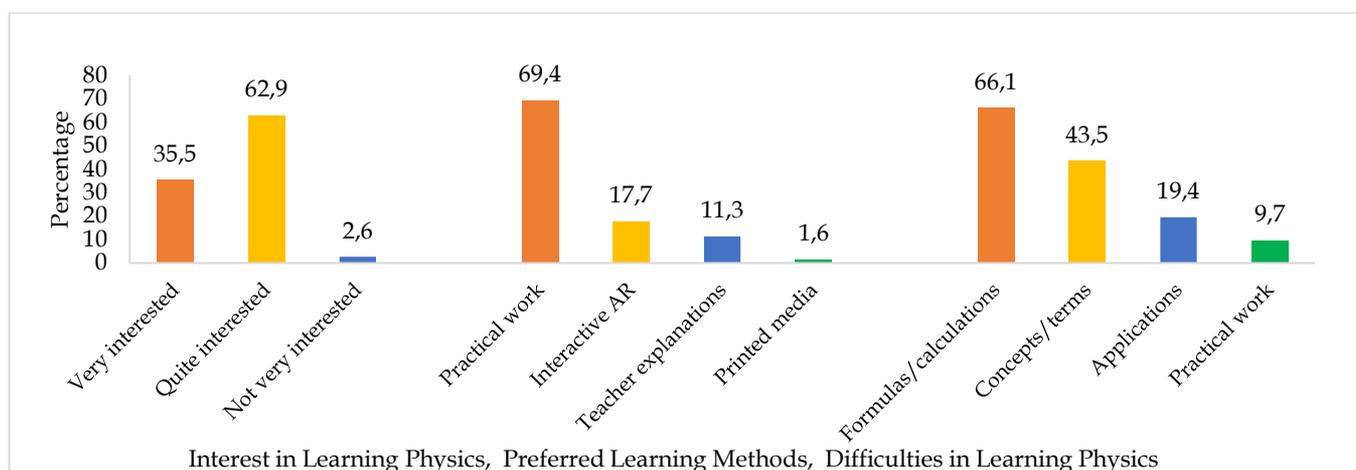


Figure 1. Characteristic physics learning

Based on Figure 1, these findings show that 98.4% of students expressed a high interest in learning physics, especially when the material was linked to real-world contexts such as the palm oil industry, for example, bioenergy. This is in line with the principles of Contextual Teaching and Learning (CTL), which emphasizes the relevance between lesson material and students' real lives (Betty Lusiana et al., 2025). However, this high level of interest has not been matched by adequate conceptual understanding.

As many as 66.1% of students reported difficulties in understanding formulas and calculations, while 43.5% had difficulty understanding scientific terms. This indicates that even though students are motivated, they still experience obstacles in the abstract cognitive dimension, which is a common characteristic in physics learning according to previous studies. In addition, preferences for learning methods show a dominance of interest in hands-on experiments (69.4%) and interactive

AR media (17.7%), while conventional methods such as lectures (11.3%) received minimal response. These findings reinforce the need for pedagogical transformation from an expository approach to experience-based learning and visual technology.

Energy Literacy Aspects

The next aspect analyzed was students' energy literacy, particularly their understanding of the energy potential of palm oil (e.g., biogas from POME, the burning of palm oil shells) and its relation to physics concepts (fluids, heat, electricity) (Kan et al., 2024). Figure 2 shows students' perspectives on energy literacy.

Based on Figure 2, in terms of energy literacy, 59.7% of students have a "fair" understanding of palm oil-based energy, and 61.3% are able to connect physics concepts with energy applications (Appiah et al., 2023). However, this understanding is general and has not yet reached an analytical level, for example, in explaining

the mechanism of heat transfer in biomass boilers or fluid flow in biogas systems (POME). In fact, almost all

students (93.6%) stated that learning about renewable energy is very important.

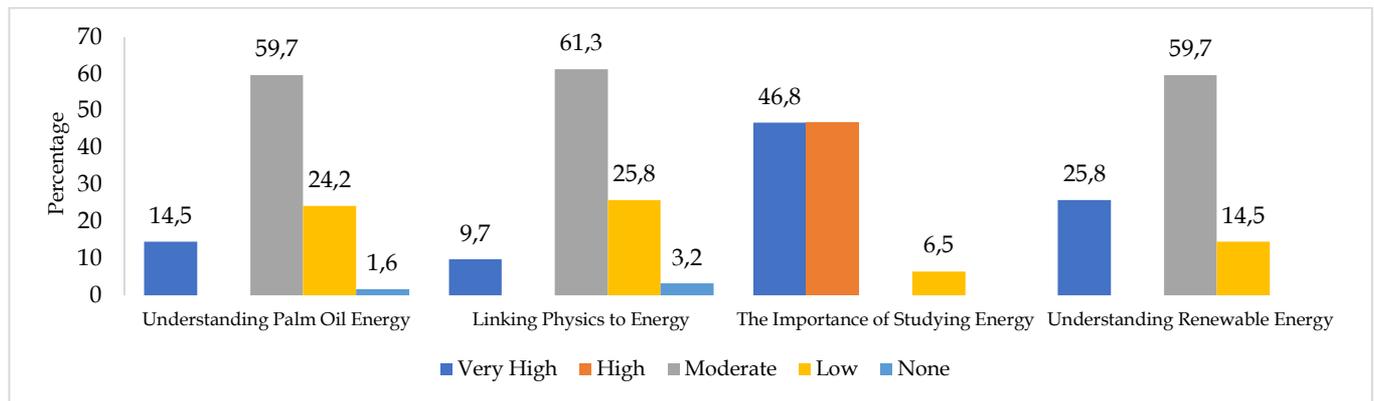


Figure 2. Students' perspective on energy literacy

This gap is in line with the findings of (Rohmatulloh et al., 2022), which state that energy literacy in Indonesia tends to focus on normative aspects (the importance of renewable energy) rather than operational aspects (how energy is produced and utilized technically). Therefore, learning media must be able to connect abstract concepts in physics with concrete industrial processes, something that existing learning resources have not yet fulfilled.

A small percentage of students also have a combination of other devices, such as laptops (21%) and tablets (6.5%), but mobile phones remain the most practical primary medium.

Aspects of Technology Readiness and Learning Media

The aspect of student technology readiness is a key factor in the development of AR-based learning media. Figure 3 presents data related to student access to technology and their readiness to use AR in physics learning relevant to the palm oil industry.

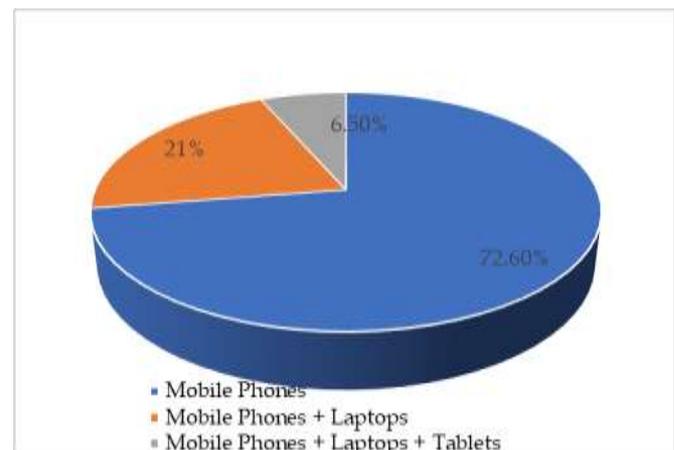


Figure 3. Digital device used

Figure 3 shows that 72.6% of students use smartphones as their primary device, making mobile-based AR a highly relevant and widely accessible option.

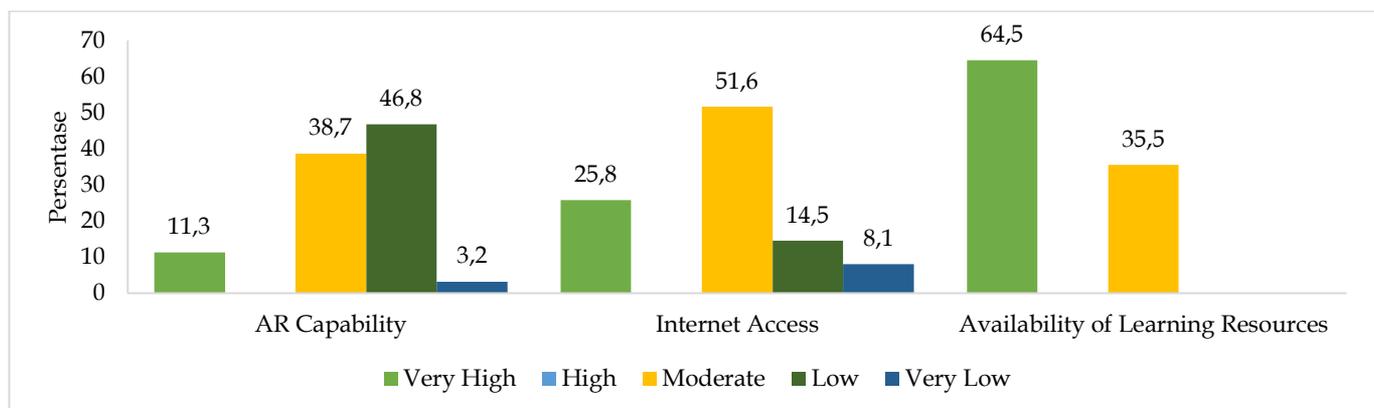


Figure 4. Technological readiness for AR learning

Figure 4 shows that analysis of students' technological readiness indicates that their ability to operate Augmented Reality (AR) technology is still

relatively low, with only 11.3% of students in the "very high" category, while 46.8% are in the low category. This condition indicates that although the use of AR has great

potential for improving understanding of physics concepts, most students still need assistance and technical training in utilizing this technology. Therefore, the AR learning media developed need to be designed with a simple interface, clear usage guidelines, and easily accessible interactive features.

However, internet access is relatively good, with 77.4% of students in the high or very high category. Only a small proportion of students reported low (14.5%) or very low (8.1%) internet access. These findings indicate that internet availability is not a major obstacle to the implementation of digital learning media, including app-based AR. Sufficiently good internet access supports the use of additional features such as videos, question banks, and online content updates (Safitri et al., 2025).

Meanwhile, in terms of learning resource availability, most students (64.5%) reported that the learning resources available at school were in the very high category, while the rest (35.5%) were in the high category. These adequate learning resources include

textbooks, digital modules, and other supporting materials. However, given the limitations of infrastructure in rural vocational schools, offline features are an important requirement. This implies that AR media must be lightweight and compatible with low-end Android devices, provide visual usage guides, and not rely on an internet connection for core functionality (simulations, quizzes, notes) (Nuryana et al., 2025). These findings support the inclusive AR design approach proposed by Aji et al. (2025), which emphasizes interface simplicity and technical accessibility for novice users.

Understanding of Physics Concepts and Interest in Energy

Understanding of physics concepts and interest in energy are important aspects in determining the direction of AR-based learning media development. Data related to students' understanding of physics concepts and interest in energy topics are presented in the following table.

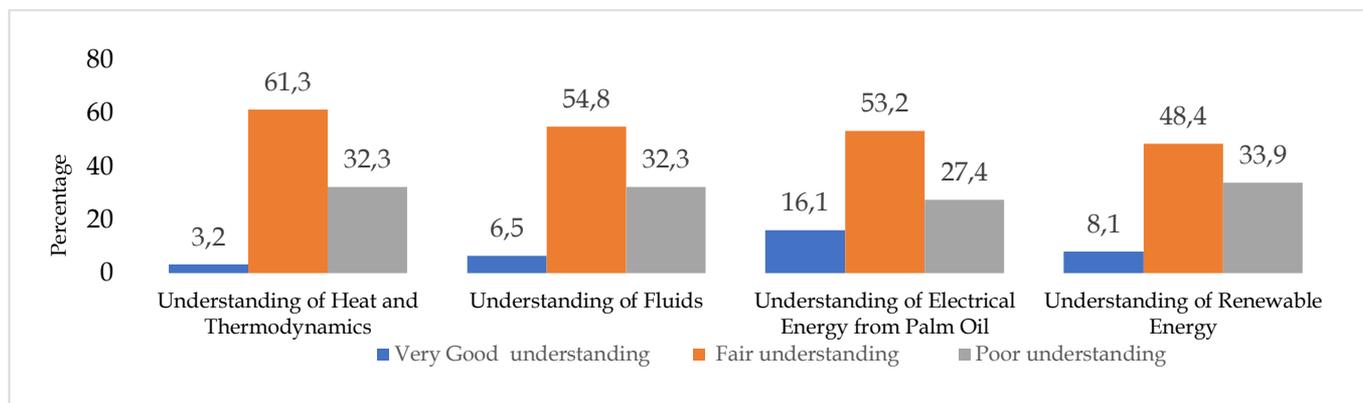


Figure 5. Understanding of physics concepts

Figure 5 shows that the concept comprehension analysis indicates that the level of mastery of energy-related material is still low: Heat and Thermodynamics: only 3.2% fully understand; Fluids: 6.5% fully understand; Electrical Energy from Palm Oil: 16.1% fully understand (the highest, but still a minority); and Renewable Energy: 8.1% fully understand. These findings indicate that the basic concepts of heat transfer and thermodynamic processes have not been fully mastered, even though these concepts are an important foundation for understanding energy efficiency in the palm oil industrial process.

Furthermore, fluid phenomena are highly relevant in palm oil processing, such as the flow of crude oil, steam, and other process fluids. The low level of understanding indicates the need for learning media that provides concrete and contextual visualization. Direct experience in an industrial environment has not been fully converted into a strong understanding of

electrical energy concepts. Not only that, the concept of sustainable energy, which is an important part of the 4.0 education curriculum and policy, has not been optimally understood by students.

These findings confirm that vocational students need dynamic visual representations to understand physics processes that cannot be observed directly, such as fluid flow, thermal efficiency, or biomass energy conversion. AR media have great potential here, as they can present interactive 3D models that can be manipulated, thereby helping students build accurate mental models (Cai et al., 2021).

Aspects of AR Media Content Requirements & Independent Learning Patterns

The final aspect analyzes the specifications of AR media content that students expect for palm oil bioenergy simulations, as well as their independent learning patterns. Figure 4 presents data related to

material format, evaluation methods, interactive features, assignments, assessments, and student learning independence.

Figure 6 shows the results of a needs analysis of 63 vocational school students, indicating a strong preference for the use of varied and interactive digital learning media. Students consistently want multimodal and interactive learning media. In terms of material presentation format (Q1), 77.7% of students stated that they liked material presented in the form of text, images, videos, and simulations, indicating that the learning media developed must integrate various forms of

information representation to improve understanding of physics concepts related to the palm oil industry. Preferences for evaluation forms were also clear. Most students, namely 85.5% (Q2), liked exercises and evaluations in the form of multiple-choice questions, and this support was reinforced by the finding that 91.9% of students expressed a preference for structured feedback mechanisms. In addition, 67.7% of students (Q4) stated that they preferred assignments in the form of quizzes, indicating that short and direct evaluation models were in high demand for monitoring understanding.

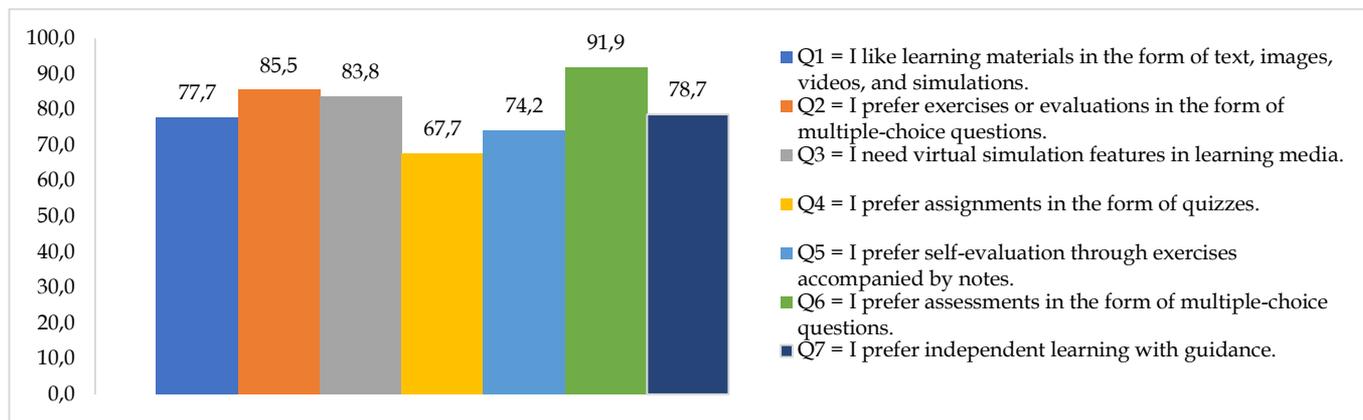


Figure 6. Learning media content requirements

The need for interactive features in learning media is very prominent. As many as 83.8% of students (Q3) stated that they need virtual simulations, which is a strong indication that the integration of Augmented Reality (AR) is very relevant for visualizing energy concepts in the context of the palm oil industry. In addition, 90.4% of students (Q7) prefer to measure their learning progress through progress by material, so the ideal digital learning system should provide clear tracking features. In terms of learning style, 78.7% of students (Q8) stated that they prefer to learn independently with guidance, while 74.2% of students (Q5) prefer self-evaluation through exercises with notes.

These findings indicate that students value learning autonomy but still need structure and immediate feedback features that can be integrated into AR through progress tracking by material, adaptive exercise systems, storable digital notes, and instant quizzes with automatic scoring. This type of design also supports the development of self-regulated learning and 21st-century skills (Ateş & Polat, 2025).

Discussion

Energy literacy and understanding of physics concepts are important aspects in vocational physics education, especially in the context of the palm oil industry. Energy literacy is defined as the ability of

students to understand, evaluate, and apply energy concepts in everyday life and industrial practices, including the use of palm oil bioenergy such as biogas from POME, palm kernel shell combustion, and other biomass utilization (Bhatia et al., 2025; Derasid et al., 2021). In vocational education, energy literacy is a fundamental competency because students are expected to be able to connect physics concepts with industrial work practices. However, various studies show that students' energy literacy in Indonesia is still relatively low, especially in terms of understanding concepts and applying knowledge in real-life situations.

Research findings show that students' high interest in physics learning is not automatically followed by adequate conceptual understanding, particularly in the areas of energy, heat, fluids, and renewable energy. This difficulty arises because physics material tends to be presented theoretically, while the visualization of energy processes in the palm oil industry, such as biogas fluid flow, biomass combustion, or heat transfer in boilers, is not easily observed directly. These findings are in line with the study by Scheel et al. (2022), which confirms that the ability to understand abstract physics concepts declines when learning relies solely on conventional media.

In this context, Augmented Reality (AR) media are a relevant solution to bridge the gap between theory and

practice (Akhsan et al., 2023). AR allows students to visualize physics phenomena that are difficult to observe directly, such as fluid flow in biogas pipes or heat transfer in biomass boilers and POME piping systems. With 3D visualizations that can be rotated, enlarged, and simulated, AR makes abstract concepts more concrete, contextual, and easier to understand. Research Arymbekov et al. (2024) and Nisyah et al. (2022) shows that the use of AR has been proven to improve students' conceptual understanding, motivation, and engagement in physics learning.

In addition to improving cognitive understanding, energy literacy requires an applied, problem-solving-based learning experience (Karagozlu, 2018). AR media enable students to learn through simulations that closely resemble industrial practices by providing interactive simulations, allowing students to independently evaluate energy processes, make decisions, and solve data-based problems (Sabbah et al., 2023; Zhao et al., 2022). The findings of O'Connor et al. (2023) and Wang et al. (2022) indicate that AR media can increase self-efficacy and learning independence, especially in students who previously had difficulty understanding abstract concepts.

Students' technological readiness also supports the development of mobile-based AR media. The majority of students use smartphones as their primary learning device, although their ability to use AR varies. This is in line with the findings Radosavljevic et al. (2020) which state that lightweight and efficient mobile-based AR media can be widely implemented, even in schools with limited infrastructure. With adaptive and inclusive designs, AR media allows students to learn independently while obtaining scaffolding as needed (Fathurohman et al., 2023).

Content aspects and independent learning patterns are also important considerations in media development. Students want materials that integrate text, images, videos, 3D models, and interactive quizzes for evaluation (Sofianidis, 2022). The use of simulations and independent exercises has been proven to increase students' motivation and ability to understand and apply energy concepts (Al Mamun & Lawrie, 2023; Toli & Kallery, 2021). Integrating these features into AR media will help students not only understand the theory but also connect physics concepts with the palm oil industry process in greater depth (Murti et al., 2025).

Overall, this phenomenon indicates a gap between learning motivation and the effectiveness of the learning media used, rather than the absence of media capable of bridging abstract theory with industrial practice. Context-based AR media are not merely a technological innovation, but a pedagogical strategy that responds to the empirical needs of students (Chiang et al., 2022). By integrating 3D simulations, interactive evaluations, and

multimodal content in a lightweight mobile format, AR media can improve understanding of physics concepts through the visualization of invisible processes, strengthen energy literacy through local contextualization, and support independent learning and 21st-century skills. Therefore, the next stage of AR media development must be based on the specific needs identified in this study, with the principle of user-centered design (Agustina et al., 2025).

The main contribution of this study lies in providing an empirical basis for the development of contextual and relevant Augmented Reality-based physics learning media for vocational education. Unlike previous studies that emphasized the general use of AR, this study places the palm oil industry as an authentic learning context that allows students to relate physics concepts to real industrial processes. Thus, this research not only contributes to the development of innovative learning media, but also strengthens the integration of energy literacy in vocational school physics education.

Conclusion

This study presents a needs analysis for the development of palm oil industry-based Augmented Reality (AR) learning media in vocational physics education at SMK Negeri Pertanian Sembawa. The findings show that students demonstrate high learning interest and strong awareness of renewable energy issues; however, they report difficulties in understanding abstract physics concepts related to heat, fluids, and energy conversion. It should be emphasized that these results reflect students' perceived understanding, not direct measurements of conceptual mastery. The analysis indicates the need for AR media that integrates interactive 3D simulations of palm oil industrial processes, visualization of invisible physical phenomena, mobile-based and offline-capable design, and learning support features such as progress tracking, short quizzes, and instant feedback. This study contributes empirical, context-specific design guidelines for developing AR media that supports energy literacy and independent learning in vocational physics education.

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Author Contributions

Conceptualization, E.A.S, A.F, H.A.; methodology, E.A.S, A.F, H.A.; validation, A.F and H.A.; formal analysis, E.A.S.; investigation, E.A.S.; resources, E.A.S.; data curation, E.A.S.; writing – original draft preparation, E.A.S.; writing – review

and editing, E.A.S, A.F, and H.A.; visualization, E.A.S.; All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declares that there is no conflict of interest regarding the writing and publication of this paper.

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