

## **AUGMENTED REALITY, ARTIFICIAL INTELLIGENCE, AND LOCAL WISDOM-BASED RENEWABLE ENERGY LEARNING MEDIA TO IMPROVE STUDENTS' 5C SKILLS**

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### **Abstract**

This study evaluated a renewable energy learning media that integrates augmented reality, artificial intelligence, and local wisdom to enhance students' five C skills. Using a design-based research approach, we analysed needs, designed prototypes, developed interactive modules, and reflected on implementation with physics education students. Expert validators rated content, media, and language highly, and a limited trial indicated improved engagement and conceptual understanding. The media visualizes drying, carbonization, cooling, packaging, and combustion processes, while adaptive feedback supports personalized learning. Integrating local wisdom contextualizes physics principles and strengthens sustainability awareness. These elements improved critical thinking, creativity, collaboration, communication, and character because immersive visualization and adaptive support made abstract concepts concrete and culturally meaningful. Findings suggest that combining augmented reality, artificial intelligence, and local wisdom is an effective pathway for twenty-first-century skill development, particularly in renewable energy learning, and the approach can be extended to other science topics that require visualization and contextualization.

Keywords: 5C skills, AI, Augmented reality, Lentera\_aralis, Local wisdom, Physics education, Renewable energy.

## 1. Introduction

The demands of the 21st-century education emphasize the development of the five C skills: critical thinking, creativity, collaboration, communication, and computational thinking. These competencies are essential for students to face complex global challenges and participate effectively in modern work and social environments. Meta-analyses confirm that integrating these skills improves students' preparedness for real-life problem-solving and professional success [1-3].

To meet these demands, emerging technologies offer new pedagogical opportunities. Augmented Reality (AR) enhances the visualization of abstract scientific concepts and promotes deeper engagement and understanding [4-7]. At the same time, Artificial Intelligence (AI) enables adaptive and personalized learning through intelligent tutoring systems and real-time feedback that supports higher-order thinking [8-11]. When combined, AR and AI can create immersive and adaptive learning experiences, which are especially relevant for nurturing 5C skills.

Beyond technology, local wisdom plays a critical role in education by connecting scientific knowledge with students' cultural backgrounds. Incorporating local values into learning increases relevance, meaning, and sustainability [12, 13]. Prior research shows that such integration fosters student motivation and environmental consciousness [14, 15]. However, existing studies involving AR in science or environmental education often concentrate only on motivation or conceptual learning without merging it with AI or local culture [16-18].

This limitation is also evident in renewable energy education. Although VR/AR simulations have been applied to topics like solar and wind power [19, 20], they usually overlook cultural context and skill development. Local wisdom-based learning about renewable energy can enhance sustainability education while embedding cultural awareness [21]. Yet, few studies integrate AR, AI, renewable energy, and local wisdom into a single learning platform that directly targets the development of 5C skills.

Furthermore, most renewable energy learning approaches rely on conceptual modules or basic lab experiments [22], lacking interactive tools and a clear emphasis on 21st-century competencies. Thus, a research gap exists in combining AR, AI, and local wisdom for renewable energy learning with a specific focus on 5C skill formation.

This study addresses that gap by developing and evaluating LenTeRa\_AraLis, a learning media that integrates AR, AI, and local wisdom to teach renewable energy. The urgency of this innovation grows amid the global energy crisis and climate change, which requires youth to possess renewable energy literacy and high-level problem-solving skills [23, 24]. Using a design-based research approach through stages of analysis, design, development, and reflection, this study introduces a novel model. The novelty lies in: (i) combining AR, AI, and local wisdom in one platform; (ii) delivering immersive content on renewable energy; (iii) supporting personalized learning via AI; (iv) contextualizing content with cultural heritage; and (v) fostering integrated development of five C skills.

## **2. Literature Review**

### **2.1. Augmented reality**

Figure 1 illustrates how AR operates by linking the real environment, computer systems, and synthetic environments to generate immersive, interactive learning experiences. In this system, humans interact with their surroundings through perception and influence. The real environment is processed by computer systems, which then produce synthetic visualizations. These virtual objects are projected back to the user through AR devices, allowing real-time integration of digital and physical data for enriched educational engagement.

AR in science education has seen rapid advancement over the past decade due to its ability to blend interactive digital visualizations with real-world settings. This capability makes abstract scientific phenomena (such as molecular structures, microscopic processes, or physical laws) more accessible than when conveyed through text or static diagrams alone. Numerous meta-analyses and systematic reviews have reported significant positive impacts of AR on student learning outcomes and motivation across educational levels [25]. For instance, one meta-analysis of 62 quantitative studies found moderate to strong learning gains, while a broader review by Chang et al. [26] covering 134 quasi-experimental studies concluded that AR enhances cognitive outcomes, skills acquisition, and performance when well implemented.

In addition to learning outcomes, conceptual studies highlight several specific affordances of AR in science instruction. These include its capacity to present multiple levels of representation (macro and micro), simulate laboratory activities safely and cost-effectively, and enable students to manipulate three-dimensional scientific models. These affordances can significantly strengthen students' mental representations and conceptual understanding [27, 28].

However, the literature also points to critical design considerations. If visualizations are not optimized, AR can increase cognitive load. Infrastructural readiness (such as access to compatible devices and stable networks) also influences AR effectiveness. Moreover, successful integration depends on teachers' pedagogical skills and understanding of AR. Studies further emphasize that most research focuses on short-term cognitive outcomes, while long-term impacts and non-cognitive skills (e.g., creativity, collaboration, and computational thinking) remain underexplored [1, 5, 17, 26-28].

Therefore, while AR presents strong potential for science education, its success depends on carefully designed pedagogical models, well-supported implementation, and holistic evaluation strategies that consider both cognitive and affective dimensions of student learning.

### **2.2. Artificial intelligence**

AI in education continues to expand rapidly, offering applications such as intelligent tutoring systems, learning analytics, automated feedback, and personalized learning pathways [29-34]. Research has demonstrated that AI can improve instructional effectiveness through adaptive support and data-driven insights, although its successful implementation requires the involvement of educators in pedagogical planning [11].

Despite the promise of AI, there is a persistent gap between technical development and educational practice. Many AI solutions are technologically advanced but lack theoretical grounding or measurable impacts on student learning outcomes [18]. Recent studies indicate a shift from perception-based applications, such as pattern recognition, toward cognitive functions like adaptive feedback and tutoring. This shift emphasizes the importance of ethical considerations, privacy concerns, and infrastructure readiness [10].

In the context of science learning, AI has the potential to identify misconceptions, personalize laboratory simulations, and support higher-order thinking through scaffolded feedback. However, its effectiveness is closely linked to sound instructional design, high-quality data, and collaborative development between educators and technology designers [18, 35]. Therefore, AI-based learning tools must be supported by empirical evidence and rooted in local pedagogical contexts to ethically and effectively support twenty-first-century skills.

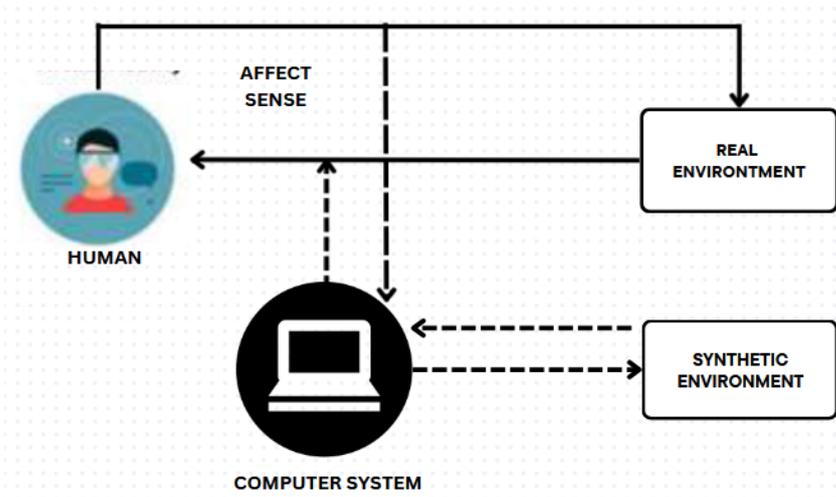


Fig. 1. The working mechanism of AR.

### 2.3. Local wisdom

Local wisdom is essential in contextualizing science education, making learning more meaningful and culturally responsive. Its integration with instructional content can increase students' motivation, relevance, and environmental awareness [12, 13]. Educational models that incorporate local culture help bridge abstract scientific knowledge with students' lived experiences, resulting in deeper engagement and sustainable learning [14, 15].

Studies affirm that embedding local wisdom into science education not only supports the development of sustainability-oriented values but also reinforces identity and community relevance. However, despite its pedagogical value, local wisdom is rarely combined with technological innovations such as Augmented Reality or Artificial Intelligence. As a result, opportunities to create learning environments that are both culturally grounded and technologically enhanced remain largely untapped.

## **2.4. Renewable energy**

Renewable energy refers to energy derived from ongoing natural processes, including solar, wind, hydro, geothermal, biomass, and ocean-based sources. Its principles are deeply rooted in physics, such as the photovoltaic effect, energy conversion through fluid motion, and heat transfer via conduction and convection. The study of renewable energy also involves core concepts like radiant energy, thermodynamic laws, and energy efficiency related to storage and distribution systems [36].

Physics-based approaches to renewable energy include the use of semiconductor band gaps in solar panels, the mechanical conversion in wind turbines, and thermodynamic cycles in geothermal systems. Understanding these processes is crucial for addressing sustainability challenges in the real world. However, educational materials often fail to make these concepts tangible and relatable, particularly when they are delivered without cultural context or technological interactivity.

By integrating AR and AI technologies with renewable energy topics and grounding them in local wisdom, educators can create immersive learning environments that make abstract content more accessible and culturally meaningful.

## **2.5. Five C skills in students**

The development of twenty-first-century competencies, particularly the five C skills (critical thinking, creativity, collaboration, communication, and computational thinking), has become a key objective in science education. These skills are not only foundational for academic success but also necessary for navigating complex, real-world challenges. To cultivate them effectively, instructional strategies must promote inquiry, technology integration, and collaborative learning environments [37].

Frameworks for integrating computational thinking into science education suggest using simulations, models, and digital tools to help students analyse and solve scientific problems. Research supports the idea that disciplinary learning activities involving modelling and problem-solving enhance students' computational thinking skills [38].

In addition to computational thinking, critical and creative thinking can be strengthened through interdisciplinary approaches such as Problem-Based Learning (PBL) integrated with STEM. This method has been shown to improve students' ability to think independently, generate solutions, and evaluate outcomes in science classrooms. Communication and collaboration are equally important. Learning environments that incorporate online, and blended elements offer students more opportunities to interact, negotiate meaning, and co-construct understanding [39].

Altogether, the literature underscores the importance of active, technology-supported instructional designs that explicitly target the development of five C skills in balanced and integrated ways.

## **2.6. LenTeRa\_AraLis: Integrated media based on AR, AI, and local wisdom**

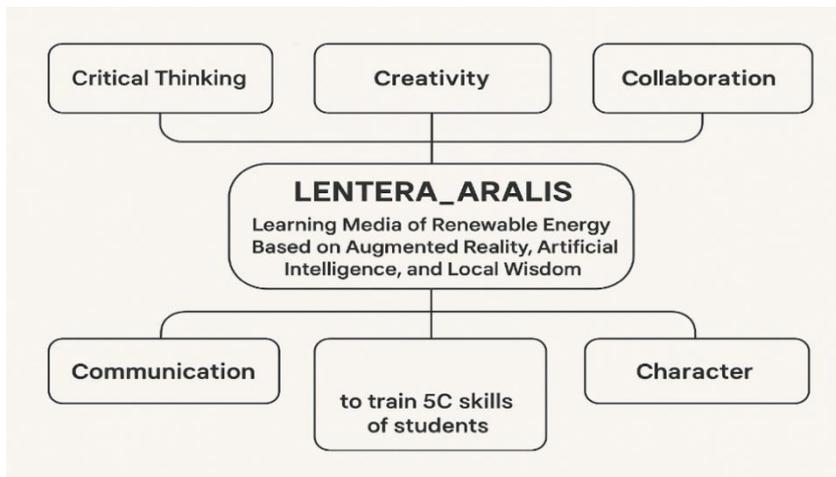
Figure 2 presents the conceptual framework of LenTeRa\_AraLis, a learning media that integrates AR, AI, and local wisdom to enhance students' five C skills: critical thinking, creativity, collaboration, communication, and character. This media was

designed to support renewable energy learning in a way that is both technologically immersive and culturally contextual.

AR is employed to visualize complex physics concepts related to renewable energy systems such as solar panels, wind turbines, and hydroelectric power. These visualizations help transform abstract scientific principles into concrete, interactive experiences that students can easily grasp. AI, in turn, serves as an adaptive learning engine by offering real-time feedback, generating performance analytics, and recommending learning paths tailored to individual student needs.

Local wisdom is integrated to root learning in authentic, culturally relevant contexts. This includes showcasing traditional technologies such as waterwheels, utilizing agricultural waste as biomass, and drawing on community knowledge for sustainable energy practices. These elements not only bridge formal science with daily life but also promote environmental responsibility and cultural appreciation.

By uniting AR, AI, and local wisdom, LenTeRa\_AraLis enables students to engage in energy-related problem-solving, collaborate in project-based tasks, communicate scientific ideas effectively, and internalize values that support sustainability. The media thus acts as a holistic educational tool that merges technological innovation with character development and contextual relevance.



**Fig. 2. Concept map of LenTeRa\_AraLis.**

### 3. Methods

This study adopted a Design-Based Research (DBR) approach to develop the LenTeRa\_AraLis learning media. The DBR model was chosen due to its iterative and reflective characteristics, which are suitable for developing and evaluating innovative educational products in real learning environments. The research procedure followed four main stages: (i) identification and problem analysis, (ii) design, (iii) development, and (iv) reflection.

The study involved students from the Physics Education Study Program who were enrolled in a renewable energy course. The selection of participants was based on their exposure to physics concepts relevant to energy systems and their need for contextual

and interactive learning tools. These students possessed basic digital literacy but had limited experience using AR and AI technologies in their learning process.

The research began with a needs analysis, which identified gaps in students' understanding of renewable energy concepts and the lack of meaningful connection between theoretical physics and local environmental practices. This was followed by the design phase, where the storyboard, learning flow, interface, and integration of local wisdom were conceptualized to form the foundation of the LenTeRa\_AraLis prototype.

In the development phase, 3D assets and animations were created using software such as Blender and Unity 3D, while Vuforia was used for AR implementation. AI components were embedded to allow personalized feedback and adaptive material delivery. Validation was conducted through expert review in three domains: physics content, media quality, and pedagogical alignment with five C skills. Experts evaluated the prototype using a Likert-scale questionnaire, and data were analysed using Aiken's V to determine the validity level of each component.

The final reflection stage involved a limited classroom implementation to observe practicality, identify usability issues, and gather initial student responses. This reflective cycle informed improvements to the learning media, ensuring its readiness for broader application. The design emphasized not only scientific accuracy and interactive features but also alignment with cultural context and the development of 21st-century competencies.

#### **4. Results and Discussion**

LenTeRa\_AraLis was developed as an interactive learning media for physics education students, following the principles of the DBR model. The outcomes of each DBR phase are presented in the following.

##### **4.1. Identification and problem analysis**

The initial phase of the LenTeRa\_AraLis development focused on identifying core challenges in renewable energy learning, particularly in connecting abstract physics concepts to local environmental contexts. Analysis of the existing learning process revealed that instruction remained predominantly theoretical, with limited practical or contextual engagement. As a result, students struggled with conceptual understanding and demonstrated underdeveloped five C skills: critical thinking, creativity, collaboration, communication, and character.

To address this, the development of a learning media that integrates AR, AI, and local wisdom was proposed. The media would specifically contextualize learning through the Halaban charcoal-making process, a local renewable energy practice in South Kalimantan. This approach aimed to support students in building both conceptual knowledge and twenty-first-century competencies through immersive and adaptive experiences.

Participants in this study were students in the Physics Education Study Program. Although they possessed basic digital literacy, they had limited exposure to AR-based instructional tools. However, their motivation increased significantly when learning materials were related to familiar cultural practices. Accordingly, a

technology-supported, locally contextualized learning model was expected to foster deeper engagement and active participation.

An analysis of the learning context also examined available facilities and technological infrastructure. Most students had access to Android or iOS-based smartphones, and the media was designed to utilize AI modules for adaptive learning support. Content integration included physics principles related to renewable energy and local knowledge concerning the Halaban charcoal production process.

The outcomes of this phase included: (i) a clear mapping of learning needs and challenges, (ii) characterization of student digital readiness and motivation, and (iii) specification of the targeted five C skills as key development priorities. These insights formed the foundation for the subsequent design phase.

## 4.2. Designing

Figure 3 presents the storyboard for the LenTeRa\_AraLis learning material, structured around the stages of Halaban charcoal production. The learning design integrates local practices with renewable energy physics concepts to provide interactive, contextualized learning experiences that cultivate students' five C skills.

During this design phase, the learning flow, interface, and content structure were systematically developed. The physics material was anchored in the Halaban charcoal-making process and addressed key scientific principles, including the law of conservation of energy, conduction, convection, radiation, and pyrolysis. The instructional sequence began with an apperception phase, introducing students to traditional uses of Halaban wood, followed by targeted explanations of related physics concepts.

Students were then presented with contextual problems, such as calculating the heat energy produced from specific masses of charcoal. Understanding this matter is important since this phenomenon can be found in daily life [40]. These problem-solving tasks were aligned with challenges designed to foster the five C skills, encouraging students to think critically, design solutions creatively, collaborate in groups, communicate findings, and reflect on sustainability and cultural values.

A distinctive feature of this phase was the integration of AR modules. These included 3D simulations of wood drying, chemical changes during pyrolysis, energy conversion, and thermal processes. AR features were supported by AI components for automatic feedback and personalized learning recommendations. In addition, the design phase incorporated the development of a five C skills assessment instrument to evaluate cognitive and non-cognitive learning outcomes.

Through this structured approach, the media evolved from a content delivery tool into a pedagogical innovation that emphasizes immersive learning, cultural relevance, and twenty-first-century competency development.

Table 1 illustrates the alignment between learning content, AR visualizations, underlying physics concepts, student learning activities, and the integration of five C skills within the LenTeRa\_AraLis framework. Each stage (ranging from drying, carbonization, cooling, packaging, to combustion) is supported by interactive AR that represents real-world processes such as evaporation, thermal conduction, and pyrolysis.

These visualizations guide students in conducting meaningful scientific tasks, including energy calculations, process explanations, simulations, and material testing. The learning sequence culminates in a mini-project where students collaboratively design local energy solutions. This integrated structure ensures that science content is not only delivered but also experienced through contextualized, technology-enhanced learning that fosters critical competencies.

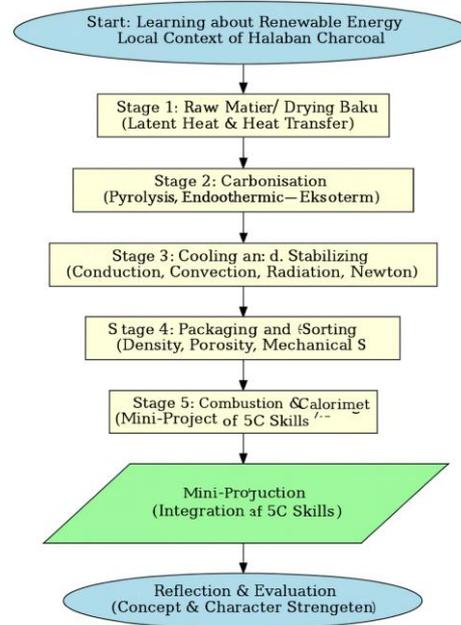


Fig. 3. Storyboard of LenTeRa\_AraLis learning material.

Table 1. Integration between subject matter, AR, physics concepts, student activities, and 5C skills in LenTeRa\_AraLis.

Stage	Visual & AR Description	Physics Concept	Student Activities	5C Integration
Raw Material Drying	AR animation of Halaban wood being dried under the sun, with evaporation effects	Latent heat of vaporization; heat transfer (conduction, convection, radiation)	Calculate the energy required to evaporate water content in the wood	Critical Thinking, Character
Carbonization	AR animation showing the pyrolysis process	Pyrolysis; endothermic/exothermic reactions; $Q = m \cdot c \cdot \Delta T$	Mini-presentation explaining the carbonization process	Critical Thinking, Communication

**Table 1 (continue). Integration between subject matter, AR, physics concepts, student activities, and 5C skills in LenTeRa\_AraLis.**

Stage	Visual & AR Description	Physics Concept	Student Activities	5C Integration
Cooling & Stabilization	AR of burning charcoal transitioning to cooling phases	Newton's Law of Cooling; heat transfer mechanisms	Simulate cooling rates with varying mass and temperature variables	Collaboration, Critical Thinking
Packaging & Sorting	AR of packaged and sorted charcoal based on quality	Density; porosity; mechanical strength	Conduct virtual experiments testing charcoal density and compressive strength	Creativity, Character
Combustion & Heat Testing	AR showing combustion process and heat efficiency visualization	Heat calculation $Q = m \cdot c \cdot \Delta T$ ; energy efficiency	Compare heat efficiency of Halaban charcoal with other fuels	Critical Thinking, Citizenship
Mini Project	Group work synthesizing learned concepts into a product	Integration of heat, density, and efficiency concepts	Develop poster or video proposing local renewable energy solutions	All 5C skills: Critical Thinking, Creativity, Communication, Collaboration, Character

### 4.3. Developing

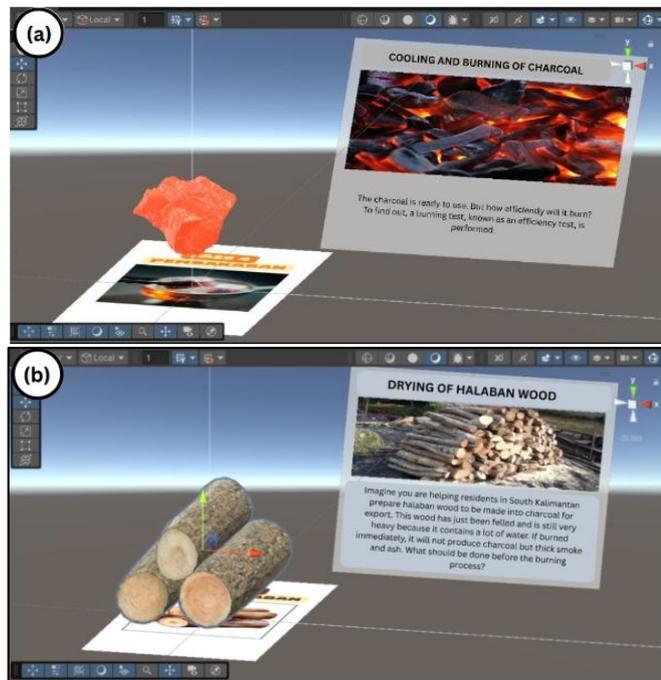
Figure 4 shows the development stage of LenTeRa\_AraLis, which involved implementing the storyboard design into a functional prototype. The development phase began with the creation of 3D visual assets (such as models of Halaban wood and charcoal) designed in Blender. These assets were imported into Unity 3D, the main development platform, and integrated with AR features using the Vuforia Engine. Marker-based tracking allowed students to scan images and trigger animations, such as combustion processes or wood drying simulations.

Two AR illustrations were developed for early deployment: (a) a simulation of the cooling and burning of charcoal and (b) an animation of Halaban wood drying under sunlight, highlighting conduction, convection, and radiation.

Following the prototype development, expert validation was conducted in three areas: (i) content accuracy in renewable energy and physics, (ii) media quality, including visual presentation and interactivity, and (iii) pedagogical suitability for

enhancing five C skills. Experts used a Likert-scale questionnaire, and responses were analysed using Aiken’s V to measure inter-rater consistency and item relevance.

Subsequently, a limited classroom trial was carried out with undergraduate students in physics education. This phase aimed to evaluate the practicality of the media, detect technical issues, and capture student responses to the integration of local cultural content into renewable energy instruction. Observations during the trial indicated improved engagement and strong interest in the AR components.



**Fig. 4. The 3D models of (a) Charcoal and (b) Halaban wood for AR in the unity application.**

#### 4.4. Reflection

Table 2 presents the alignment between the stages of the Halaban charcoal-making process and the corresponding physics concepts embedded in the LenTeRa\_AraLis application. Each stage—from drying raw materials to combustion testing—is designed not only to reflect real-world local practices but also to deepen students’ conceptual understanding of temperature, heat, energy transfer, and thermodynamic principles.

This mapping ensures that every phase of the learning process is anchored in authentic content while reinforcing core physics knowledge. The learning materials integrate fundamental equations, such as latent heat ( $Q = m \cdot L$ ) and sensible heat ( $Q = m \cdot c \cdot \Delta T$ ), alongside qualitative and quantitative models of pyrolysis, Newton’s Law of Cooling, and energy efficiency testing. Through this integration, the application enables students to see the direct relevance of physics in everyday energy practices rooted in local wisdom.

**Table 2. Relationship between physics concepts and material in the application.**

Stage	Physics Concept	Formula	Journal Source
Wood Drying	Latent heat of vaporization; heat transfer	$Q = m \cdot L$	[41]
Carbonization (Pyrolysis)	Heating towards pyrolysis; volatile evolution	$Q = m \cdot c \cdot \Delta T$ (preheating); qualitative description of pyrolysis	[42, 43]
Cooling & Stabilization	Newton's law of cooling; conduction/convection/radiation	$\frac{dT}{dt} = -k(T - T_{\infty})$	[44]
Packaging & Sorting	Density; mechanical strength (compression)	$\rho = \frac{m}{V}, \sigma = \frac{F}{A}$ [40]	[45-47]
Combustion & Heat Test	Water heating; charcoal HHV; thermal efficiency (boil test)	$Q_{water} = m_{water} \cdot c_{water} \Delta T$ $Q_{char.} = m_{char.} \cdot c_{char} \Delta T$ $\eta = \frac{Q_{water}}{Q_{char.}} \times 100\%$	[44, 48-52]

#### 4.5. User interface overview

Figure 5 displays the main interface of the LenTeRa\_AraLis application, which serves as the user's entry point into the learning experience. The main page includes a brief description of the application and a visual representation of Halaban charcoal to provide immediate context for the renewable energy theme. The interface is designed with three primary navigation menus: (i) Learning Material, which provides access to structured physics content; (ii) AR Menu, which enables interactive visualizations through augmented reality features; and (iii) Profile, which offers user guidance and background information about the application. This layout emphasizes ease of access and user-friendly navigation, ensuring that students can explore both conceptual material and AR simulations seamlessly.



**Fig. 5. Main page of the LenTeRa\_AraLis application.**

Figure 6 presents the physics material page of the LenTeRa\_AraLis application, which serves as the central hub for accessing renewable energy content. The page provides structured instructional materials supported by visual elements that

enhance students' conceptual understanding. In addition to content delivery, the interface includes clearly stated learning outcomes and integrated quiz features. These quizzes allow students to assess their comprehension and reflect on their mastery of key physics concepts throughout the learning process. The layout is designed to support self-paced and formative learning, enabling students to engage with the material actively and independently.

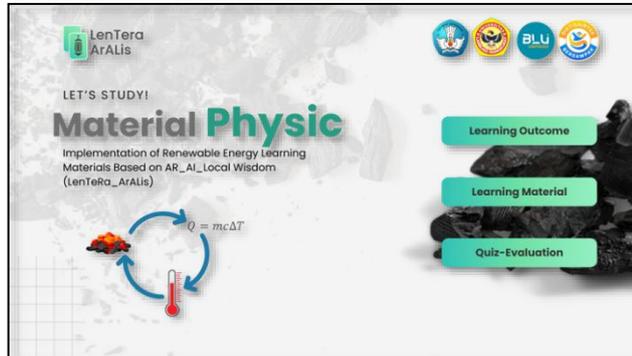


Fig. 6. Physics material page in the LenTeRa\_AraLis application.

Figure 7 shows the Learning Outcome menu, which communicates the instructional goals of the LenTeRa\_AraLis application. This section clearly outlines the expectation that students will master key physics concepts related to Halaban charcoal production while simultaneously developing critical, creative, collaborative, and communicative skills. The learning objectives are aligned with twenty-first-century educational priorities and include an emphasis on character development and citizenship. Each of the five C skills is explicitly articulated: critical thinking involves problem analysis and science-based decision-making; creativity fosters innovation in energy solutions; collaboration emphasizes effective teamwork; communication promotes idea articulation both orally and in writing; and character supports responsibility, discipline, and ethical awareness. The inclusion of global citizenship reflects a broader aim of cultivating environmentally conscious learners who appreciate local values while addressing global energy challenges.

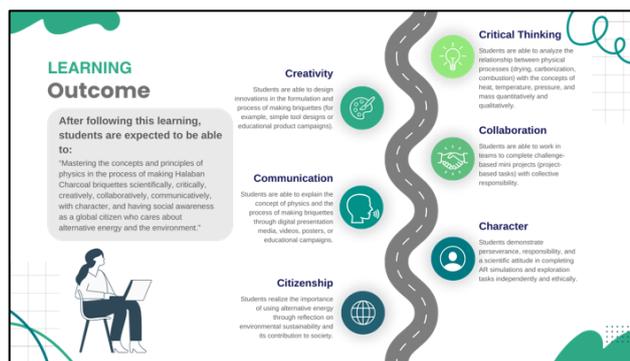
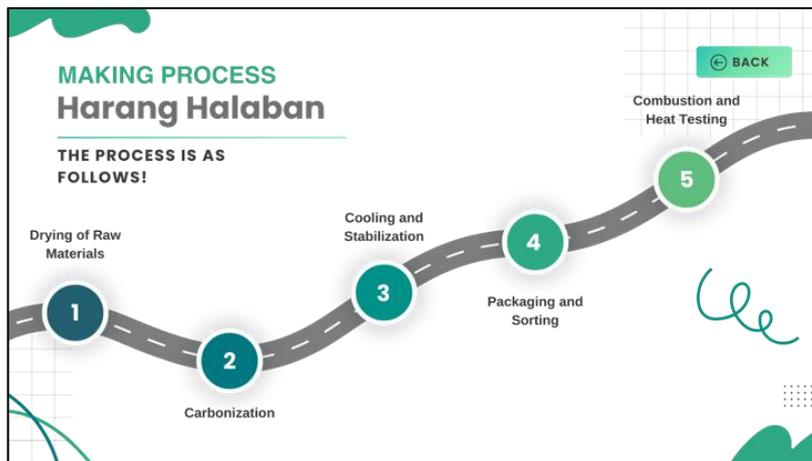


Fig. 7. Learning outcome page of the LenTeRa\_AraLis application.

Figure 8 illustrates the structured Material Page menu that outlines the sequential stages of Halaban charcoal production. These stages serve as the foundation for integrating physics concepts into culturally grounded learning. The flow consists of five interconnected phases: (i) Drying of Raw Materials, where students explore the principles of heat transfer and moisture evaporation; (ii) Carbonization, which introduces the transformation of biomass into charcoal through pyrolysis; (iii) Cooling and Stabilization, which involves thermal regulation to preserve charcoal quality; (iv) Packaging and Sorting, focusing on physical properties such as density and strength; and (v) Combustion and Heat Testing, which allows students to examine energy efficiency and thermal output. This stepwise structure ensures that learners can trace the scientific principles underlying each stage of the charcoal-making process while experiencing them in a culturally and technologically enriched context.



**Fig. 8. Material page menu outlining the charcoal-making stages in LenTeRa\_AraLis.**

Figure 9 illustrates Stage 1 of the learning sequence in the LenTeRa\_AraLis application, focusing on the Drying of Raw Materials. This page introduces students to the initial phase of Halaban charcoal production by presenting an interactive visualization of wood being dried under environmental conditions. The objective is to link this traditional process to physics concepts such as latent heat, conduction, convection, and radiation.

On the right side of the interface, three interactive menu options are provided to enrich the learning experience. The Physics Material menu offers theoretical content explaining the scientific principles behind drying. The AR-Material menu enables students to engage with the process through Augmented Reality, allowing them to observe drying dynamics in real time. Lastly, the Ask to AI feature supports adaptive learning by permitting students to submit questions and receive immediate, tailored responses generated by the system's AI engine.

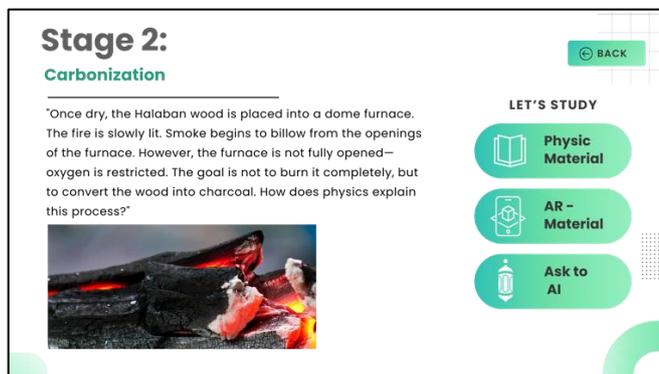
This multimodal approach encourages both conceptual understanding and interactive exploration, fostering critical and reflective engagement with physics principles grounded in local wisdom.



**Fig. 9. Stage 1: Drying of raw materials in the LenTeRa\_AraLis application.**

Figure 10 presents Stage 2 of the charcoal production process in the LenTeRa\_AraLis application, focusing on the Carbonization phase. This stage depicts the transformation of Halaban wood into charcoal through incomplete combustion, a process scientifically known as pyrolysis. The visual display features burning charcoal as a representation of the thermal decomposition of organic material in the absence of sufficient oxygen.

To support deeper learning, the interface includes three interactive menu options. The Physics Material section explains key scientific concepts such as endothermic and exothermic reactions, energy conservation, and the application of the heat transfer equation. The AR-Material allows students to visualize the carbonization process through dynamic, immersive Augmented Reality simulations. The Ask to AI feature facilitates inquiry-based learning, enabling students to pose questions and receive AI-generated explanations that are both scientifically accurate and personalized. This combination of content delivery, visual immersion, and adaptive support helps students understand the carbonization process both scientifically and contextually, while also reinforcing 5C skills development.



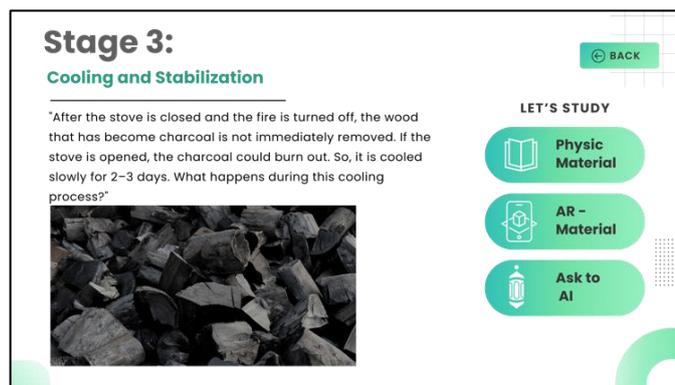
**Fig. 10. Stage 2: Carbonization in the LenTeRa\_AraLis application.**

Figure 11 illustrates Stage 3 of the LenTeRa\_AraLis application, focusing on the Cooling and Stabilization phase in the Halaban charcoal production process.

This stage represents the transition of charcoal from a high-temperature state to a stable condition, which is critical for ensuring product quality and safety before storage or use. The visual component features charcoal undergoing gradual cooling, contextualized within environmental conditions.

To facilitate scientific understanding, the page includes three interactive learning menus. The Physics Material section explores relevant physics concepts, including Newton's Law of Cooling and mechanisms of heat transfer such as conduction, convection, and radiation. The AR-Material menu enables students to interact with Augmented Reality simulations that model the cooling process under varying conditions. The Ask to AI feature allows students to inquire about the process and receive adaptive, AI-generated explanations tailored to their queries.

This interface supports scientific reasoning and contextual learning, enabling students to grasp thermal stabilization as both a physics phenomenon and a vital step in traditional charcoal processing.



**Fig. 11. Stage 3: Cooling and stabilization in the LenTeRa\_AraLis application.**

Figure 12 depicts Stage 4 in the LenTeRa\_AraLis application, which focuses on the Packaging and Sorting phase of the Halaban charcoal production process. This stage involves the classification and storage of charcoal based on physical quality indicators. The visual interface presents charcoal being packaged in bamboo containers, representing a traditional method of storage that aligns with local cultural practices.

To enhance conceptual understanding, the page offers three interactive learning menus. The Physics Material section introduces key scientific concepts such as density, porosity, and mechanical strength, which are essential for evaluating the structural integrity and usability of the charcoal. The AR material enables students to observe and manipulate 3D models that simulate how these physical properties affect sorting criteria. The Ask to AI feature provides an inquiry-based learning experience, allowing students to pose questions and receive context-aware explanations generated by the AI system.

This interactive environment supports students in connecting theoretical physics with practical, real-world quality control processes, reinforcing both scientific reasoning and cultural awareness.



Fig. 12. Stage 4: Packaging and sorting in the LenTeRa\_AraLis application.

Figure 13 presents Stage 5 of the LenTeRa\_AraLis application, centred on the Combustion and Heat Testing phase in the Halaban charcoal-making process. This stage illustrates the process of burning charcoal as a means to examine its thermal performance and energy efficiency, which are critical indicators of fuel quality.

The page integrates three interactive learning menus to guide students through this process. The Physics Material section explains key concepts such as combustion reactions, calorimetry, and heat energy calculations. The AR-Material provides Augmented Reality simulations that model the combustion process and allow students to visualize the thermal behaviour of charcoal under different conditions. The Ask to AI feature supports student inquiry by enabling real-time access to AI-generated explanations tailored to their questions.

Through this combination of theoretical content, visual experimentation, and adaptive support, students are encouraged to understand combustion not only as a chemical and physical process but also as a practical test of renewable energy efficiency.

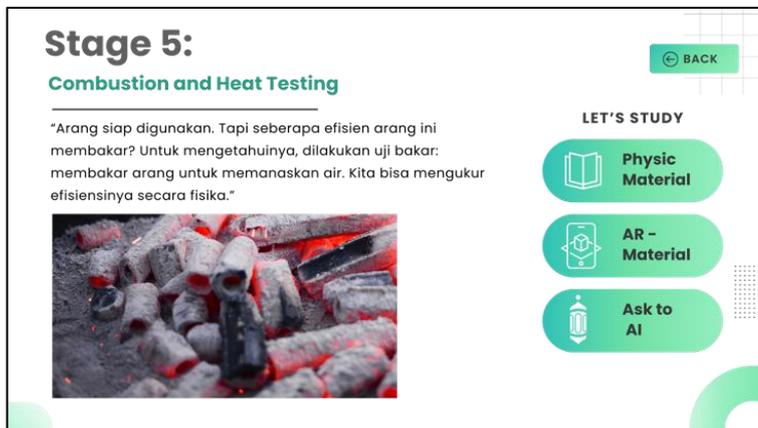
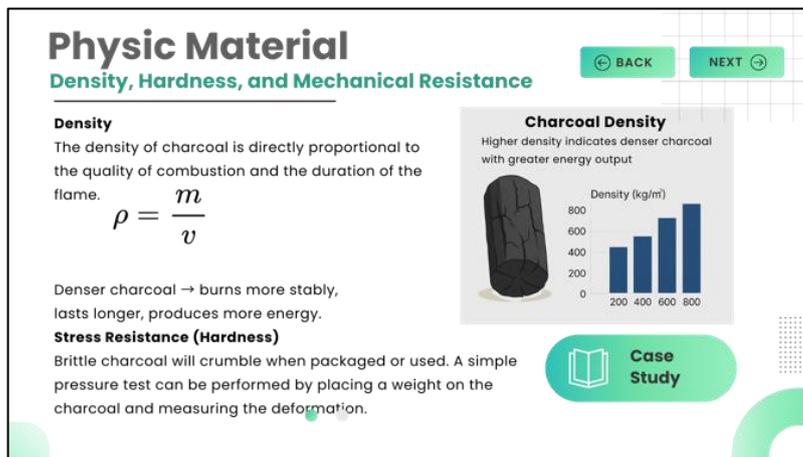


Fig. 13. Stage 5: Combustion and heat testing in the LenTeRa\_AraLis application.

Figure 14 displays the Physics Material page within the LenTeRa\_AraLis application, specifically focusing on the physical characteristics of charcoal in relation to combustion efficiency. The content emphasizes scientific concepts such as density, hardness, and mechanical resistance-critical parameters that influence the performance of charcoal as a renewable fuel source.

The visual component features a chart representing variations in charcoal density, illustrating the correlation between higher density and greater energy output during combustion. To enhance contextual understanding, the page includes a Case Study menu that presents real-world scenarios and datasets. This allows students to examine practical examples and explore how physical properties (such as compactness and structural integrity) affect the quality and efficiency of combustion.

By linking empirical data to conceptual theory, this section encourages students to analyse, interpret, and apply physics principles in evaluating renewable energy materials, fostering deeper critical and scientific thinking.

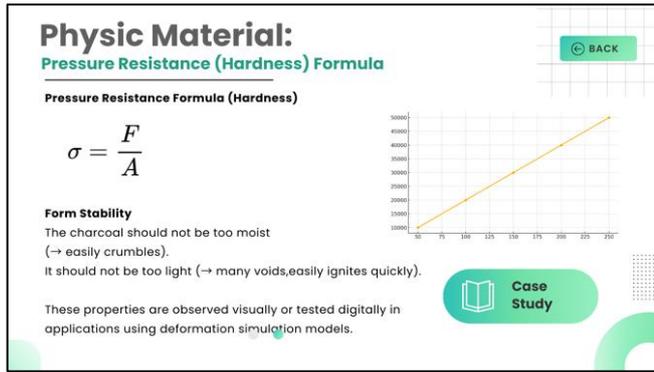


**Fig. 14. Physics material page on density, hardness, and mechanical resistance in LenTeRa\_AraLis.**

Figure 15 presents the Physics Material page of the LenTeRa\_AraLis application, focusing on the concept of Pressure Resistance (Hardness) in the context of charcoal packaging. This section introduces the relationship between applied force and surface area, grounded in the fundamental physics formula for pressure, where pressure is the result of force distributed over a contact area.

The page explains that high-quality charcoal must exhibit optimal mechanical resistance, meaning it should not retain excessive moisture, which would cause it to crumble easily, nor should it be too light, which would indicate high porosity and a tendency to ignite too quickly. These physical traits are linked directly to the durability and safety of the product during packaging, transport, and use.

To support practical learning, the page integrates deformation simulation models that allow students to observe and test these material properties virtually. Through this interactive approach, students can better understand how physics principles inform quality standards in renewable energy materials.

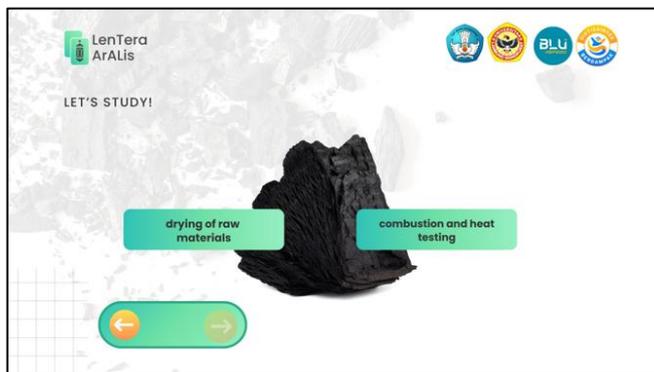


**Fig. 15. Physics material page on pressure resistance and packaging quality in LenTeRa\_AraLis.**

Figure 16 shows the AR Menu interface in the LenTeRa\_AraLis application, which serves as the gateway for students to access AR-based simulations. The page prominently displays a visual representation of charcoal, accompanied by two main AR options: Drying of Raw Materials and Combustion and Heat Testing. These features enable users to explore critical stages in the Halaban charcoal production process through immersive, interactive visualizations.

By selecting these options, students can engage with dynamic 3D simulations that depict the physics principles underlying evaporation, heat transfer, combustion, and energy efficiency. At the bottom of the interface, intuitive navigation buttons allow users to return to the previous screen or proceed to the next activity, ensuring smooth interaction and accessibility.

This menu is designed to enhance conceptual understanding by providing experiential learning opportunities through AR technology. By visualizing abstract processes in a real-world context, students can deepen their comprehension of renewable energy topics while developing spatial reasoning and analytical skills.



**Fig. 16. AR menu page in the LenTeRa\_AraLis application with interactive options.**

Figure 17 displays the Case Study feature in the LenTeRa\_AraLis application, titled *Latent Heat and Heat Transfer*. This page presents a contextualized physics

problem that allows students to apply theoretical knowledge to real-life scenarios. The objective is to strengthen students' understanding of thermodynamic principles through problem-based learning, while also enhancing their analytical and problem-solving skills.

The case study focuses on a sample problem involving 300 kg of Halaban wood with a moisture content of 40%. Students are asked to determine the heat energy required to evaporate the water content in preparation for the carbonization process. The task utilizes the concept of latent heat of vaporization and guides students through the necessary steps, including calculating the mass of water and applying the formula to compute the energy required for phase change.

By solving this practical problem, students gain hands-on experience in applying physics concepts to renewable energy processes grounded in local wisdom. This approach supports critical thinking, contextual reasoning, and mastery of scientific calculations in a meaningful educational setting.

**Case Study**  
**Latent Heat and Heat Transfer**

Answer this question!

A 300 kg piece of Halaban wood has a moisture content of 40%. Calculate the heat energy required to evaporate all the water so that the wood is ready for carbonization. Use the latent heat of vaporization of water.

Ready  
**FOR NEXT QUESTION?**  
 Next

**Answer:**

Step 1: Counting mass of water:  
 •  $m = 0,4 \times 300 = 120$  kg

Step 2: counting the energy :  
 •  $Q = \dots\dots$

BACK

**Fig. 17. Case study: Latent heat and heat transfer in the LenTeRa\_AraLis application.**

#### 4.6. Media validation and scientific discussion

The validation of the LenTeRa\_ARaLis learning media was conducted through expert evaluation involving three validators representing the domains of material, media, and learning. Using a four-point Likert scale (1 = very poor to 4 = very good), all items were rated within the 3 and 4 range. The average score across all items was 3.683, which falls within the good to very good category. This indicates that the media was perceived as appropriate in terms of physics content accuracy, interface appearance, interactivity, and integration of local cultural contexts.

In terms of quantitative validation, Aiken's V coefficient was calculated at 0.683, indicating moderate to quite strong content validity. According to validation standards, a coefficient  $\geq 0.60$  is considered acceptable, while a coefficient of  $\geq 0.80$  is considered very strong. These results suggest that the media is suitable for limited implementation, although minor revisions may be applied to improve items with lower V values. The validators affirmed that the application sufficiently addressed key physics topics (such as latent heat, heat transfer, pyrolysis, and combustion efficiency) while also supporting the development of 5C skills.

These findings align with prior meta-analyses on the impact of AR in science, technology, and engineering education, which consistently demonstrate AR's effectiveness in improving learning outcomes, engagement, and understanding of abstract concepts [1]. Furthermore, systematic reviews confirm AR's advantages for motivation and knowledge retention, although they emphasize the importance of interface design, mirroring the recommendation from the validator feedback for minor revisions [1].

The pedagogical approach of LenTeRa\_ARaLis also reflects broader trends in STEM and sustainability education. Prior studies show that AR can significantly enhance learning outcomes related to complex scientific processes, particularly in visualizing difficult concepts such as those presented in this application (drying, pyrolysis, cooling, and energy efficiency) in 3D interactive formats [53]. Cross-disciplinary evidence further indicates that AR and VR tools support the Education for Sustainable Development (ESD) agenda, making the integration of local wisdom-based renewable energy, such as Halaban charcoal, highly relevant for sustainability-focused curricula [54].

In terms of scientific content validity, the modelling of pyrolysis in the carbonization stage refers to classical studies on biomass decomposition and the transport of heat and mass during thermal degradation. These sources support the presentation of volatile gas formation and char production as observed in the simulation-based visuals and learning flow [42]. Similarly, the combustion and heat testing module is grounded in established thermochemical calculations, including Higher Heating Value (HHV) estimates from elemental analysis, which validate the design of example problems involving energy efficiency and charcoal performance metrics [44].

Empirical studies on stove performance and fuel testing also reinforce the use of boiling tests and emissions evaluations to assess the quality of solid fuels. These findings support the scientific rationale behind the combustion efficiency activities in the LenTeRa\_ARaLis application [55]. Furthermore, the integration of local cultural knowledge into science learning (highlighted by the use of Halaban charcoal) has been widely recommended in literature as a way to increase educational relevance, foster cultural preservation, and promote sustainable science learning [48, 49].

In summary, the LenTeRa\_ARaLis media demonstrates content validity, pedagogical effectiveness, and contextual relevance. It integrates physics concepts, AR technology, and local wisdom into a cohesive platform that supports both conceptual learning and the development of 21st-century skills. These qualities affirm their readiness for broader implementation within renewable energy education frameworks aligned with sustainability goals [1, 42, 44, 53-55].

## **5. Conclusions**

This study concludes that the development of a learning media integrating AR, AI, and local wisdom is effective in enhancing students' 21st-century competencies (specifically the 5C skills: critical thinking, creativity, collaboration, communication, and character). Expert validation confirmed high quality in content, interactivity, and design, while limited trials showed positive student responses. The media successfully visualized abstract physics concepts and supported active, contextual, and adaptive learning. These findings indicate its

potential as an innovative, pedagogically grounded tool for strengthening conceptual understanding and competency-based science education.

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