

ANALYSIS OF TRENDS AND INNOVATIONS IN SCIENCE LEARNING MEDIA ON THE TOPIC OF EARTH STRUCTURE (2020- 2026): A LITERATURE REVIEW

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ABSTRACT

21st-century education requires the integration of technology in science learning to overcome misconceptions regarding Earth's structure, which reach 55–64% among junior high school students. This research aims to analyze innovation trends in learning media and examine the characteristics, advantages, and challenges of their implementation. The method used is a Systematic Literature Review (SLR) following PRISMA guidelines to ensure transparency and quality in data synthesis. A total of 16 relevant articles were identified from Scopus-indexed publications ranging from Q1 to Q4 quartiles. These articles, which specifically discuss learning media for Earth's structure topics, were published between 2020 and 2026. The results show a transformation of media toward interactive, immersive, and data-driven technologies that offer three-dimensional visualization and experiential learning. Simulation-based media and Virtual Reality (VR) dominate due to their advantages in supporting spatial inquiry and analysis, despite cost constraints and the risk of cybersickness. Meanwhile, video and animation remain relevant as foundational tools for conceptual understanding to avoid cognitive overload. This study concludes that the effectiveness of media depends on the integration of active learning strategies aligned with digital literacy and subject matter characteristics. This review provides comprehensive references to optimize science learning and minimize student misconceptions about Earth's structure. However, this study is limited by potential publication bias and the restricted inclusion of articles indexed primarily in Scopus and other accessible databases.

Keywords: learning media; structure of the earth; SLR; innovation; science

INTRODUCTION

21st-century education necessitates significant transformations within the educational system, one of which is the integration of technology as a learning medium to bolster students' skills, particularly in science (Rahayu et al., 2022). According to Hamzan (2022), science education aims to facilitate the mastery of complex concepts, fostering learning that is both contextual and meaningful. To achieve optimal learning outcomes, this can be implemented through effective instructional methods and the strategic application of technology.

The success of science education can be measured by students' ability to apply knowledge acquired in formal settings to their surrounding environment (Ansya & Salsabila, 2025). Therefore, science learning must be contextual, ensuring students feel a connection to the subject matter. One topic that is complex yet highly relevant to students' lives is Earth's structure. According to Ummah et al. (2025), Earth's structure is often perceived as an abstract topic at the junior high school level. This is further supported by Hutapea & Atmojo (2025), who found that this material is frequently prone to

misconceptions, with rates ranging from 55% to 64%. Consequently, concrete solutions are required to make the learning process more meaningful.

The view of learning theory with an emphasis on spatial intelligence confirms that the use of Virtual Reality (VR) and Augmented Reality (AR) technologies can represent visuals that build more accurate mental models of abstract concepts, thereby training the ability to discern, describe, and transform the spatial visual world (Wijayanto et al., 2020). In line with these needs, the technology used is expected to present objects in an interactive, immersive, and three-dimensional manner, which has the potential to increase students' understanding of concepts and spatial visualization skills, especially in science learning. However, research using a randomized controlled trial (RCT) design to test the effectiveness of VR/AR media on learning the structure of the Earth at the junior high school level is still relatively limited, especially in the context of developing countries (Radianti et al., 2020). Research related to technologies such as VR and AR is still dominated by development and experimental methods (Zhang et al., 2021), although it is undeniable that analyzing media innovation trends is also necessary to identify the direction of future research development.

Observations made by the author during teaching practices in several junior high schools align with these findings. Instruction regarding Earth's layers often relies solely on verbal explanations or textbooks, which is insufficient for building a comprehensive contextual understanding. According to Kamila & Sukartono (2023), students require learning environments that enhance understanding through visual representations, models, or scientific

simulations to bolster engagement. To address this, Augmented Reality (AR) and Virtual Reality (VR) have emerged as technologies that integrate virtual objects into real-world environments and vice versa (Darlianti et al., 2025). Furthermore, Zhu et al. (2016) noted that developing media for Earth structure topics can utilize real-time data from tools like Google Earth. The integration of such interactive media fosters student involvement (Hakim & Wibowo, 2023) and simplifies the teaching of geological concepts that are otherwise difficult to observe directly.

Studies specifically analyzing development trends in science learning media regarding Earth's structure as well as examining their characteristics and innovation potential remain limited. In contrast to geoscience topics such as volcanism or earthquakes, which can be observed through phenomena on the Earth's surface, the material on Earth's structure discusses internal layers that cannot be directly observed by students (Alisanti et al., 2025). This condition demands higher spatial visualization skills, requiring students to build understanding through visual representations, models, or three-dimensional simulations (Wijayanto et al., 2020). Therefore, the development of learning media is crucial for the topic of Earth's structure to help students form accurate mental models of abstract and invisible concepts. Existing research primarily focuses on isolated media types, thereby failing to provide a holistic overview. Consequently, a systematic literature review is necessary to analyze various scientific sources related to instructional media for Earth's structure, ensuring that innovations and their implications for science education are

clearly elucidated. This study addresses the following research questions:

RQ1: What are the trends and innovations in science learning media focused on Earth's structure topics?

RQ2: What are the advantages and challenges of utilizing these learning media in Earth's structure education?

The objective of this study is to systematically review the existing literature

to analyze innovation trends, characteristics, and the implementation potential of science learning media on the topic of Earth's structure. Specifically, it seeks to evaluate the effectiveness of these technologies in minimizing student misconceptions and fostering meaningful learning through interactive and immersive experiences.

METHODS

This study uses a Systematic Literature Review (SLR) to identify, evaluate, and synthesize empirical findings regarding the development and transformation of Natural Science learning media on Earth's structure topics. The SLR approach was chosen for its ability to provide a comprehensive overview of existing research, as well as to systematically identify research patterns, trends, and gaps. Additionally, this method provides a stronger foundation for evidence-based decision-making compared to traditional narrative reviews (Snyder, 2019). Thus, this approach ensures that the analysis of science learning media trends remains objective, rigorous, and free from

the inherent biases often found in less structured reviews.

The implementation of this systematic review refers to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, designed to guarantee transparency, replicability, and quality of reporting (Page et al., 2021). The retrieved data are managed using Microsoft Excel for the initial filtering process, duplication removal, and selection based on inclusion and exclusion criteria. Furthermore, Mendeley is utilized as a reference and citation management tool to ensure a systematic and organized citing process. The PRISMA diagram is shown in Figure 1.

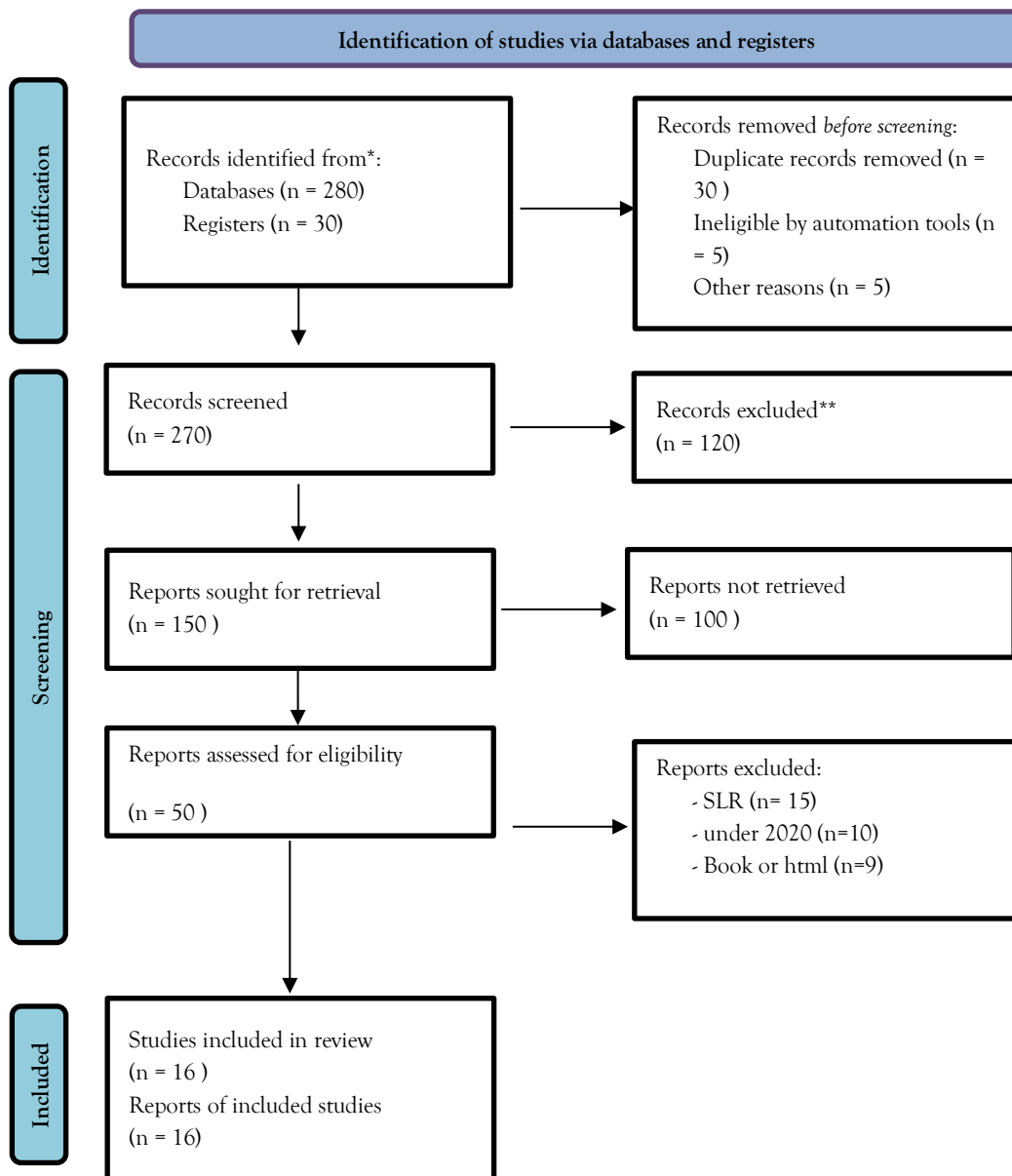


Figure 1. PRISMA Flowchart

The screening process in this study was conducted systematically through several stages. The first stage involved the identification of articles, where 310 records were retrieved from various databases. After removing duplicates, 270 articles remained for further evaluation. The next stage consisted of screening titles and abstracts for relevance, which narrowed the selection down to 150 articles. These remaining articles then underwent a full-

text eligibility assessment to ensure they aligned with the predetermined criteria, resulting in 50 eligible articles. In the final stage, 16 articles were determined for synthesized analysis, as they strictly met all inclusion and exclusion criteria.

The literature search process was conducted systematically across several reputable scientific databases, including Scopus, Web of Science, ERIC, and Google Scholar. This Systematic Literature Review

(SLR) followed the PRISMA guidelines, and the review protocol was registered through the Open Science Framework (OSF) to ensure transparency and methodological consistency. Search strings were developed using a combination of Boolean operators (AND, OR) to broaden and refine the results: ("augmented reality" OR "virtual reality" OR "interactive multimedia" OR "interactive simulation" OR "simulation-based learning") AND ("science education" OR "earth science education" OR "STEM education") AND

("Earth structure" OR "layers of the Earth" OR "Earth's internal structure" OR "plate tectonics") AND ("learning outcomes" OR "conceptual understanding" OR "scientific literacy" OR "student engagement"). Article selection was conducted independently by two reviewers, and inter-rater reliability analysis using Cohen's Kappa showed a strong level of agreement ($k = 0.84$), indicating high consistency in the screening process. The inclusion and exclusion criteria are detailed in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Articles published in the year 2020–2026	Articles published before 2020
Focuses on science/geoscience learning (earth structure, geology, earthquakes, volcanism, disaster mitigation, etc.)	Not related to learning science or geoscience
Using innovative technology-based media (VR, AR, Web-GIS, 3D simulation, interactive videos, educational games, etc.)	Conventional media without technological innovation
Articles indexed on reputable databases (Q1–Q4)	Unindexed articles
Articles in the form of original research	Articles in the form of literature reviews

Data Analysis

The data analysis in this study employs a thematic analysis approach to identify and synthesize patterns of findings from the articles retrieved through the Systematic Literature Review (SLR) process. The analysis procedure follows the stages developed by Braun and Clarke, which include familiarization, initial coding, grouping codes into themes, reviewing and validating themes, and defining and naming the final themes. Data from each article are coded based on key aspects, such as the type of technology (Augmented Reality, Virtual Reality, and

interactive simulations), the context of science learning specifically Earth's structure concepts research methods, and outcomes such as enhanced conceptual understanding and student engagement. Furthermore, codes with similar meanings are grouped into overarching themes representing research trends and variable relationships. The results are then presented descriptively to reveal research trends, identify the advantages and limitations of previous studies, and pinpoint relevant research gaps as a foundation for future research development.

RESULTS AND DISCUSSION

A total of 16 relevant articles were identified from Scopus-indexed

publications ranging from Q1 to Q4 quartiles. These articles, which specifically

discuss learning media for Earth's structure topics, were published between 2020 and 2026. The comprehensive matrix of articles

that met the inclusion criteria is presented in Table 2.

Table 2. Matrix of Articles Used in Research

References	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Willis & Stern (2025)	✓	✓	✓	✓	✓
Aludos et al (2025)	✓	✓	✓	✓	✓
Horota et al (2022)	✓	✓	✓	✓	✓
Fleming (2022)	✓	✓	✓	✓	✓
Ishutov et al (2021)	✓	✓	✓	✓	✓
Easter (2026)	✓	✓	✓	✓	✓
Hakim et al (2022)	✓	✓	✓	✓	✓
Feng et al (2020)	✓	✓	✓	✓	✓
Volioti et al (2022)	✓	✓	✓	✓	✓
Nirmala et al (2025)	✓	✓	✓	✓	✓
Mansour et al (2025)	✓	✓	✓	✓	✓
Faria (2024)	✓	✓	✓	✓	✓
Garg & Hats (2022)	✓	✓	✓	✓	✓
Hansen et al (2022)	✓	✓	✓	✓	✓
Chenrai & Keir (2021)	✓	✓	✓	✓	✓
Fang et al (2025)	✓	✓	✓	✓	✓

(*) A check mark (✓) indicates that the article meets the inclusion criteria

Media Trends and Innovations in Earth Structure Materials

Based on data collected from a total of 16 articles, a mapping of the types of media used as a means of conveying information on earth structure material has

been carried out. Graphs of trends and innovations in earth structure learning media based on the articles obtained are shown in Figure 2. The topics of the material studied using the learning media that have been found are shown in Table 3.

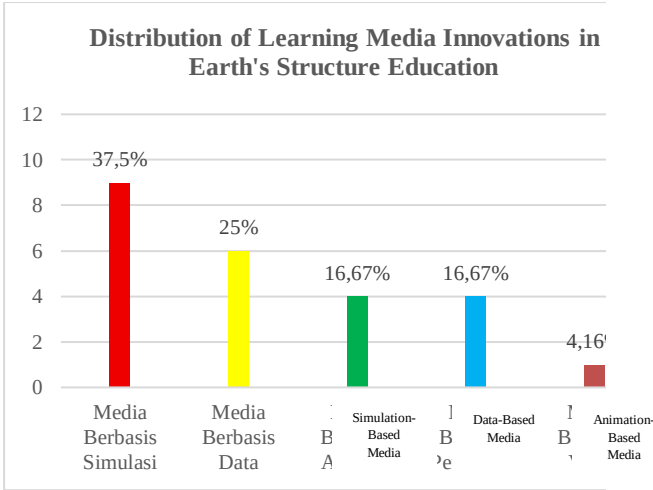


Figure 2. Distribution of Learning Media Innovations in Earth Structure Education

Table 3. Science Learning Media Earth Structure Material

References	Types of Learning Media Innovation	Topic/ Material
Willis & Stern (2025)	Video Animation	Metamorphism and Plate tectonics
Aludos et al (2025)	Card Game	Earth Science Concepts
Horota et al (2022)	Immersive Virtual Reality (iVR) and georeferenced data	Geology
Fleming (2022)	Virtual Outcrop Models (VOMs) and Field Data Photo	Geological Concepts (Folds and Cracks)
Ishutov et al (2021)	Application of 3D printing, geoscience data sets, digital model (CAD)	Geological Structures, Topography, Rocks
Easter (2026)	Google Earth	Earth's Crust and Natural Phenomena
Hakim et al (2022)	Landsat-8 and Sentinel-2 satellite imagery, as well	Volcanoes

References	Types of Learning Media Innovation	Topic/ Material
Feng et al (2020)	Immersive Virtual Reality, Serious Games	Earthquake preparedness, behavioral response, post-earthquake evacuation
Verma et al (2022)	Game-based Augmented Reality	Geography learning (visualization of concepts, maps, geographical phenomena)
Nirmala et al (2025)	Web-GIS InaRisk, model group investigation	Disaster mitigation, risk map
Mansour et al (2025)	Game-based Augmented Reality	Earth and space
Faria (2024)	Marker-based Augmented Reality (AR) and interactive 3D models	Volcanism (Volcanic structure and eruption processes)
Garg & Hats (2022)	Simulation of 3D Magma Dynamics	Volcanoes
Hansen et al (2022)	Virtual Reality (VR) in the form of the VolcanoVR application	Volcanic Eruptions
Chenrai & Keir (2021)	Digital data in the form of 2D and 3D seismic datasets	Geoscience (structural geology and seismic interpretation)
Fang et al (2025)	Virtual Reality (VR)-based digital learning	Structure of the earth and geological phenomena (rocks, faults, weathering)

Overall, simulation-based media were the most predominantly used, appearing in 9 articles (37.5%), indicating a strong tendency toward presenting interactive, procedural, and experiential learning experiences to help students understand complex material. Data-driven media ranked second, with 6 articles (25%), emphasizing the importance of presenting valid information through data visualization and analysis. Meanwhile, animation-based and game-based media were each used in 4 articles (16.67%), playing a role in visually clarifying abstract concepts while increasing students' active engagement. In contrast, video-based media appeared in only 1 article (4.16%), an interesting finding that suggests that although videos are generally popular, they receive less attention than more interactive media in the context of this study.

Discussion based on Table 3 shows that learning media innovations in the field of earth sciences are developing in highly diverse ways and tend to align with the complexity of the subject matter characteristics. Each type of media is selected not only based on technological advancements, but also adapted to the needs of concept representation, ranging from abstract and dynamic concepts to those requiring spatial visualization and contextual experience. A critical review of the evidence indicates that studies reporting positive effects of learning media vary in methodological rigor, where some use quasi-experimental or experimental designs with control groups, while many others rely on descriptive surveys or small case studies that mainly capture perceptions rather than learning outcomes, thus limiting the strength of causal claims. Simple visual-based media, such as videos and animations (Willis & Stern, 2025), are widely used in

metamorphism and plate tectonics topics because they are able to visualize long-term processes that are difficult to observe directly. This suggests that non-interactive media remain relevant as an initial stage for building conceptual understanding before students engage in more complex learning experiences.

Furthermore, game-based media such as card games and AR-based games (Aludos et al., 2025; Volioti et al., 2022; Mansour et al., 2025) are used to increase students' active engagement in topics related to basic earth science, geography, and earth and space concepts. This approach emphasizes engagement and collaboration through interactive learning experiences.

Meanwhile, the development of immersive technologies such as Immersive Virtual Reality and VR applications, including *VolcanoVR* (Horota et al., 2022; Feng et al., 2020; Fang et al., 2025; Hansen et al., 2022), shows a shift toward experiential learning, particularly for complex and high-risk topics such as geology, Earth's structure, and disaster mitigation. These media allow students to gain learning experiences that closely resemble real-world conditions without immediate risk.

In addition, data-driven media and modeling tools such as Google Earth, InaRisk Web-GIS, satellite imagery, 3D printing, VOMs, magma simulations, and seismic datasets (Pascu, 2026; Nirmala et al., 2025; Hakim et al., 2022; Ishutov et al., 2021; Fleming, 2022; Garg & Papale, 2022; Chenrai & Keir, 2021) emphasize the importance of spatial analysis, data interpretation, and research-based approaches. These media not only help students understand concepts, but also develop critical thinking skills and data-

driven decision-making. Overall, the more complex the subject matter, the more interactive, immersive, and data-driven media are needed. On the other hand, for basic concepts, simpler media are still effective. Therefore, the selection of learning media must consider their suitability to the characteristics of the material and the learning objectives in order to create meaningful and contextual learning experiences.

Analysis of the advantages and disadvantages of learning media

The analysis of the advantages and disadvantages of learning media in Earth structure topics is presented in Table 4. The

table compares various types of media used, including simulation-based media, videos, data-driven media, animations, and educational games, together with key findings related to their effectiveness and implementation challenges. Through this analysis, it can be identified how each type of media contributes differently to supporting students' understanding of the concept of Earth's structure, while also revealing limitations that need to be considered in practice. Therefore, the findings presented in this table provide an important basis for determining more optimal and contextual strategies for the selection and integration of learning media.

Table 4. Analysis of the Advantages and Disadvantages of Learning Media

Categories Media innovation	References	Key Advantages Findings	Weaknesses/Challenges Findings
Simulation-Based Media (VR, 3D Printing, HPC Simulation, VOM)	Horota et al (2022); Fleming (2022); Ishutov et al (2021); Easter (2026); Hakim et al (2022); Feng et al (2020); Faria (2024); Hansen et al (2022); Fang et al (2025)	3D/tactile visualization of concrete; safe observation access to remote/hazardous locations; high modeling accuracy.	Cost & specifications of computing tools are high; requires special technical expertise; risk of cybersickness.
Video-Based Media	Willis & Stern (2025)	Effective for reinforcing basic concepts; high accessibility and easy to integrate in the classroom.	Less than optimal for complex tectonic systems; prone to cognitive overload.
Data-Driven Media (Spatial Platforms, Web-GIS, InaRisk, Google Earth, AR)	Horota et al (2022); Fleming (2022); Ishutov et al (2021); Nirmala et al (2025); Hansen et al (2022); Chenrai & Keir (2021)	Exploration of direct/kinesthetic data (embodied learning); strengthens spatial analysis and critical thinking.	Heavily reliant on the internet; Need qualified equipment and basic spatial/digital literacy.
Animation Media	Willis & Stern (2025); Feng et al (2020); Faria (2024); Garg & Hats (2022)	Effective dynamic visual representation to clarify abstract concepts.	Low physical interactivity; placing students only as passive observers.
Educational Game-based Media	Aludos et al (2025); Feng et al (2020); Volioti et al (2022); Mansour et al (2025)	Engagement is very high; encourages collaboration/discussion; safe for simulating disaster procedures.	Initial instructions are often confusing; it takes time to adapt; Entertainment elements risk distracting from the main material.

The discussion of the results presented in Table 4 shows that each category of learning media innovation makes a distinct contribution to supporting concept understanding, particularly in complex topics such as the Earth system, while also facing limitations that should be considered during implementation. Simulation-based media such as VR, 3D printing, HPC simulation, and VOM (Horota et al., 2022; Fleming, 2022; Ishutov et al., 2021; Easter, 2026; Hakim et al., 2022; Feng et al., 2020; Faria, 2024; Hansen et al., 2022; Fang et al., 2025) demonstrate key advantages by providing concrete and even tactile three-dimensional visualizations. This allows learners to understand abstract phenomena through more immersive and contextual experiences, including observing hard-to-reach or dangerous areas firsthand. The high level of modeling accuracy also supports inquiry-based learning. However, their implementation is still constrained by the need for high-specification devices, relatively high costs, and technical competency requirements for both teachers and students. In addition, the use of VR has the potential to cause cybersickness, which may reduce students' comfort during learning. Video-based media (Willis & Stern, 2025) has proven to be effective in strengthening the understanding of basic concepts due to its accessible nature and flexibility to be used in a variety of learning scenarios. Video is also relatively easy to integrate into online and offline learning. However, for more complex concepts such as tectonic dynamics, these media are less able to represent processes in depth. In addition, the presentation of information that is too dense in the video has the potential to cause cognitive overload, thus hindering student understanding.

Data-driven media such as spatial platforms, Web-GIS, InaRisk, Google Earth, and AR (Horota et al., 2022; Fleming, 2022; Ishutov et al., 2021; Nirmala et al., 2025; Hansen et al., 2022; Chenrai & Keir, 2021) provide a more active learning experience through hands-on data exploration. This approach supports embodied learning, in which students not only observe but also interact with data, thereby improving spatial analysis and critical thinking skills. However, the effectiveness of these media is highly dependent on the availability of a stable internet connection, adequate devices, and sufficient digital and spatial literacy, which may not always be available to all learners.

Animation media (Willis & Stern, 2025; Feng et al., 2020; Faria, 2024; Garg & Papale, 2022) offer the advantage of presenting dynamic visual representations to explain abstract concepts. Animation can simplify complex processes, making them easier to understand through visual movement. However, the main limitation of these media is their low level of interactivity, so students tend to become passive recipients of information. This has the potential to reduce deeper cognitive engagement when not combined with active learning strategies.

Overall, no single type of media is universally superior for all learning objectives. Therefore, an integrative approach that combines multiple forms of media is recommended, allowing the strengths of each medium to complement one another while reducing their respective limitations. Such an approach aligns with the demands of 21st-century learning, which emphasizes interactive, contextual, and learner-centered learning experient

CONCLUSION

Learning media innovations in Earth structure education are increasingly shifting toward interactive, immersive, and data-driven technologies that enable three-dimensional visualization and experiential learning for complex subject matter. While simulation-based tools and VR are particularly effective in promoting spatial inquiry and analytical thinking, their adoption remains limited by high costs, technical requirements, and the potential risk of cybersickness. Meanwhile, conventional media such as videos and animations continue to play an important foundational role in developing initial conceptual understanding, provided they are carefully designed to minimize cognitive overload. Overall, the effectiveness of any media depends largely on its integration with active learning strategies that correspond to learners' digital literacy and the characteristics of the content.

To strengthen future development, three key recommendations are proposed: researchers should prioritize rigorous randomized controlled trials (RCTs) in junior high schools for stronger causal evidence; educators need targeted training in spatial literacy and digital technology integration to optimize classroom media; and policymakers should back systematic cost-effectiveness analyses to ensure investments in tools like VR are both pedagogically effective and economically sustainable.

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