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DEVELOPMENT AND EFFECTIVENESS OF POP-UP BOOK MEDIA INTEGRATED WITH AUGMENTED REALITY FOR SCIENCE LEARNING IN ELEMENTARY SCHOOL

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Abstract

This research aimed to develop, validate, and test the effectiveness of pop-up book integrated with augmented reality (AR) technology for teaching Earth structure concepts in 5th-grade students. The study employed a Research and Development (R&D) approach using the ADDIE model (Analyze, Design, Development, Implementation, Evaluation). The participant group consisted of 30 fifth-grade students at SDN Bandungan 01, Semarang. Data collection involved validation questionnaires from subject matter experts and media experts, teacher and student response questionnaires, and pretest-posttest assessments. Results indicated that the developed media received very favorable validation ratings from subject matter experts (90%) and media experts (97%). Both teachers (100%) and students (92%) provided highly positive feedback regarding the media's usability and attractiveness. Statistical analysis using paired sample t-tests revealed a significant difference in student learning outcomes ($p = 0.000 < 0.05$), with mean scores improving from 53.97 (pretest) to 79.72 (posttest), representing a moderate effect size (N-Gain = 0.55). These findings suggest that pop-up book integrated with augmented reality technology is an effective and viable instructional tool for enhancing student comprehension of complex abstract concepts in earth structure.

Keywords: Augmented Reality, Pop-Up Book, Earth Structure, Elementary Education, Learning Effectiveness

Abstrak. Penelitian ini bertujuan untuk mengembangkan, memvalidasi, dan menguji efektivitas media Pop-Up Book berbasis Augmented Reality (AR) untuk mengajarkan konsep struktur lapisan bumi pada siswa kelas 5 SD. Studi ini menggunakan pendekatan Penelitian dan Pengembangan (R&D) dengan model ADDIE (Analisis, Desain, Development, Implementasi, Evaluasi). Kelompok partisipan terdiri dari 30 siswa kelas 5 SD di SDN Bandungan 01, Kabupaten Semarang. Pengumpulan data melibatkan kuesioner validasi dari ahli materi dan ahli media, kuesioner tanggapan guru dan siswa, serta asesmen pretest- posttest. Hasil menunjukkan bahwa media yang dikembangkan mendapat peringkat validasi yang sangat baik dari ahli materi pelajaran (90%) dan ahli media (97%). Baik guru (100%) maupun siswa (92%) memberikan umpan balik yang sangat positif mengenai kegunaan dan daya tarik media tersebut. Analisis statistik menggunakan uji t sampel berpasangan mengungkapkan perbedaan signifikan dalam hasil belajar siswa ($p = 0,000 < 0,05$), dengan nilai rata-rata meningkat dari 53,97 (pretest) menjadi 79,72 (posttest), yang menunjukkan ukuran efek sedang (N-Gain = 0,55). Temuan ini menunjukkan bahwa media Pop-Up Book berbasis Augmented Reality merupakan media pembelajaran yang efektif dan layak untuk meningkatkan pemahaman siswa terhadap konsep abstrak yang kompleks dalam pembelajaran struktur lapisan bumi.

Kata-kata Kunci : *Augmented Reality, Pop-Up Book,* Struktur Bumi, Pendidikan Dasar, Efektivitas Pembelajaran

Introduction

Education serves as a cornerstone for national development and progress (Indonesian Law on National Education System No. 20 of 2003, 2003). The quality of education is significantly determined by the learning process and the instructional methods employed. Learning, as conceptualized by (Slameto, 2018) represents an individual's effort to acquire comprehensive behavioral changes through personal experience within their environment. Consequently, the teaching-learning process constitutes a critical component in which educators transmit knowledge and skills to learners.

The integration of Natural Science (IPA) and Social Studies (IPS) under Indonesia's Merdeka Curriculum resulted in a combined subject known as Natural and Social Science (IPAS). IPAS is designed as an integrated subject that connects scientific and social perspectives, enabling students to develop a holistic understanding and contextual reasoning aligned with real-life phenomena (Kemendikbudristek, 2022). Furthermore, (Rambe et al., (2024) emphasized that IPAS learning has significant potential to prepare human resources for the globalization era by developing critical thinking skills, addressing social issues, instilling ethical and aesthetic values, and fostering independence, creativity, and responsibility among learners.

However, current IPAS learning outcomes remain suboptimal. This condition is reflected in international assessment results. The Programme for International Student Assessment (PISA) 2022 reported that Indonesian students' average science achievement score was 383, indicating performance below the OECD average (OECD, 2023). Similarly,

results from the Trends in International Mathematics and Science Study (TIMSS) 2015 showed that Indonesia's science achievement score remained relatively low compared to participating countries (Retnowati & Ekayanti, 2020). Collectively, these findings highlight the need for instructional innovations that can enhance students' conceptual understanding and engagement in science learning.

Instructional media function as intermediaries that support the delivery of learning content by enhancing students' cognitive processing, attention, and motivation. According to (Ahmadi, 2017), instructional media assists in clarifying presented content, facilitating effective and efficient achievement of learning objectives. The pedagogical significance of instructional media extends beyond simple content delivery; such tools fundamentally restructure how learners process and internalize complex information. Edgar Dale's Cone of Experience framework provides theoretical grounding for media selection in education (Arsyad, 2013). The cone illustrates that learning progresses from concrete, direct experiences toward increasingly abstract representations.

Pop-Up books represent three-dimensional literary works that incorporate movable elements and tactile components (Dzuanda in Nengsi, Anggoro, & Nuryatin, 2021). (Setiyanigrum, 2020) describes pop-up books as three-dimensional media whose opening mechanism creates immediate visual impressions matched to instructional content. These books engage multiple sensory modalities, incorporating visual, kinesthetic, and tactile learning pathways. Empirical evidence supports pop-up book effectiveness. Research by (Elisa, 2018) examining pop-up book implementation in third-grade science education demonstrated validation scores of 95.8% (subject matter experts), 88% (instructional design experts), and 98.5% (media experts), alongside mean learning gains from 53.33 (pretest) to 88.21 (posttest). Nurfitra Yanto et al., (2023) conducted a systematic literature review establishing that pop-up book media enhances learning outcomes, develops higher-order thinking capabilities, provides cognitive reinforcement, and increases student motivation across diverse instructional models.

Augmented reality (AR) represents a technology that enables real-time integration of computer-generated content with real-world environments through digital devices (Zulfa et al., 2023). In educational contexts, AR overlays three-dimensional models, animations, and multimedia content onto physical learning materials using image recognition and marker-based systems. A growing body of empirical research has demonstrated the effectiveness of AR-based instructional media. For instance, Yuniawatika et al. (2023) Yuniawatika et al. (2023) reported substantial improvements in students' learning achievement following the implementation of an augmented reality–based history learning application. Similarly, Zulfa et al. (2023) found that AR-supported mathematics instruction produced moderate effect sizes

in enhancing students' understanding of spatial and volume concepts. Furthermore, Fakhrudin et al. (2019) demonstrated, through ANCOVA analysis, that AR-integrated instruction resulted in significantly higher motivation and problem-solving performance compared to conventional learning approaches. Collectively, these findings indicate that augmented reality has strong pedagogical potential to support conceptual understanding, learning motivation, and higher-order thinking skills.

Research exploring the integration of pop-up books and augmented reality remains relatively limited; however, existing studies suggest promising potential for instructional applications. (Mahadzir, 2013) investigated the use of augmented reality–enhanced pop-up books in elementary English language instruction and found that this integrated approach effectively captured students' attention, increased motivation and self-confidence, and promoted greater enjoyment in the learning process. These findings suggest that combining physical and digital elements can enrich students' learning experiences by fostering higher levels of emotional and cognitive engagement.

Similarly, (Kaliwanovia & Oktaviani, 2024) developed an augmented reality–enhanced pop-up textbook for pantomime instruction by integrating full-color illustrations, three-dimensional pop-up elements, and QR-code-activated digital animations. Their study demonstrated that such integration effectively stimulated students' curiosity and engagement during learning activities. Although these studies have not specifically addressed IPAS instruction or Earth structure content, their findings provide a strong theoretical foundation indicating that the integration of pop-up books and augmented reality has the potential to support the learning of abstract concepts through interactive and multimodal learning experiences.

Preliminary observations conducted at SDN Bandungan 01, Kabupaten Semarang, revealed several instructional challenges. Although teaching practices generally adhered to established educational standards, the utilization of instructional media remained limited. Teachers predominantly relied on traditional lecture-based approaches without technological integration, particularly when teaching abstract topics such as Earth's layered structure. Earth's internal structure represents an abstract scientific concept because it cannot be directly observed, thus requiring visual and concrete representations to support elementary students' understanding (Suyanto & Jihad, 2013). Such instructional conditions potentially hinder students' conceptual understanding and learning outcomes. To address these challenges, this study developed a pop-up book integrated with augmented reality features, in which the printed pop-up content serves as the primary learning medium, while augmented reality provides additional interactive visualizations. Based on these issues, this study aimed to develop, validate, and examine the effectiveness of a pop-up book integrated with

augmented reality for teaching Earth structure concepts to fifth-grade elementary school students.

Method

This study employed a Research and Development (R&D), (Sugiyono, 2017) defines Research and Development (R&D) as a research method aimed at producing a specific product and evaluating its effectiveness. Methodology using the ADDIE model as proposed by (Branch, 2009). The model was selected because it provides a systematic framework for developing instructional media, encompassing the stages of analysis, design, development, implementation, and evaluation. In addition, its structure is systematic and iterative, which is suitable for developing and refining learning media in the context of basic education. The study was conducted at SDN Bandungan 01, Kabupaten Semarang, and was aligned with the Kurikulum Merdeka. The developed material focused on IPAS content, specifically the topic of Earth's layered structure for fifth-grade students. The research participants consisted of 30 fifth-grade students.

Data were collected through interviews, observations, questionnaires, and learning outcome tests. Interviews and observations were conducted to identify instructional needs and examine initial classroom conditions. Expert validation was carried out using evaluation questionnaires to assess the quality of the developed instructional content and media, while user responses were obtained through Likert-scale questionnaires administered to teachers and students. Students' learning outcomes were measured using pretests and posttests to determine improvements in understanding following the use of the instructional media. Subsequently, the collected data were analyzed using descriptive quantitative techniques. Validation data were analyzed using percentage analysis to determine the level of media validity. Learning outcome data were examined through the Shapiro–Wilk normality test, followed by a paired sample t-test to identify significant differences between pretest and posttest scores. The magnitude of learning improvement was calculated using the normalized gain (N-gain).

Result and Discussion

Result

Development of a Pop-Up Book Integrated with Augmented Reality

The results of the needs analysis indicated that fifth-grade IPAS learning required students to understand abstract concepts related to Earth's layered structure. However, instructional practices were predominantly lecture-based, with limited use of technology-

integrated learning media. This condition affected students' initial learning achievement, as only 32% (10 out of 31 students) met the Learning Achievement Criteria (KKTP) score of 75.

The analysis also showed consistency between teachers' instructional needs and students' media preferences, supporting the development of a pop-up book integrated with augmented reality featuring interactive and visually rich content. Teachers perceived the existing instructional media as monotonous and expressed the need for more visual and interactive learning resources with complete instructional components. Students also demonstrated interest in innovative and interactive media. These findings served as the basis for designing instructional media that aligned with user characteristics.

During the design stage, the development of the instructional media was conducted comprehensively by considering learning needs and student characteristics. The media was structured systematically, beginning with an introductory section that included learning outcomes, learning objectives, and a concept map, followed by a main content po section as the core of instruction, and a closing section containing a material summary and author profile. The learning content was organized into five interconnected units and presented progressively, starting from general concepts of Earth structure to more specific components. From a visual perspective, the media employed full-color illustrations with a soft pastel color palette and medium-sized typography to ensure readability for elementary school students. In addition, the media incorporated interactive components in the form of augmented reality models activated through QR-code scanning to support three-dimensional visualization of abstract concepts. The overall design of the developed instructional media is presented in Figure 1.

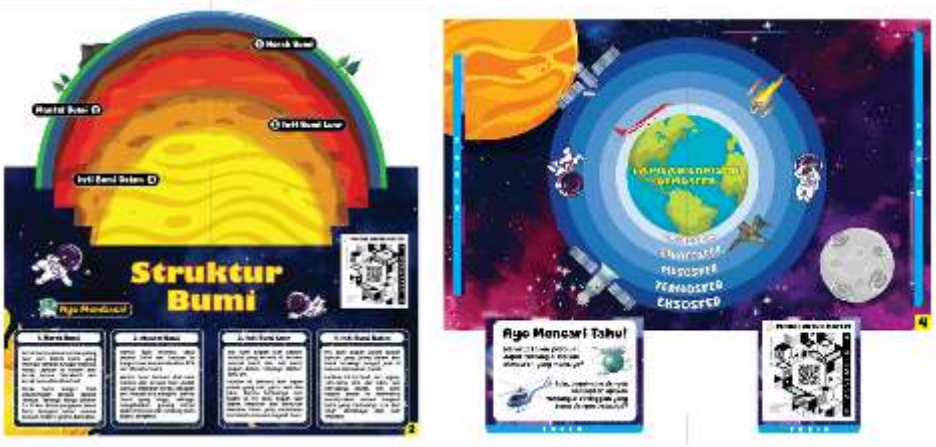

Figure 1. Design of the pop-up book integrated with augmented reality

The designed instructional media was transformed into a tangible learning product through a series of integrated production processes. The design and illustration stages were completed using Adobe Illustrator to produce visual elements aligned with the cognitive characteristics of elementary school students. The physical production process involved

high-quality color printing on specialized cardboard to ensure durability and visual clarity. Pop-up mechanisms were constructed using V-fold and lift-the-flap techniques to generate functional three-dimensional effects. To maintain product quality, each pop-up component was manually inspected to ensure proper functionality.

Augmented reality integration was implemented using the Assemblr EDU platform, which provides ready-made three-dimensional scientific models. The developed media incorporated four interactive AR visualizations, including Earth's internal structure (crust, mantle, outer core, and inner core), the five primary atmospheric layers, the hydrological cycle illustrating water circulation, and lithosphere composition depicting tectonic plate structures. The augmented reality features can be accessed by scanning a QR-code embedded on each page of the pop-up book using a mobile device. Once scanned, a three-dimensional visualization appears on the screen, allowing students to interact directly with the learning content.

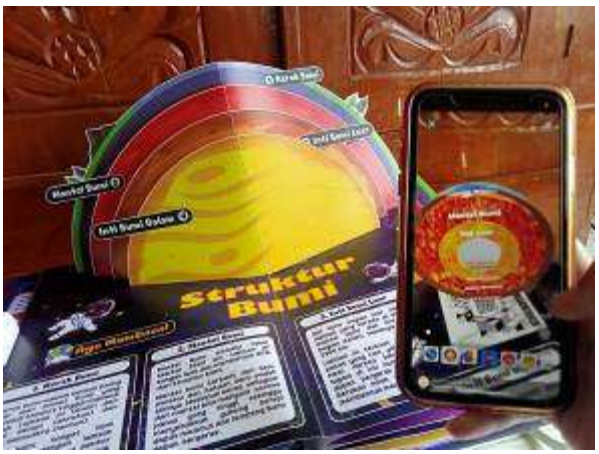

Figure 2. Augmented reality visualization displayed after QR-code scanning.

Validity of a Pop-Up Book Integrated with Augmented Reality

The validity of the pop-up book integrated with augmented reality was evaluated through expert judgment involving a subject matter expert and a media expert to ensure the feasibility of the product prior to classroom implementation. The results of expert validation are presented in Table 1

Table 1. Expert Validation Results

Validator	Percentage	Criteria
Subject Matter Expert	90%	Very Valid
Media Expert	97%	Very Valid
Average	93,5%	Very Valid

As shown in Table 1, the average expert validation score reached 93.5%, indicating that the developed media met high standards of pedagogical and technical quality. Although the media was categorized as very valid, minor suggestions were provided by the experts,

particularly regarding content consistency and the inclusion of real-world contextual elements. These suggestions were addressed through minor revisions to enhance instructional clarity and coherence.

Media feasibility was further supported by user responses. Teachers provided highly positive feedback with an acceptance rate of 100%, indicating that the media was considered appropriate, easy to use, and supportive of instructional activities. Student responses also showed a very high level of acceptance at 92%, suggesting that the media was engaging and helpful in facilitating understanding. The slight difference between teacher and student responses was likely related to variations in familiarity with technological terminology rather than issues with media functionality.

Effectiveness of a Pop-Up Book Integrated with Augmented Reality

The effectiveness of the pop-up book integrated with augmented reality was examined by comparing students' learning achievement before and after the implementation of the instructional media. Students' learning achievement was measured using a pretest and a posttest administered to fifth-grade students. A summary of the descriptive statistics for students' scores is presented in Table 2.

Table 2. Descriptive Statistics of Pretest and Posttest Scores

Statistic	**Pretest**	**Posttest**
Maximum score	73	100
Minimum score	33	60
Mean	53.97	79.72
Standard deviation	12.48	13.64

Based on Table 2, the mean posttest score showed a substantial increase compared to the mean pretest score. The mean score improvement of 25.75 points indicates a notable enhancement in students' understanding of the Earth's layered structure following the use of the instructional media. In addition, both the minimum and maximum posttest scores increased, suggesting an overall improvement in students' learning achievement compared to their initial performance.

The standard deviation of posttest scores exhibited a change relative to the pretest scores, indicating variability in the magnitude of learning improvement among students. This finding suggests that, although overall learning achievement increased, individual students experienced different degrees of improvement.

Prior to hypothesis testing, the data were analyzed using the Shapiro–Wilk normality test to ensure that the pretest and posttest scores were normally distributed, as required for parametric statistical analysis. The results indicated that the significance values for both datasets were greater than 0.05, confirming that the data met the normality assumption. Subsequently, a paired sample t-test was conducted to determine whether there was a

statistically significant difference between students' pretest and posttest scores. The results of the paired sample t-test are presented in Table 3.

Table 3. Paired Sample t-Test Results

Comparasion	Mean Difference	t	df	Sig. (2-tailed)
Pretest – Posttest	25.75	4.70	29	0.000

A paired sample t-test was conducted to examine differences between students' pretest and posttest scores after the implementation of the pop-up book integrated with augmented reality. As presented in Table 3, the analysis revealed a statistically significant difference between pretest and posttest scores ($t = 4.70$, $df = 29$, $p < 0.05$). The analysis revealed a statistically significant difference ($p < 0.05$), indicating that the instructional media had a significant effect on students' learning achievement.

To determine the magnitude of learning improvement, the normalized gain (N-gain) was calculated. The results of the N-gain analysis are presented in Table 4.

Table 4. N-gain Analysis

Indicator	Pretest Mean	Posttest Mean	N-Gain	Interpretation
Learning Achievement	60.21	8.34	0.56	Moderate Improvement

The results showed an increase in the mean score from 60.21 in the pretest to 87.34 in the posttest. The calculated N-Gain value was 0.56, Based on Hake's criteria, an N-Gain value of $0.3 \leq g < 0.7$ is classified as moderate improvement. This finding indicates that the pop-up book integrated with augmented reality was moderately effective in improving students' understanding of Earth structure concepts.

Discussion

The application of the ADDIE model in this study functioned not merely as a procedural framework but as a strategic approach to addressing the pedagogical challenges identified in fifth-grade IPAS learning. The development of a pop-up book integrated with augmented reality provided concrete representations of the Earth's layered structure, a topic that is inherently abstract and difficult to observe directly. This finding supports the theoretical assumptions proposed by (Arsyad, 2013) and Dale's Cone of Experience, which emphasize the importance of concrete and visual learning experiences in enhancing elementary students' conceptual understanding. Accordingly, the results align with the initial hypothesis that integrating concrete media with digital technology can overcome the limitations of conventional, lecture-based instruction. Three-dimensional learning media support elementary students in constructing conceptual understanding gradually through visual and

spatial experiences, thereby promoting meaningful learning rather than rote memorization (Apriani et al., 2025)

User involvement during the needs analysis phase contributed significantly to aligning the media design with learner and teacher characteristics. This participatory design approach strengthened user acceptance during the implementation stage, as reflected in the very high ratings provided by teachers and students. From a technical perspective, the use of QR-code-activated augmented reality enabled relatively easy access to digital content, thereby minimizing technological barriers in elementary school settings. Furthermore, the use of pre-built scientific models available on the Assemblr EDU platform helped maintain content accuracy while reducing production complexity, without compromising the visual or functional quality of the instructional media. Interactive and visually engaging media have been shown to sustain students' attention and encourage active participation during learning activities. High levels of learning engagement play a crucial role in supporting the effectiveness of instructional media (As'zaroh & Arianti, 2024).

Augmented reality enables students to visualize scientific phenomena that cannot be directly observed through conventional instructional methods. National research has demonstrated that augmented reality–based learning media effectively enhance elementary students' conceptual understanding in science learning by supporting interactive visualization (Chairunnisa et al., 2023). In addition, interactive instructional media can enhance students' learning motivation by encouraging active participation and stimulating curiosity throughout the instructional process (Uno, 2016). Therefore, augmented reality functions as a pedagogically meaningful instructional tool rather than merely a technological novelty. Studies on immersive learning technologies further indicate that interactive and immersive representations support meaningful learning by facilitating deeper conceptual understanding (Radianti et al., 2020)

In terms of feasibility, the high expert validation scores and positive user responses indicate that the developed media meets strong technical and pedagogical standards for classroom implementation. Alignment with Indonesia's Merdeka Curriculum further demonstrates that the media is not only technologically innovative but also curriculum-relevant. Media that aligns with curricular objectives tends to be more easily integrated into teachers' daily instructional practices (Saski & Sudarwanto, 2021). Nevertheless, expert feedback regarding content consistency and the inclusion of real-world contextual examples highlights that instructional media development is an iterative process requiring continuous refinement to enhance contextual relevance and instructional clarity.

Regarding learning effectiveness, the significant improvement in students' learning outcomes—reflected in both mean score gains and mastery levels—indicates that the pop-up

book integrated with augmented reality produced meaningful instructional impact. The moderate N-gain value suggests substantial learning improvement, although the maximum level of gain was not achieved. Moderate N-gain values are commonly reported in short-term instructional interventions and should be interpreted as meaningful learning improvement, particularly during initial implementation of technology-based learning media (Hake, 1998; Pamorti et al., 2024). Similar findings have been reported in a national study by Muzanni, Kusuma, and Muliadi (2024), which showed that augmented reality–based learning media significantly improved elementary students' learning outcomes, particularly in science and IPAS subjects. It is important to note that the observed learning improvements cannot be attributed solely to the augmented reality component, as the pop-up book itself already provided structured and concrete learning representations, while augmented reality functioned as an enrichment tool that extended visualization and interactivity.

This outcome should be interpreted comprehensively. High validation results primarily reflect the quality and feasibility of the developed media, whereas learning gains are influenced by a broader range of instructional factors. Learning effectiveness is shaped not only by media quality but also by students' prior knowledge, instructional strategies, learning context, and the duration and intensity of media implementation (Reigeluth et al., 2017; Slavin, 2018). In addition, national studies on augmented reality–based learning emphasize that short implementation periods and limited instructional exposure may constrain the magnitude of learning gains, even when the instructional media is pedagogically sound (Pamorti et al., 2024). From a theoretical perspective, these findings support multimedia learning principles, suggesting that the integration of tangible and digital representations facilitates deeper conceptual understanding in elementary science learning. (Mayer, 2020).

From a learning ecology perspective, learning is understood as a dynamic system shaped by the interactions among learners, technology, learning activities, and social environments (Luckin, 2010; OECD, 2016). Consequently, the moderate N-gain observed in this study does not indicate limitations in media effectiveness but rather reflects the influence of contextual factors, such as students' relatively low initial achievement levels and the limited implementation period. With more sustained integration within a supportive learning ecosystem, the developed media has the potential to yield stronger instructional outcomes.

Conclusion

This study successfully developed, validated, and evaluated the effectiveness of an Augmented Reality (AR)–based Pop-Up Book as an instructional medium for teaching Earth structure concepts to fifth-grade elementary students using a Research and Development (R&D) approach with the ADDIE model. The findings indicate that the developed media

demonstrated very high validity, as reflected by expert evaluations from subject matter experts (90%) and media experts (97%). In addition, both teachers (100%) and students (92%) provided highly positive responses regarding the usability, attractiveness, and instructional value of the media, confirming its feasibility for classroom implementation.

From the learning effectiveness perspective, statistical analysis revealed a significant improvement in students' learning outcomes following the use of the pop-up book integrated with augmented reality ($p = 0.000 < 0.05$). Students' mean scores increased from 53.97 on the pretest to 79.72 on the posttest, with a moderate effect size (N-Gain = 0.55). These results indicate that the developed media effectively supports students' conceptual understanding of abstract and complex Earth science content.

Within the context of this study, the pop-up book integrated with augmented reality demonstrated potential effectiveness in supporting elementary students' understanding of earth structure concepts. Practically, this study demonstrates that pop-up book integrated with augmented reality can serve as an innovative, engaging, and accessible learning medium without requiring complex technological infrastructure. Therefore, the media has strong potential for broader application in IPAS learning and other subject areas. Future research is recommended to examine its effectiveness across diverse educational contexts, extended implementation periods, and wider content domains to further strengthen the generalizability of these findings. This study is limited by the duration of media implementation and the sample size. Future research is encouraged to examine sustained use of the media and employ broader experimental designs.

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