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The Effect of Graphic Design Integration in Augmented Reality Learning Media on Junior High School Students' Conceptual Understanding

Yolandita Angga Reza

Program Studi Desain Grafis, Fakultas Komunikasi dan Desain, Universitas Sains Indonesia
*Corresponding Author e-mail: yolandita.angga@lecturer.sains.ac.id

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Abstract: *Augmented Reality (AR) has emerged as an effective educational tool for visualizing abstract concepts and increasing student engagement through interactive digital content. This study aims to examine the impact of integrating pedagogical graphic design principles into the development of AR-based learning media for junior high school science subjects. Using a mixed-methods approach, the research involved the design, implementation, and evaluation of an AR prototype comprising three modules: the solar system, human anatomy, and basic chemical reactions. Each module was designed using pedagogically informed visual strategies such as color coding, 3D modeling, and intuitive interactivity to support conceptual understanding. The study adopted a quasi-experimental design involving pretest and posttest procedures with 60 junior high school students, divided into two groups: an experimental group (AR with optimized graphic design) and a control group (standard AR). Sample selection criteria included students in grades 7 and 8 with basic access to digital devices. Data were analyzed using an independent sample t-test to compare conceptual understanding improvements between the groups. Results indicated a statistically significant increase in the experimental group (27.8%) compared to the control group (12.3%), with a significance level of p < 0.01. In addition to cognitive gains, observational and interview data revealed strong emotional engagement, longer interaction times, and higher learning motivation among students in the experimental group. These findings highlight the crucial role of pedagogical graphic design in enhancing both cognitive and affective outcomes of AR-based learning. The study recommends the development of accessible, teacher-friendly AR platforms equipped with modular visual design libraries to facilitate broader implementation in educational environments.*

Kata Kunci:
Desain Grafis Pedagogis, Media Pembelajaran Imersif, Pemodelan 3D, Motivasi Belajar, Kuasi-Eksperimen, Augmented Reality (AR)

Abstrak: Augmented Reality (AR) telah berkembang menjadi alat pendidikan yang efektif untuk memvisualisasikan konsep abstrak dan meningkatkan keterlibatan siswa melalui konten digital interaktif. Penelitian ini bertujuan untuk mengkaji pengaruh integrasi prinsip desain grafis pedagogis dalam pengembangan media pembelajaran berbasis AR untuk mata pelajaran sains di tingkat sekolah menengah pertama. Menggunakan pendekatan metode campuran, penelitian ini mencakup tahap desain, implementasi, dan evaluasi prototipe AR yang terdiri dari tiga modul: tata surya, anatomi manusia, dan reaksi kimia dasar. Setiap modul dirancang dengan strategi visual berbasis pedagogi, seperti penggunaan kode warna, pemodelan 3D, dan interaktivitas intuitif untuk mendukung pemahaman konsep. Penelitian menggunakan desain kuasi-eksperimen dengan uji prates dan pascates yang melibatkan 60 siswa SMP, yang dibagi menjadi dua kelompok: eksperimen (AR dengan desain grafis yang dioptimalkan) dan kontrol (AR standar). Kriteria pemilihan sampel mencakup siswa kelas VII dan VIII dengan akses dasar terhadap perangkat digital. Data dianalisis menggunakan uji *independent sample t-test* untuk membandingkan peningkatan skor pemahaman konseptual antara kedua kelompok. Hasil menunjukkan peningkatan signifikan pada kelompok eksperimen (27,8%) dibandingkan kelompok kontrol (12,3%), dengan nilai signifikansi p < 0,01. Selain itu, data observasi dan wawancara menunjukkan keterlibatan emosional yang tinggi, waktu interaksi yang lebih lama, dan peningkatan motivasi belajar pada kelompok eksperimen. Temuan ini menegaskan pentingnya integrasi desain grafis pedagogis dalam meningkatkan dampak kognitif dan afektif dari media pembelajaran berbasis AR. Penelitian ini merekomendasikan pengembangan platform AR yang mudah diakses, ramah guru, serta menyertakan pustaka desain visual modular yang dapat disesuaikan dengan kebutuhan pembelajaran untuk mendukung adopsi luas di lingkungan pendidikan.

Introduction

The era of digital transformation in education has significantly shifted the paradigm of instructional design and learning interaction. Among emerging technologies, Augmented Reality (AR) stands out for its capacity to enrich learning environments by merging the physical world with interactive digital elements. AR enables students to engage with three-dimensional (3D) representations of abstract concepts in real time, offering immersive experiences that are often lacking in conventional classroom settings.

In Indonesia, the urgency to adopt interactive learning media is underscored by a preliminary survey conducted among 120 junior high school teachers across five provinces. The results indicated that 78% of the respondents faced difficulties in explaining complex scientific concepts such as planetary motion, human anatomy, and molecular reactions using conventional methods. Additionally, 82% of teachers expressed a strong need for visually engaging and interactive media to foster student motivation and comprehension. These findings align with research by Yulianti et al. (2024), which suggests that students in the digital era—often termed "digital natives"—respond more positively to multisensory and interactive content compared to static, text-based learning.

Traditional learning models frequently rely on linear, unidirectional instruction that does not accommodate the diversity of student learning styles. The lack of visual dynamism and interactivity can hinder students' ability to grasp abstract or complex topics, particularly in science education. Visual limitations in textbooks, such as two-dimensional diagrams, often fail to convey depth, spatial relationships, or dynamic processes effectively.

In this context, graphic design plays a pivotal role—not merely as an aesthetic addition but as a cognitive and pedagogical instrument. Elements such as color schemes, typography, spatial layout, visual hierarchy, and iconography significantly affect how information is perceived, processed, and retained. According to Mayer's (2009) Multimedia Learning Theory, a well-balanced combination of text and visuals reduces cognitive overload and improves comprehension. Graphic design within AR can guide attention, clarify complex relationships, and stimulate emotional engagement through intuitive user interfaces and immersive storytelling.

While prior research has explored the use of AR in education (Bacca et al., 2014; Chen et al., 2017), few studies have specifically examined how pedagogical graphic design principles can enhance learning outcomes in AR-based educational media. For instance, *Assemblr Edu*—a popular Indonesian AR platform—has been praised for its user-friendly interface and customizable content (Wardani, 2022). Similarly, Rahman et al. (2020) found that visually engaging AR flashcards improved early childhood learning. However, most of these studies stop short of offering a structured framework for designing educational AR based on graphic design principles.

In Indonesia, studies on AR in education remain fragmented and largely focus on technical implementation rather than pedagogical integration. Moreover, literature that combines graphic design theory and instructional design in AR media is limited, particularly in peer-reviewed SINTA-indexed publications. Therefore, this study attempts to fill the gap by proposing an original framework for integrating pedagogical graphic design into AR media development, aimed at improving students' conceptual understanding and learning motivation in junior high school science subjects.

Research Objectives

This study seeks to design, implement, and evaluate an AR-based educational media prototype that applies evidence-based graphic design principles tailored for science learning in Indonesian junior high schools. Specifically, it aims to:

1. Identify optimal graphic design principles for educational AR media, focusing on cognitive effectiveness, visual clarity, and digital ergonomics.
2. Develop a structured framework for integrating graphic design into the AR media development cycle—from conceptualization and prototyping to deployment and evaluation.
3. Design and test a science-focused AR prototype that incorporates the identified graphic design strategies.
4. Evaluate the impact of graphic design integration on students' conceptual understanding, motivation, and learning engagement using a quasi-experimental design and mixed-method approach.
5. Formulate recommendations for educators and media developers on how to optimize the use of visual design in immersive learning environments to maximize pedagogical effectiveness.

By addressing these objectives, this study contributes not only to the field of educational technology and AR, but also to the discipline of graphic design by demonstrating how visual communication strategies can be pedagogically embedded into technology-enhanced learning tools. Furthermore, it offers empirical insights to support the scaling of AR innovations in Indonesian classrooms, particularly in resource-constrained settings where visual support is critical for effective science instruction.

Methods

This study was designed to explore and evaluate the integration of pedagogical graphic design in the development of Augmented Reality (AR)-based learning media for junior high school science subjects. A mixed-methods approach was adopted to combine the strengths of both quantitative and qualitative data. This approach was deemed appropriate, as it enables a more comprehensive understanding of the research problem—not only from the perspective of measurable learning outcomes, but also through the exploration of students' emotional and experiential responses to AR-based media.

The research used a quasi-experimental design involving two groups: an experimental group and a control group. Each group was subjected to pre-test and post-test assessments to evaluate changes in conceptual understanding after using the respective AR learning media. The experimental group used an AR application enhanced with pedagogically informed graphic design, while the control group used a standard AR version without such enhancements. The study was conducted in four main phases: literature review, prototype development, limited implementation, and data analysis.

Research Subjects

The research subjects consisted of 60 junior high school students, drawn from two public schools located in Jakarta and Bandung. The students were selected using purposive sampling, as the study required participants who met certain criteria. The inclusion criteria were:

1. Students currently enrolled in grade 7 or 8;
2. Basic digital literacy and the ability to operate Android-based devices;
3. Access to a personal Android smartphone or tablet during the study;
4. Written informed consent from a parent or guardian.

The exclusion criteria included students with visual impairments or cognitive disabilities that could interfere with AR interaction.
The demographic distribution of participants is summarized below:

Component	*Description*
Total Sample	60 students (grades 7–8)
Sampling Technique	Purposive sampling
Inclusion Criteria	Grade 7 or 8, digital literacy, Android access, parental consent
Exclusion Criteria	Visual/cognitive impairments affecting AR interaction
Gender Distribution	31 female, 29 male students
Age Range	12–14 years
Group Assignment	Experimental group (n = 30); Control group (n = 30)

Instruments and Data Collection

To collect robust and valid data, the study employed four main instruments: (1) pre-test and post-test assessments, (2) a motivation questionnaire, (3) structured observation sheets, and (4) semi-structured interview protocols. Each instrument was subjected to validation and reliability testing.

The pre-test and post-test were designed to measure students' conceptual understanding across three science topics: the solar system, human anatomy, and chemical reactions. The test consisted of 20 multiple-choice questions developed based on national curriculum standards. These items were validated by three science education experts, achieving a Content Validity Index (CVI) of 0.87. Internal consistency reliability was measured using Cronbach's Alpha, resulting in a value of 0.82.

The motivation questionnaire was adapted from Keller's ARCS-based Instructional Materials Motivation Survey (IMMS), modified to suit the AR learning context. The adapted questionnaire was reviewed linguistically and contextually by education experts. Reliability testing yielded a Cronbach's Alpha of 0.85, indicating high internal consistency.

The structured observation sheet was used during AR sessions to record behavioral indicators such as duration of use, verbal engagement, focus, and expressions of enthusiasm. Observations were made by two trained observers using identical rating formats.

Lastly, semi-structured interviews were conducted with a total of 20 students and 4 science teachers (10 students and 2 teachers from each group). Interviews explored perceptions, emotional responses, and pedagogical feedback regarding the AR learning experience.

Summary of the data collection instruments:

Instrument	*Purpose*	*Validity & Reliability*
Pre-test & Post-test	Assess conceptual understanding	CVI = 0.87; Cronbach's Alpha = 0.82
Motivation Questionnaire	Measure affective and motivational aspects	ARCS-based IMMS; Cronbach's Alpha = 0.85
Observation Sheet	Monitor student behavior during AR use	Structured format (focus, engagement, time)
Semi-Structured Interviews	Explore students' and teachers' perceptions	10 students & 2 teachers per group; 15–20 mins

AR Prototype Development

The AR learning media prototype was developed for three key modules: Solar System, Human Anatomy, and Chemical Reactions. The development involved collaboration among AR developers, science educators, and professional graphic designers. The design incorporated educational visuals, such as color-coded systems, 3D object animations, responsive icons, and legible typography.

Module	*Visual Design Features*
Solar System	Interactive 3D planetary motion with orbit and rotation simulation
Human Anatomy	Color-coded systems, simplified visuals with accurate spatial representation
Chemical Reactions	Animated molecular and atomic structures with simplified bonding visualization

The prototype was evaluated by five experienced science teachers and three educational technology experts. Their feedback informed several improvements to ensure pedagogical alignment, user-friendliness, and visual clarity.

Data Analysis

Quantitative Analysis

Quantitative data were analyzed using inferential statistical methods. A Shapiro-Wilk test was first performed to ensure data normality, followed by Levene's Test to examine homogeneity of variances. Since both assumptions were satisfied, the main statistical test applied was the Independent Samples t-test to compare the mean gains in conceptual understanding between the two groups.

To compute learning improvement, the following formulas were used:

$$\text{Gain Score} = \text{Post-test Score} - \text{Pre-test Score}$$

$$\text{Percentage Gain} = \left(\frac{\text{Gain}}{\text{Pre-test Score}}\right) \times 100\%$$

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)}}$$

Example:

If a student's pre-test score is 48 and post-test score is 76:

1. Gain = 76 − 48 = 28
2. Percentage gain = (28 / 48) × 100% = 58.3%

All statistical analyses were conducted using SPSS software, with a significance threshold of $p < 0.05$.

Qualitative Analysis

Qualitative data from interviews were analyzed using Thematic Analysis, as proposed by Braun and Clarke (2006). This method was chosen for its systematic approach to identifying, analyzing, and reporting patterns (themes) within textual data.

The steps followed were:

1. Familiarization with the data (reading transcripts multiple times);
2. Generation of initial codes;
3. Searching for themes by clustering related codes;
4. Reviewing and refining themes;
5. Naming and defining each theme;

6. Reporting findings using selected quotes.

Examples of resulting codes and themes:

Interview Excerpt	*Emerging Theme*
"I felt like I was really inside the solar system."	Immersive engagement
"The moving atoms helped me understand reactions better."	Visual conceptualization
"It felt like a game; I didn't get bored at all."	Increased learning motivation

Coding was conducted using NVivo 12 software to ensure reliability and transparency.

Data Triangulation

To strengthen the validity of findings, triangulation was employed by comparing and cross-verifying data from multiple sources:

1. Pre-/post-test scores (objective learning outcomes),
2. Observation sheets (behavioral engagement), and
3. Interviews (student and teacher perceptions).

If similar themes emerged across all data sources—for example, students who scored high also demonstrated observable enthusiasm and described the AR experience as motivating—then those findings were considered credible and well-supported.

Results And Discussion

Prototype of AR-Based Educational Media: Combining Graphic Design with Interactive Learning

The primary output of this study is a fully functional prototype of Augmented Reality (AR)-based educational media, designed to integrate principles of pedagogical graphic design with interactive content aligned to the Indonesian *Kurikulum Merdeka*. The development focused on science topics that are conceptually abstract and typically difficult for junior high school students to comprehend through conventional learning resources. These include: (1) the solar system, (2) human anatomy, and (3) basic chemical reactions.

Each of the three modules was collaboratively developed by a team of educational technology experts, graphic designers, and science educators. The design process involved pedagogical consultation to ensure that every visual element aligned with instructional goals. For example, the solar system module applied accurate 3D representations of planetary scale and motion, supported by orbit animations, interactive zoom functions, and color contrast to enhance spatial differentiation. The human anatomy module utilized a color-coding system to distinguish organ systems, while labeling was spatially and temporally aligned to reduce cognitive overload. In the chemical reactions module, animated sequences illustrated molecular bonding and electron transfer, using visual metaphors to simplify complex atomic interactions.

These design features reflect specific theoretical foundations from Mayer's (2009) Cognitive Theory of Multimedia Learning, including the signaling principle, spatial contiguity, temporal contiguity, and modality. For instance, color coding of organ systems supports the signaling principle by guiding learner attention; meanwhile, synchronized animation and narration exemplify temporal contiguity.

On a technical level, the prototype was optimized for Android devices commonly used in Indonesian public schools. Testing across five devices showed an average loading time of 3.2 seconds, a consistent frame rate of 30–35 fps, and marker recognition accuracy of 92% in well-lit classrooms. These results validate the feasibility of deploying the prototype in real-world classroom conditions.

Quantitative Analysis: Measuring the Effectiveness of Pedagogical Graphic Design

To empirically test the impact of graphic design integration in AR-based learning, this study employed a quasi-experimental method with pre-test and post-test design involving 60 students. They were divided into an experimental group (n = 30, using AR with optimized graphic design) and a control group (n = 30, using standard AR design). The following formulas were used to analyze learning gains:

$$\text{Gain Score} = \text{Post-test Score} - \text{Pre-test Score}$$

$$\text{Percentage Gain} = \left(\frac{\text{Gain Score}}{\text{Pre-test Score}}\right) \times 100\%$$

Example Calculation

For the experimental group:

1. Average Pre-test Score = 48.3
2. Average Post-test Score = 76.1

$$\text{Gain Score} = 76.1 - 48.3 = 27.8$$

$$\text{Percentage Gain} = \left(\frac{27.8}{48.3}\right) \times 100 = 57.57\%$$

For the control group:

1. Average Pre-test Score = 49.2
2. Average Post-test Score = 61.5

$$\text{Gain Score} = 61.5 - 49.2 = 12.3$$

$$\text{Percentage Gain} = \left(\frac{12.3}{49.2}\right) \times 100 = 25.00\%$$

Independent Samples t-Test was used to evaluate the statistical significance of these gains. The results showed a p-value < 0.01, indicating a statistically significant difference in learning outcomes between the two groups.

Table 1. Comparison of Conceptual Understanding Scores

Group	*Pre-Test Average*	*Post-Test Average*	*Gain Score*	*Percentage Gain*	*Significance (p)*
AR + Optimized Graphic Design	48.3	76.1	27.8	57.6%	< 0.01
Standard AR Design	49.2	61.5	12.3	25.0%	< 0.05

These findings validate that specific design features, particularly color coding, animated object interactions, and label placement, significantly contribute to students' conceptual understanding. This supports and extends earlier work in Indonesia such as Wardani (2022), who emphasized user satisfaction with AR in science classes. Our study builds on this by providing statistically supported evidence linking graphic design enhancements directly to improved learning outcomes.

Affective Engagement: Visualization and Emotional Response

Beyond test scores, qualitative data from classroom observations and interviews indicated that students experienced increased emotional engagement while interacting with the AR application. Students who typically disengaged during conventional lessons were found to interact with AR modules for 17 to 19 minutes—nearly double the average engagement during textbook-based instruction.

Table 2. Affective Engagement Observations

Module	*Avg. Interaction Time*	*Dominant Emotional Responses*
Solar System	19 minutes	Awe, curiosity, active questioning
Human Anatomy	17 minutes	Focused attention, empathy, fascination
Chemical Reactions	18 minutes	Joy, playfulness, experimentation

Student Quotes:

- *"I finally understand how the blood flows because I saw it moving!"*
- *"It's like a movie—but I'm the one moving the planets!"*

Teachers also noted improved classroom dynamics. Passive students became vocal and posed critical questions, showing deeper conceptual processing. These findings align with Kristanto (2021), who emphasized the role of emotional immersion in increasing student motivation in Indonesian classrooms.

Implementation Challenges: Practical Barriers and Solutions

Despite positive outcomes, field observations revealed several implementation challenges that reflect broader infrastructural and pedagogical realities in Indonesia—especially in rural areas.

Table 3. Implementation Challenges and Recommendations

Challenge	*Observed Impact*	*Recommended Solution*
Limited access to AR devices	Inconsistent usage in classrooms	Develop lightweight apps for low-end devices
High complexity of 3D content	Time-consuming development cycles	Use modular, reusable visual libraries
Teacher unfamiliarity with AR	Underutilization of learning media	Provide structured digital pedagogy training

Addressing these barriers requires a multi-pronged approach involving government support, curriculum integration, and capacity building for educators under the *Kurikulum Merdeka* framework. AR should not be treated as an external add-on, but as a core learning strategy integrated with national competencies.

Theoretical, Pedagogical, and Technological Implications

From a theoretical perspective, this study reinforces the relevance of Mayer's multimedia learning principles, while contextualizing them within Indonesian classrooms. For example:

1. Color coding (Signaling Principle) helped students navigate complex anatomical structures.

2. Synchronized animation and narration (Temporal Contiguity) clarified scientific processes like chemical bonding.
3. Interactive 3D elements (Modality and Interactivity) enabled active exploration and knowledge construction.

From a pedagogical standpoint, the use of AR fosters constructivist learning, where students construct meaning through interaction, visualization, and manipulation of objects. This approach aligns with the *Kurikulum Merdeka*, which emphasizes student autonomy, contextual learning, and digital literacy.

Technologically, the study highlights the urgency of democratizing AR development by enabling teacher-led content creation. Platforms should allow the creation of localized AR media—preferably in Bahasa Indonesia—without coding expertise. This would expand AR access beyond urban schools to rural and remote areas.

Conclusion of the Findings

In conclusion, the integration of graphic design in AR-based learning is not merely an aesthetic enhancement but a critical pedagogical strategy. The findings show clear improvement in student understanding and motivation when educational content is delivered through well-designed AR visuals. To scale this innovation, future policies should focus on technological equity, teacher training, and curriculum alignment.

This study provides a strong foundation for the continued development of AR learning tools that are cognitively effective, emotionally engaging, and culturally appropriate for Indonesian education.

Conclusion

This study concludes that the integration of pedagogical graphic design into Augmented Reality (AR)-based educational media significantly improves the effectiveness of science learning at the junior high school level. The prototype developed in this research—featuring modules on the solar system, human anatomy, and chemical reactions—demonstrated the value of combining scientific accuracy with engaging and cognitively supportive visual elements.

The quantitative results revealed a statistically significant increase in conceptual understanding among students who used the AR application with optimized design features. These students not only scored higher on post-tests but also showed higher levels of motivation, engagement duration, and active interest compared to the control group. These outcomes are in line with Mayer’s Multimedia Learning Theory and Dual Coding Theory, reinforcing the impact of visual-verbal synergy in reducing cognitive overload and enhancing knowledge retention.

The qualitative findings further showed that the AR application stimulated positive emotional responses, curiosity, and a sense of personal involvement—especially among students who were typically passive in conventional learning environments. This highlights that immersive and well-structured graphic design is not merely aesthetic but serves as an essential component in fostering both cognitive and affective learning outcomes.

Nonetheless, the study also identified several practical challenges, including limited access to compatible devices, the complexity of producing educational 3D content, and the need for teacher readiness. These factors underscore the importance of scalable and inclusive educational solutions—particularly for resource-limited schools across Indonesia.

To build on the findings of this study, the following directions are recommended for future research:

1. Cross-subject Testing
   Investigate the effectiveness of AR-integrated graphic design in other school subjects, such as mathematics, geography, or history, to determine its generalizability across disciplines.
2. Longitudinal Studies
   Conduct long-term studies to examine knowledge retention, student engagement, and learning habits after extended exposure to AR media.
3. Scalability and Infrastructure Research
   Explore how AR learning systems can be scaled effectively for schools in rural or underserved areas, especially with a focus on low-spec device compatibility.
4. Teacher-centered AR Development Tools
   Evaluate the usability and pedagogical value of AR development platforms designed for non-programmer educators, to enable teacher-generated localized content.
5. Differentiated Instruction Studies
   Examine how AR-based visual interaction supports students with diverse learning needs, including those with learning disabilities or different cognitive styles.

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