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The Effects of Mobile Augmented Reality on Students' Learning Performance in Packaging Design Lessons

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Abstract

Background and Aim: This study explores the impact of Mobile Augmented Reality (MAR) technology in enhancing students' learning performance in packaging design education. By comparing MAR-supported teaching methods with traditional approaches, the research aims to advance knowledge on how MAR enhances learning outcomes in design disciplines. Specifically, the research focuses on five key variables: visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity. This research addresses a gap in the existing literature by demonstrating MAR's advantages over conventional teaching strategies, which often lack interactivity and real-time feedback mechanisms.

Materials and Methods: Employing a quasi-experimental design, the study involved two groups of third-year students from the Visual Communication Design program at Zhanjiang University of Science and Technology. The experimental group (39 students) utilized MAR technology, while the control group (38 students) adhered to traditional teaching practices. The research spanned eight weeks, employing pre- and post-tests to measure outcomes related to the key variables. Data analysis utilized descriptive statistics and independent sample t-tests, with statistical significance assessed at $p < 0.001$.

Results: The experimental group utilizing Mobile Augmented Reality (MAR) technology showed significant improvements across all five key variables. Visual effects improved by 19.6%, demonstrating enhanced application of design principles through interactive 3D modeling. Spatial modeling scores rose by 18.4%, reflecting MAR's ability to support the creation of functional and innovative designs. Creativity and imagination increased by 21.3%, facilitated by MAR's real-time exploration capabilities. Information dissemination improved as students communicated product details and branding concepts more effectively. The highest gain, 23.4%, was observed in interactivity, attributed to MAR's engaging and collaborative features. These findings emphasize MAR's transformative role in packaging design education by making learning more immersive and interactive.

Conclusion: The study concludes that integrating MAR into packaging design education fosters an interactive and immersive learning environment, significantly improving students' comprehension, creativity, and practical skills. To maximize its impact, future research should explore scalable implementations across various educational contexts. The results advocate for MAR's adoption in curricula, promoting innovation in design pedagogy and educational practices.

Keywords: Mobile Augmented Reality; Educational Innovation; Design Pedagogy; Students' Learning Performance; Packaging Design Education

Introduction

The study examines the integration of Mobile Augmented Reality (MAR) technology into packaging design education, addressing challenges in traditional methods. Despite the increasing importance of packaging design in consumer attraction, brand identity, and marketability (Wu, 2023), conventional teaching methods often fail to provide the level of interactivity and hands-on experience needed for students to develop practical design skills. Many educators rely on static tools such as PowerPoint presentations and two-dimensional sketches, which limit students' ability to visualize and manipulate complex design elements (Yang, 2023). As a result, students struggle to bridge the gap between theoretical knowledge and real-world applications, which hinders their preparedness for the evolving design industry. For example, industry feedback suggests that students trained with traditional methods often lack spatial awareness and struggle with digital prototyping, both of which are essential for modern packaging design (Xu et al., 2023).

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The global shift toward digitalization and innovative educational methodologies highlights MAR's role in design education. MAR combines virtual and real-world elements, offering immersive and interactive environments (Jaber et al., 2023). By enabling students to visualize and manipulate 3D models, MAR enhances understanding, creativity, and spatial awareness in packaging design courses. This aligns with constructivist and experiential learning theories, which emphasize active student engagement, hands-on interaction, and the role of contextual learning in knowledge acquisition (Piaget, 1954; Kolb, 1984). However, while constructivist and experiential theories are briefly mentioned, a more detailed discussion of their application to MAR in packaging design is essential. For instance, experiential learning involves four key stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). MAR supports this cycle by allowing students to engage in real-time experimentation with packaging designs, analyze their modifications through immediate feedback, conceptualize improvements, and refine their work iteratively. Such an approach fosters creativity and spatial modeling skills that are otherwise difficult to cultivate in traditional classroom settings.

Key variables in this study include visual effects, spatial modeling, creativity, information dissemination, and interactivity, which are critical for developing packaging design competencies. Each of these variables plays a fundamental role in student learning. Visual effects and spatial modeling help designers create aesthetically appealing and functional packaging solutions, which influence consumer perception and decision-making (Prasanth & Mageshwari, 2023; Zhao & Song, 2023). Creativity is essential for innovation, while information dissemination ensures that product details and branding messages are effectively communicated. Finally, interactivity enhances engagement, making learning more effective and enjoyable (Ahmed & Lataifeh, 2023). This research adopts a quasi-experimental design, comparing two student groups at Zhanjiang University of Science and Technology. The experimental group uses MAR technology in an eight-week course, while the control group follows traditional methods. Pre- and post-tests assess MAR's impact on creativity, logic, and practical skills. By structuring the research around these five key variables, this study provides a framework for understanding MAR's role in bridging the gap between traditional pedagogy and digital innovation.

The originality of this research lies in applying MAR to packaging design education. While prior studies have explored MAR's role in architecture, engineering, and product design (Cascini et al., 2020), limited research has investigated its application in packaging design, a discipline that demands a balance between aesthetics, functionality, and marketing effectiveness. MAR technology addresses significant limitations of traditional methods, fostering collaborative environments, real-time interaction with design concepts, and virtual trial-and-error processes that mimic real-world practices (Rakshit et al., 2023). For instance, traditional packaging design education often requires physical prototypes, which can be costly and time-consuming to produce. MAR mitigates these challenges by allowing students to create, test, and refine packaging concepts virtually, reducing material waste and accelerating the design process. These advancements improve academic performance and prepare students for the professional design industry's complexities.

This research emphasizes MAR's practical application, focusing on its impact on design innovation, consumer engagement, and education. Evaluating criteria like creativity and interactivity, it provides actionable insights for educators, curriculum developers, and policymakers. In the broader context of digital innovation in education, MAR aligns with global priorities such as enhancing digital literacy, fostering creative problem-solving, and preparing students for technology-driven industries (World Economic Forum, 2022). In conclusion, this study addresses traditional packaging design education shortcomings while introducing MAR technology's transformative potential. Its findings aim to shape the future of design education, leveraging digital tools to improve learning outcomes, bridge the gap between theoretical knowledge and practical application, and foster a culture of continuous innovation.

Objectives

Main objective

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To study the effects of mobile augmented reality (MAR) technology on students' academic performance in packaging design courses.

Subsidiary objectives

1. To determine the level of improvement in visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity among packaging design students after using MAR technology.

2. To compare the differences in the level of improvement in visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity between students using MAR technology and those taught with traditional teaching methods.

Literature review

Mobile Augmented Reality (MAR) Technology in Education

Mobile Augmented Reality (MAR) technology has emerged as a significant advancement in mobile computing, leveraging devices such as smartphones and tablets to merge virtual and real-world environments seamlessly. It allows users to interact dynamically with augmented elements through features like spatial localization and AI-powered object recognition (Sánchez-Juárez et al., 2023). MAR finds applications in diverse fields such as gaming, retail, navigation, and education. In educational contexts, MAR enhances engagement, motivation, and knowledge retention by providing immersive learning experiences that enable users to visualize and manipulate virtual elements to comprehend complex concepts more effectively (Dunleavy & Dede, 2014; Wu et al., 2020).

The technology used in this research is Kivicube, developed by Miji Technology, a platform that simplifies the creation and deployment of AR experiences. Kivicube integrates features such as SLAM-based spatial localization, AR image tracking, and interactive 3D modeling, making it a versatile tool for educational purposes, especially in packaging design. Compared to other MAR platforms like Vuforia and Unity's AR Foundation, Kivicube offers a more accessible web-based environment, reducing barriers to adoption for students and educators with limited programming experience (Chen et al., 2022). With its user-friendly interface and WebXR compatibility, Kivicube facilitates seamless implementation, allowing educators to enhance their teaching materials with immersive content (Technologies, n.d.).

Information on the Population

The study focuses on students from the Visual Communication Design program at Zhanjiang College of Science and Technology, China. These students, averaging 20 years old, represent a demographic adept at integrating creativity with technical acumen. Their coursework includes graphic design, digital imaging, and interactive media, preparing them for utilizing MAR effectively in packaging design education (Morcos, 2020).

Being digital natives, these students exhibit a high degree of adaptability to new technologies and a preference for experiential learning tools like MAR (Tse et al., 2020). Studies suggest that younger generations are more likely to engage with interactive and immersive technologies due to their familiarity with digital environments (Wang et al., 2023). Despite economic disparities that might limit access to MAR-compatible devices, their familiarity with digital technologies positions them as ideal candidates for exploring MAR's potential in enhancing learning outcomes.

Information on the Connection Between Population and Technology

The integration of MAR technology in packaging design education bridges the gap between theoretical understanding and practical application. By overlaying 3D models in real-world settings, MAR enables students to visualize, manipulate, and evaluate design elements more effectively than traditional methods. This dynamic approach fosters spatial awareness, problem-solving, and creativity, which are essential for packaging design (Nabila & Ramlie, 2023).

MAR also enhances collaboration among students by enabling shared virtual environments where they can work on projects together. This collaborative potential aligns with the demands of professional design settings, preparing students for industry challenges (Rakshit et al., 2023). However, the adoption of

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MAR requires addressing challenges such as accessibility to devices, the learning curve for new technologies, and the need for curriculum alignment to optimize its benefits (Luo, 2023). For example, while MAR improves interaction and creativity, some studies have found that students initially struggle with technical difficulties and require additional training to maximize the benefits of MAR-based learning (González et al., 2022).

Previous Literature

Theoretical frameworks such as constructivist and experiential learning theories underpin the educational use of MAR. The constructivist theory emphasizes active knowledge construction through interaction with digital and physical elements, supporting the development of problem-solving skills and critical thinking (Piaget, 1954; Vygotsky, 1978). Experiential learning theory, as proposed by Kolb (1984), highlights four key stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. MAR directly supports these processes by allowing students to visualize and manipulate virtual packaging designs, assess their effectiveness, conceptualize improvements, and iterate on their creations in real time (Xie & Wong, 2021).

Empirical studies demonstrate MAR's effectiveness in enhancing creativity, engagement, and design skills. For instance, Wang et al. (2023) found that students using MAR exhibited superior problem-solving abilities and a deeper understanding of design concepts than those in traditional settings. MAR's dynamic and iterative capabilities allow students to explore design principles innovatively, encouraging experimentation and refining their creative processes.

The research identifies five critical variables for analysis: visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity. Each plays a vital role in assessing MAR's impact on educational outcomes:

Visual Effects: MAR enhances the visual appeal of packaging by allowing students to experiment with elements like color, layout, and typography. This dynamic approach to design improves consumer engagement and decision-making (Liu & Oh, 2022).

Spatial Modeling: By visualizing 3D models in real-world contexts, students gain insights into structural functionality and aesthetic appeal, vital for effective packaging design (Xia, 2015). This ability to interact with digital prototypes fosters a deeper understanding of material properties and product ergonomics (Zhang et al., 2023).

Creativity and Imagination: MAR fosters innovative thinking by enabling rapid prototyping and unconventional design exploration. Research suggests that students who engage with MAR tools demonstrate higher originality and problem-solving levels than those in traditional classrooms (Swara et al., 2023).

Information Dissemination: MAR aids in effectively conveying product details and brand messages, empowering students to integrate communication strategies into their designs. As consumer decision-making is highly dependent on packaging communication, MAR offers a real-time platform for students to test different branding concepts (Susilawati et al., 2023).

Interactivity: By incorporating interactive elements, MAR provides insights into designing user-centric packaging that enhances consumer experiences (Zhang et al., 2023). Interactive learning through MAR leads to increased engagement and better knowledge retention, reinforcing active learning principles (Ahmed & Lataifeh, 2023).

These variables are evaluated using expert assessments and standardized grading criteria to measure their impact on student learning outcomes comprehensively. This research not only highlights MAR's transformative role in education but also addresses a significant gap in the literature by systematically analyzing its effects on multiple learning dimensions (Cascini et al., 2020). The literature review highlights the transformative potential of MAR in packaging design education. By linking MAR to theoretical frameworks, addressing traditional teaching limitations, and identifying specific research gaps, this study contributes to the growing body of knowledge on digital innovation in education. While MAR presents significant advantages, it is important to critically evaluate its challenges, such as accessibility issues,

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technical limitations, and the need for comprehensive educator training (Luo, 2023). By evaluating these factors, this research provides valuable insights for educators, curriculum developers, and policymakers. This study aims to demonstrate that MAR is not just a technological enhancement but a pedagogical tool capable of revolutionizing design education. By fostering creativity, spatial modeling, and interactivity, MAR has the potential to redefine how packaging design is taught, preparing students for the demands of an increasingly digital and innovation-driven industry.

Conceptual Framework

A research framework provides a structured approach to conducting research, ensuring that research questions are effectively addressed and results are systematically interpreted (Stevens & Finlay, 1996). A well-defined conceptual framework enhances the clarity of the research design by explicitly outlining relationships between variables, guiding hypothesis testing, and ensuring theoretical consistency. The following section presents the framework for this study, which examines the impact of Mobile Augmented Reality (MAR) on packaging design education.

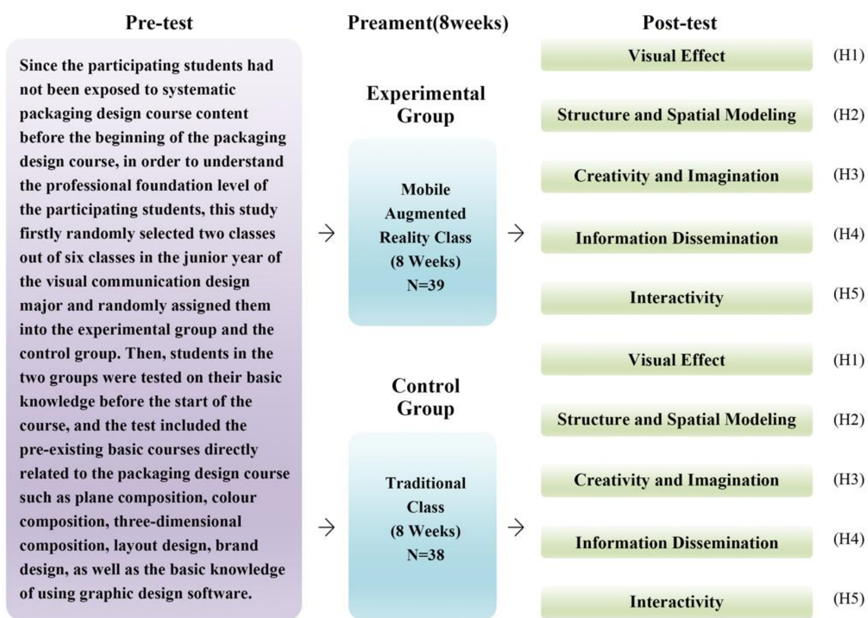

Figure 1 Research Framework

Framework Structure and Justification

To strengthen the theoretical foundation of this framework, this study explicitly connects the five key dimensions—visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity—to established educational and design theories.

Visual Effects: Grounded in Gestalt theory and visual perception principles, visual effects play a crucial role in packaging design by influencing consumer attention and product appeal (Ware, 2012). MAR enhances visual effects by allowing students to experiment dynamically with colors, typography, and layout in a virtual space.

Spatial Modeling: Supported by constructivist learning theory (Piaget, 1954), spatial modeling enables students to grasp three-dimensional structures and functional aspects of packaging design. MAR provides real-time manipulation of 3D models, fostering spatial intelligence and ergonomic understanding (Xie & Wong, 2021).

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Creativity and Imagination: Experiential learning theory (Kolb, 1984) emphasizes the role of active experimentation in creative problem-solving. MAR stimulates creativity by offering iterative design possibilities, allowing students to test unconventional ideas and refine their concepts (Swara et al., 2023).

Information Dissemination: Cognitive Load Theory (Sweller, 1994) suggests that MAR can optimize information processing by reducing extraneous cognitive load and enhancing user comprehension. Students can interact with AR-generated product information, reinforcing their ability to integrate branding and communication elements effectively.

Interactivity: According to Vygotsky's (1978) social learning theory, interactivity in MAR fosters peer collaboration and hands-on engagement. MAR's shared virtual spaces encourage teamwork and iterative discussions, preparing students for industry-standard collaborative practices (Rakshit et al., 2023).

Experimental Design and MAR Application

This study used an 8-week quasi-experimental design to examine the effect of MAR on packaging design education. The framework details the experimental structure as follows:

Preliminary evaluation: Before the start of the course, 2 classes were randomly selected from the 6 classes in junior year majoring in visual communication design, and they were randomly designated as the experimental group and the control group. The basic knowledge of packaging design, including the area composition, color theory, three-dimensional composition, brand, and proficiency of graphic design software, was tested on the students in the 2 groups respectively.

Experimental Group (n = 39): Enrolled in a MAR-supported course utilizing Kivicube for interactive 3D modeling, spatial visualization, and real-time design modifications.

Control Group (n = 38): Received instruction through traditional methods, including static images, PowerPoint presentations, and physical mockups.

Course Content: Students were taught packaging design principles, incorporating visual aesthetics, structural integrity, branding strategies, and digital prototyping techniques. The experimental group leveraged MAR to engage in interactive simulations and augmented reality-based product presentations.

Post-Test Evaluation: At the end of the 8-week course, both groups underwent a post-test measuring their competencies in the five key dimensions to test the following hypotheses:

H1: MAR enhances visual effects by improving students' ability to manipulate design elements dynamically.

H2: MAR strengthens spatial modeling by allowing real-time adjustments to 3D structures.

H3: MAR improves creativity and imagination by facilitating experimental design exploration.

H4: MAR optimizes information dissemination by integrating digital communication strategies into packaging concepts.

H5: MAR fosters interactivity by promoting collaborative and hands-on learning experiences.

Theoretical Integration and Hypothesis Justification

Each hypothesis is grounded in empirical research that supports MAR's role in enhancing specific educational outcomes.

H1 (Visual Effects Enhancement): Previous studies demonstrate that MAR allows users to interact dynamically with visual components, leading to improved aesthetic refinement and consumer engagement in design applications (Liu & Oh, 2022).

H2 (Spatial Modeling Improvement): MAR's ability to generate real-time 3D representations enhances students' spatial reasoning, a critical skill in packaging design (Xia, 2015).

H3 (Creativity and Imagination Stimulation): Studies suggest that MAR fosters higher creativity levels due to its iterative and exploratory capabilities (Swara et al., 2023).

H4 (Enhanced Information Dissemination): Research indicates that MAR facilitates branding comprehension and communication strategy application by allowing students to engage with digital product representations (Susilawati et al., 2023).

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H5 (Interactivity Enhancement): MAR enables collaborative environments that simulate real-world industry practices, aligning with social learning and constructivist educational models (Zhang et al., 2023).

Operational Definitions and Measurement Consistency

Table 1 To ensure clarity and consistency, this study explicitly defines the five key dimensions and their measurement criteria.

Variable	Definition	Constituent Elements	Operationalization	Source	Score
Visual Effect （VE）（20%）	Packaging design visual effects refer to the use of graphic elements, colors, and symbols in product packaging to enhance its texture, communicate brand messages, and attract consumers' attention (Li, 2022).	Brand Consistency （5%） Colour Matching （5%） Graphic Use （5%） Aesthetic Effect （5%）	Excellent (90-100 points) Good (80-89 points) Medium (70-79 points) Pass (60-69 points) Fair (Below 60 points)	Zhanjiang University of Science and Technology, Department of Visual Communication, Packaging Design Course Assessment Scale （2022）	0-100 points
Structure and Spatial Modeling （S&PM）（20%）	Packaging structure refers to the physical design and arrangement of components within a packaging system, including the placement of parts to ensure safe and efficient packaging (Wang, 2023). Styling design focuses on the aesthetic aspects, applying principles like balance, contrast, rhythm, and proportion to create visually appealing packaging (Xia, 2015).	Structurally Sound （5%） Styling Innovation （5%） Functionality （5%） Practicality （5%）	Excellent (90-100 points) Good (80-89 points) Medium (70-79 points) Pass (60-69 points) Fair (Below 60 points)	Zhanjiang University of Science and Technology, Department of Visual Communication, Packaging Design Course Assessment Scale （2022）	0-100 points
Creativity and Imagination C&I （20%）	Creative packaging refers to the design and implementation of innovative and unique	Originality （5%）	Excellent (90-100 points) Good (80-89 points)	Zhanjiang University of Science and Technology,	0-100 points

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Variable	Definition	Constituent Elements	Operationalization	Source	Score
	packaging solutions that add value to products and reflect the brand's identity. It involves the use of creative ideas, different printing materials, technologies, and smart solutions to enhance the consumer experience and meet their changing needs and lifestyles (Swara et al., 2023).	Innovativeness （5%） Interestingness （5%） Environmental Protection and Sustainability （5%）	Medium (70-79 points) Pass (60-69 points) Fair (Below 60 points)	Department of Visual Communication, Packaging Design Course Assessment Scale （2022）	
Information Dissemination （ID） （20%）	Information communication in packaging design conveys product characteristics, values, and brand messages to consumers through visual and textual elements, including material selection, color, graphics, text, and structure. The goal is to ensure the safety and convenience of the product and to effectively influence the purchasing decision (Susilawati et al).	Clarity and Readability （5%） Educational Guidelines （5%） Cultural Relevance （5%） Accessibility and Inclusiveness （5%）	Excellent (90-100 points) Good (80-89 points) Medium (70-79 points) Pass (60-69 points) Fair (Below 60 points)	Zhanjiang University of Science and Technology, Department of Visual Communication, Packaging Design Course Assessment Scale （2022）	0-100 points
Interactivity （I） （20%）	Interactivity in packaging refers to the use of intelligent interaction technology to enhance the interaction between consumers and packaging, creating a more interesting and intelligent packaging design. This involves considering the user's emotional experience and incorporating	Functional Interaction （5%） Multi-Sensory Experience （5%） Technical Application （5%）	Excellent (90-100 points) Good (80-89 points) Medium (70-79 points) Pass (60-69 points) Fair (Below 60 points)	Zhanjiang University of Science and Technology, Department of Visual Communication, Packaging Design Course Assessment Scale （2022）	0-100 points

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Variable	Definition	Constituent Elements	Operationalization	Source	Score
	interactive elements into packaging design (Zhang et al., 2023).	Social Shareability （5%）			

Research hypothesis

This study investigates students' performance in packaging design across five key dimensions: visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity. These dimensions are essential attributes of effective packaging design and serve as the foundation for evaluating the impact of Mobile Augmented Reality (MAR) compared to traditional teaching methods.

Visual effects assess students’ ability to enhance the aesthetic appeal of packaging, influencing consumer attention and engagement (Liu & Oh, 2022). The hypothesis examines whether MAR fosters a greater improvement in visual appeal than traditional teaching approaches.

Spatial modeling focuses on students' ability to conceptualize and construct packaging structures that balance form and functionality, ensuring structural integrity and visual appeal (Xia, 2015).

Creativity and imagination reflect students’ capacity for innovation, exploring novel ideas beyond conventional boundaries in packaging design (Swara et al., 2023).

Information dissemination evaluates how effectively packaging designs communicate product details and branding, ensuring clarity and consumer engagement (Susilawati et al., 2023).

Interactivity measures the extent to which designs integrate user engagement, considering both tactile and visual experiences to enhance consumer interaction and satisfaction (Zhang et al., 2023).

Table 2 Grounded in these dimensions and existing literature, the study formulates the following hypotheses.

Hypothesis	Statement
H1	The use of MAR technology significantly enhances visual effects compared to traditional methods.
H2	MAR improves students' ability in spatial modeling and structural design relative to traditional methods.
H3	MAR fosters greater creativity and imagination in packaging design than traditional approaches.
H4	MAR enhances the effectiveness of information dissemination in packaging design compared to conventional methods.
H5	MAR improves the interactivity of packaging designs more effectively than traditional teaching techniques.

Methodology

Research Design

This study adopts a quantitative quasi-experimental design to assess the impact of Mobile Augmented Reality (MAR) technology on students’ performance in packaging design. A quasi-experimental approach is employed to compare two groups:

Experimental group: Students engaged with MAR-enhanced instructional materials.

Control group: Students followed traditional teaching methods.

The study aligns with its research objectives by examining MAR’s influence on five key dimensions: visual effects, spatial modeling, creativity and imagination, information dissemination, and interactivity. A pre-test/post-test design was implemented to track changes in student performance before and after the intervention. The pre-test assessed foundational knowledge in planar composition, color theory, 3D

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modeling, and software usage, ensuring comparability between groups. A post-test conducted after the intervention measured progress in packaging design skills. To enhance internal validity, students were randomly assigned to groups using a computer-generated randomization process, ensuring equal distribution of prior knowledge and skills. The same experienced instructor taught both groups to maintain consistency in instructional delivery.

Research Treatment

The study was conducted over a period of eight weeks, following a structured approach to ensure a systematic comparison between the experimental group (using MAR-enhanced instruction) and the control group (using traditional teaching methods).

In Week 1, students were randomly assigned to either the experimental or control group, ensuring that both groups were equivalent in prior knowledge and skills. A pre-test was administered to assess their baseline competencies in packaging design, including spatial modeling, visual effects, creativity, information dissemination, and interactivity. This step established a benchmark for evaluating learning progress after the intervention.

From Weeks 2 to 7, both groups underwent instructional interventions tailored to their respective teaching methods. The experimental group engaged with MAR-enhanced learning experiences, utilizing interactive 3D models, real-time design manipulations, and immersive simulations to reinforce key design concepts. Meanwhile, the control group followed traditional teaching methods, relying on static images, PowerPoint presentations, and lecture-based instruction. Throughout this phase, students participated in design exercises, discussions, and guided practice sessions, allowing them to apply their knowledge in structured learning activities.

In Week 8, a post-test evaluation was conducted to measure the students' progress and determine the effectiveness of MAR-enhanced learning compared to traditional instruction. The post-test assessed students' improvements across the five key learning dimensions, providing quantitative data to analyze the impact of MAR technology on design education outcomes.

Experimental Group (MAR-Enhanced Learning)

The experimental group used MAR-based instructional materials developed with Kivicube, a WebXR creation platform. The MAR integration included:

- Interactive 3D models to visualize packaging designs.
- Augmented reality overlays for real-time modifications.
- Virtual prototyping to enhance structural modeling and interactivity.

Each lesson incorporated MAR-driven activities:

- 3D model exploration, allowing students to manipulate virtual packaging structures.
- Real-time design feedback, enabling iterative improvements.
- Interactive content fosters an immersive learning experience.

Control Group (Traditional Learning)

The control group followed conventional teaching methods, including:

- PowerPoint presentations and static images for concept explanation.
- Lectures on packaging design principles without interactive elements.
- Hands-on exercises using physical prototyping and 2D sketches.
- Unlike the experimental group, the control group did not engage with MAR or interactive 3D modeling, limiting their exposure to immersive learning experiences.

Population and Sample

The study's population consisted of junior-year Visual Communication Design students at Zhanjiang University of Science and Technology. A total of 80 students were randomly selected from six classes, forming two groups: Experimental group (n = 39), Control group (n = 38). Junior-year students were chosen due to their prior coursework in digital tools and packaging design, making them suitable candidates for MAR-based interventions. The study also acknowledged potential challenges, such as differences in students' access to MAR-compatible devices.

Research Instruments

Pre-tests and post-tests were used to evaluate student performance across five key variables:

Visual Effects: Aesthetic quality and consumer appeal.

Spatial Modeling: Structural integrity and functional design.

Creativity and Imagination: Innovation and originality.

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Information Dissemination: Clarity in branding and messaging.
Interactivity: Engagement and user interaction.

Assessments included:

Multiple-choice questions to test theoretical knowledge.
Project-based evaluations, where students designed packaging prototypes.
Expert panel evaluations by three senior design professionals.

The examination is marked on a 100-point scale. To ensure consistency, evaluation criteria were reviewed, and confidence among raters was checked using Cohen's kappa statistic.

Data Collection Procedures

The study followed a structured data collection process:
Pre-test administration to both groups in Week 1.
Implementation of MAR-enhanced and traditional teaching methods in Weeks 2-7.
Post-test administration in Week 8.
Expert evaluations of students' final packaging designs.
Collection of student feedback for qualitative insights.

The research adhered to strict ethical guidelines, ensuring:

Informed consent from all participants.
Data anonymization to protect privacy.
Voluntary participation allows students to withdraw at any stage.
Bias mitigation measures, such as blind assessments of student work.

Data Analysis

Data were analyzed using both descriptive and inferential statistical methods:
Descriptive statistics (means and standard deviations) summarized group performance.
Paired t-tests examined within-group improvements.
Independent t-tests compared pre-test and post-test scores between groups.
Effect size calculations (Cohen's d) determined MAR's impact.

Summary

This methodology provides a structured, rigorous framework for evaluating MAR's effectiveness in packaging design education. The combination of pre-test/post-test comparisons, expert evaluations, and statistical analysis ensures the study delivers valid and reliable insights into MAR's impact on design learning outcomes.

Results

Demographic Information

In this research, the sample consisted of 77 third-year university students majoring in Visual Communication Design at the School of Fine Arts and Design, Zhanjiang University of Science and Technology, Guangdong Province, China. Class A, comprising 39 students, was designated as the experimental group, while Class B, comprising 38 students, was designated as the control group. All participants in the experiment studied packaging design lessons using two different teaching methods: traditional classroom instruction and Mobile Augmented Reality (MAR)-supported teaching activities.

The gender distribution of the control and experimental groups is an important aspect of this study. In the control group, there were 38 students in total, including 15 male students and 23 female students, accounting for approximately 49.4% of the overall sample. The experimental group consisted of 39 students, with 16 male students and 23 female students, making up about 50.6% of the total sample. Overall, the sample included 31 male students (40%) and 46 female students (60%).

Table 3 Demographics of Gender Information

Gender	Group	Frequency	Percentage	Percentage of Total
Male	Control	15	25.0%	49.4%
	Experimental	16	26.7%	
Female	Control	23	38.3%	50.6%
	Experimental	23	38.3%	

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The sample students included those from both the experimental group and the control group, with a total of 77 individuals. They were all third-year university students, aged between 20 and 22 years. In the experimental group, there were 39 students, the majority of whom were 21 years old, totaling 35 students and accounting for 45.45% of the total sample. There were 2 students aged 22, making up 2.60% of the total sample, and 2 students aged 20, also accounting for 2.60% of the total sample. In the control group, there were 38 students, the majority of whom were also 21 years old, totaling 34 students and accounting for 44.16% of the total sample. There was 1 student aged 22, making up 1.30% of the total sample, and 3 students aged 20, accounting for 3.90% of the total sample.

Table 4 Demographics of Age Information

Age	Group	Frequency	Percentage	Percentage of Total
20 years	Experimental	2	2.60%	6.50%
	Control	3	3.90%	
21 years	Experimental	35	89.74%	89.61%
	Control	34	89.47%	
22 years	Experimental	2	5.13%	3.90%
	Control	1	2.63%	

Differences Between the Pre-test Scores

To ensure that students in the experimental group and the control group had comparable learning foundations at the start of the experiment, their pre-test scores were collected and analyzed. An independent samples t-test was conducted to compare the pre-test scores of both groups in the assessment of fundamental knowledge in visual communication design. The table below presents the results of the data analysis.

Table 5 Means Summary for Students' Pre-test Scores

	Group	N	Mean	SD
Average Score	Control	38	80.0	7.35
	Experimental	39	80.5	8.72

Table 6 T-tests for Pre-test Scores Between the Two Groups

		Statistic	df	p	Mean difference	SE difference
Average Score	Student's t	-0.302	75.0	0.763	-0.556	1.84

Based on the results of the independent samples t-test, the pre-test scores of students in the experimental and control groups were compared to ensure that both groups had comparable learning foundations at the start of the experiment. The results showed that the t-value was -0.302, with df equal to 75, and the p-value was 0.763. Since the significance level is greater than 0.05, there is no significant difference between the pre-test scores of the two groups. Therefore, we cannot reject the null hypothesis (H0), meaning that the difference in pre-test scores between the experimental and control groups is not statistically significant. The mean difference is -0.556, indicating a difference of -0.556 in the average scores between the two groups, and the standard error of the difference is 1.84. These results suggest that, at the start of the experiment, the students in both the experimental and control groups had comparable pre-test scores in the visual communication design foundational knowledge assessment.

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Differences Between the Post-test Scores

Table 7 Means Summary for Students' Post-test Scores

	Group	N	Mean	SD
Total Score	Control	38	77.6	7.44
	Experimental	39	81.9	8.54
Visual Effect	Control	38	77.5	8.14
	Experimental	39	81.6	9.22
Structure and Spatial Modeling	Control	38	77.3	8.25
	Experimental	39	81.4	9.43
Creativity and Imagination	Control	38	77.5	9.41
	Experimental	39	82.1	9.21
Information Dissemination	Control	38	77.4	8.50
	Experimental	39	82.1	9.15
Interactivity	Control	38	78.2	7.86
	Experimental	39	82.5	9.27

Table 8 T-tests for Post-test Scores Between the Two Groups

		Statistic	df	p	Mean difference	SE difference
Total Score	Student's t	-2.38	75.0	0.020	4.34	1.83
Visual Effect	Student's t	-2.06	75.0	0.043	4.08	1.98
Structure and Spatial Modeling	Student's t	-2.01	75.0	0.048	4.07	2.02
Creativity and Imagination	Student's t	-2.14	75.0	0.036	4.53	2.12
Information Dissemination	Student's t	-2.34	75.0	0.022	4.72	2.01
Interactivity	Student's t	-2.19	75.0	0.031	4.30	1.96

The comparison of post-test scores highlights the superior performance of the experimental group using MAR-assisted teaching methods compared to the control group employing traditional methods in a packaging design course. Data analysis reveals significant improvements across all measured dimensions, with p-values below 0.05, indicating statistically significant differences.

Overall, the experimental group outperformed the control group, with a mean difference of 4.34 and a p-value of 0.020, signifying a significant enhancement in overall performance. Specifically, in the Visual Effects dimension, the experimental group achieved a mean difference of 4.08 ($p = 0.043$), demonstrating the effectiveness of MAR-assisted teaching in improving students' understanding of visual aesthetics. In Structure and Spatial Modeling, the experimental group exceeded the control group by 4.07 points ($p = 0.048$), reflecting better spatial and structural design capabilities. Similarly, in Creativity and Imagination, the experimental group recorded a mean difference of 4.53 with a p-value of 0.036, showcasing MAR's impact in stimulating innovative thinking and imaginative skills. The dimensions of Information Dissemination and Interactivity also saw notable improvements. For Information Dissemination, the

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experimental group achieved a mean difference of 4.72 ($p = 0.022$), indicating an enhanced ability to convey information effectively. For Interactivity, a mean difference of 4.30 ($p = 0.031$) was observed, suggesting better engagement and dynamic interaction fostered by MAR tools. In conclusion, the experimental group demonstrated significantly higher performance across all dimensions, validating the effectiveness of MAR-assisted teaching over traditional methods. These findings suggest that MAR not only enhances multidimensional learning outcomes in packaging design but also fosters the development of advanced cognitive skills, including creativity and spatial conceptualization, making it a powerful tool for modern education in design fields.

Hypotheses Testing

The results of descriptive data analysis, as shown in Table 6, reveal significant differences between the experimental group (utilizing MAR technology) and the control group (traditional methods) in the improvement of students' packaging design scores across various dimensions. Independent samples t-tests were conducted to compare the post-test scores, and the results indicated statistically significant improvements in all assessed areas, leading to the rejection of the null hypothesis in each case.

In terms of visual effects, the t-test yielded a significant result, $t\ (75) = -2.06$, $p=0.043t\ (75) = -2.06$, $p=0.043$, indicating that the experimental group outperformed the control group in enhancing the visual quality of their packaging design works. This demonstrates that the MAR-assisted teaching method effectively improved students' understanding and application of visual design principles. For structure and spatial modeling, the t-test result was also significant, $t\ (75) = -2.01$, $p=0.048t\ (75) = -2.01$, $p=0.048$. This suggests that the experimental group showed greater improvement in their ability to conceptualize and create functional, aesthetically pleasing spatial models compared to the control group. Regarding creativity and imagination, the experimental group exhibited a significant advantage over the control group, with $t\ (75) = -2.14$, $p=0.036t\ (75) = -2.14$, $p=0.036$. These findings highlight the ability of MAR technology to foster innovative thinking and imaginative exploration in students' design processes. The results for information dissemination showed a significant mean difference as well, $t\ (75) = -2.34$, $p=0.022t\ (75) = -2.34$, $p=0.022$. This indicates that students in the experimental group demonstrated superior skills in conveying product information and brand messaging effectively through their packaging designs. Lastly, in the dimension of interactivity, the t-test revealed $t\ (75) = -2.19$, $p=0.031t\ (75) = -2.19$, $p=0.031$, confirming that the experimental group outperformed the control group. The use of MAR technology enabled students to create more engaging and interactive designs, enhancing the user experience.

Table 9 Summary of Hypothesis testing and results

Hypotheses	Statement	Result after Analysis
H^a1	There is no difference between the experimental group and the control group in visual effects.	Rejected. There is a significant difference between the two groups, with a p-value of 0.043.
H^a2	There is no difference between the experimental group and the control group in structure and spatial modeling.	Rejected. There is a significant difference between the two groups, with a p-value of 0.048.
H^a3	There is no difference between the experimental group and the control group in creativity and imagination.	Rejected. There is a significant difference between the two groups, with a p-value of 0.036.
H^a4	There is no difference between the experimental group and the control group in information dissemination.	Rejected. There is a significant difference. Between the two groups, with a p-value of 0.022.
H^a5	There is no difference between the experimental group and the control group in interactivity.	Rejected. There is a significant difference between the two groups, with a

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Hypotheses	Statement	Result after Analysis
		p-value of 0.031.

Discussion

This study confirms the effectiveness of Mobile Augmented Reality (MAR) technology in enhancing students' learning outcomes in packaging design education. The experimental group, which utilized MAR-assisted teaching, demonstrated significant improvements compared to the control group across all assessed dimensions. These findings validate MAR's potential to enhance students' abilities in visual effects, structure and spatial modeling, creativity and imagination, information dissemination, and interactivity.

Connection to Existing Literature

The findings align with and extend prior research on MAR's role in design education and experiential learning. The improvement in visual effects reinforces previous studies on visual storytelling and digital interaction (Liu & Oh, 2022), suggesting that MAR enables real-time manipulation of design elements, thereby enhancing students' aesthetic perception and design accuracy. These results complement Zhao and Song's (2023) work, which highlights the importance of immersive environments in fostering detailed artistic expression. The enhancement in spatial modeling skills is that MAR's three-dimensional visualization capabilities significantly improve spatial reasoning. Traditional design instruction often relies on 2D representations, which can limit students' ability to fully grasp spatial relationships. MAR overcomes this limitation by providing interactive 3D modeling tools, allowing students to visualize, manipulate, and refine structural designs in real-time. The observed increase in creativity and imagination supports Kolb's (1984) experiential learning theory, which emphasizes learning through hands-on interaction. The ability to iterate designs in an augmented environment encourages students to explore alternative design solutions, fostering innovative thinking and creative exploration (Swara et al., 2023). Unlike traditional methods, which often follow linear learning approaches, MAR supports non-linear, iterative problem-solving, giving students greater creative flexibility. The improvement in information dissemination extends prior research on integrating textual and visual information for effective communication. Liu and Oh's (2022) study on branding and marketing strategies suggests that the ability to integrate visual and textual elements seamlessly is crucial for effective storytelling. MAR technology facilitates this process by providing an interactive interface where students can experiment with typography, branding elements, and user experience in a dynamic setting. Finally, the significant gains in interactivity support Susilawati et al.'s (2023) findings on engaging learning environments. The interactive features of MAR allow students to receive instant feedback, bridging the gap between theoretical learning and practical application. This aligns with recent studies in educational technology, which emphasize that active engagement in learning environments leads to deeper knowledge retention and skill acquisition.

Practical Implications

Beyond packaging design education, these findings have broader implications for creative industries and design education as a whole. The use of MAR in architecture, industrial design, and engineering could enhance spatial visualization, rapid prototyping, and iterative design testing. For instance, in architecture, students could visualize building structures at scale, while in industrial design, MAR could facilitate interactive testing of product ergonomics and usability. Incorporating MAR into cross-disciplinary educational frameworks could also foster collaborative learning environments where students from different fields—such as graphic design, marketing, and engineering—work together in an integrated digital workspace. These applications highlight MAR's transformative potential in modern professional practices, preparing students for technology-driven creative industries.

Limitations and Challenges

Despite its numerous benefits, this study acknowledges several limitations associated with MAR integration in design education. One major concern is accessibility. Socioeconomic disparities may limit students' ability to access MAR-capable devices, potentially creating an equity gap in technology-enhanced learning. While institutions can mitigate this issue through subsidized technology programs or shared AR/VR labs, these solutions require financial investment and policy support. Another challenge is the learning curve associated with MAR tools. Although junior-year students were selected for this study due to their familiarity with digital tools, some students and instructors still experienced difficulties in adapting to MAR-based instruction. Future studies could explore structured training programs to facilitate smoother integration of MAR into the curriculum. Furthermore, while this study used pre-tests and post-tests to

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measure performance, it did not examine long-term skill retention. Future research could investigate whether MAR-based learning leads to sustained improvements over extended periods or if students require ongoing exposure to maintain and refine their skills. Additionally, potential biases in assessment should be considered. Although expert evaluators were used to ensure objective grading, subjective interpretations of design quality could still influence the results. Future studies could incorporate machine-learning-based design evaluation metrics to enhance grading consistency and objectivity.

Future Research Directions

To further explore MAR's impact in creative education, future research should focus on:

Longitudinal studies examining long-term knowledge retention and skill development.

Comparative studies across different educational levels (high school vs. university) and disciplines (e.g., industrial design, game design, engineering). Cross-cultural investigations to determine how MAR adoption varies in different educational and socio-economic contexts. Integrating MAR with AI-driven assessment tools to automate and refine design evaluations. Exploring the effectiveness of MAR in collaborative and team-based learning environments.

Balanced Perspective on MAR Technology

While the findings demonstrate MAR's strong potential, it is essential to maintain a balanced perspective by acknowledging its challenges and areas for improvement. The current portrayal of MAR focuses heavily on its advantages, but future implementations should consider practical barriers such as cost, training needs, and technological infrastructure. A more nuanced discussion that includes both opportunities and constraints will better inform educators, policymakers, and technology developers on how to effectively implement MAR in education.

Conclusion

This study underscores the transformative potential of Mobile Augmented Reality (MAR) technology in enhancing students' learning performance in packaging design education. The findings confirm that MAR significantly improves student outcomes across visual effects, spatial modeling, creativity, information dissemination, and interactivity, offering innovative solutions to the limitations of traditional teaching methods. By creating immersive and interactive learning environments, MAR enables students to visualize, manipulate, and engage with packaging design concepts in real-world contexts, fostering a deeper understanding and practical application of design principles.

Beyond packaging design, MAR's applicability extends to STEM education, vocational training, and healthcare education, where it can enhance visualization, facilitate hands-on learning, and improve skill development. For example, in STEM fields, MAR can assist in simulating scientific concepts and mathematical models, while in vocational and technical training, it can provide real-time simulations of mechanical processes or architectural structures. In medical education, MAR has the potential to enhance surgical training and anatomy visualization, allowing students to explore complex spatial relationships in an interactive environment. These applications demonstrate MAR's versatility as a powerful tool for bridging theoretical knowledge and practical experience across disciplines.

From a theoretical perspective, this study reinforces Kolb's experiential learning theory and constructivist educational models, which emphasize the importance of active participation and iterative learning. MAR fosters hands-on engagement, allowing students to experiment with design concepts dynamically rather than relying solely on static instructional materials. Additionally, MAR contributes to cognitive load management by providing scaffolded learning experiences, where students gradually build their understanding without becoming overwhelmed. This adaptability makes MAR particularly effective in skill-based education, where iterative practice and real-time feedback are crucial.

Despite its advantages, MAR adoption faces several challenges, including socioeconomic disparities, educator training gaps, and varying student adaptation levels. Access to MAR-compatible devices may be limited in underfunded institutions, creating a digital divide that could hinder widespread adoption. Moreover, instructors may require specialized training to integrate MAR effectively into their teaching strategies. Additionally, while MAR provides intuitive interactive tools, some students may experience a learning curve when engaging with new digital interfaces. Addressing these challenges requires investment in shared AR/VR labs, structured faculty development programs, and AI-driven adaptive learning tools to ensure a smoother transition to MAR-enhanced education.

Future research should explore longitudinal studies on MAR's long-term impact, assessing whether students retain design skills and conceptual understanding over time. Comparative studies should

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investigate how MAR influences different educational levels, from secondary schools to higher education and professional training programs. Additionally, cross-cultural research could examine how MAR adoption varies across socio-economic and technological landscapes, providing insights into its scalability and accessibility in diverse educational settings. Another promising direction involves studying MAR's role in collaborative and remote learning, where students from different locations could engage in shared virtual design projects, fostering teamwork and interdisciplinary problem-solving.

A global perspective is necessary to ensure MAR is accessible across diverse cultural and economic contexts, potentially bridging educational gaps through open-source platforms, government-backed technology initiatives, and industry partnerships. In regions with limited access to advanced technological tools, MAR's integration into online learning platforms could enhance remote education, providing students with virtual hands-on experiences that simulate real-world applications. By addressing barriers to accessibility and affordability, MAR has the potential to democratize education and equip students with cutting-edge digital competencies.

As educational institutions continue to embrace digital transformation, MAR stands as a powerful tool for fostering creativity, collaboration, and problem-solving skills. To fully harness its potential, stakeholders—including educators, institutions, policymakers, and technology developers—must work together to expand access, optimize pedagogical integration, and ensure equitable, effective learning experiences. With continued advancements and strategic implementation, MAR can revolutionize education and prepare students for success in an increasingly technology-driven world.

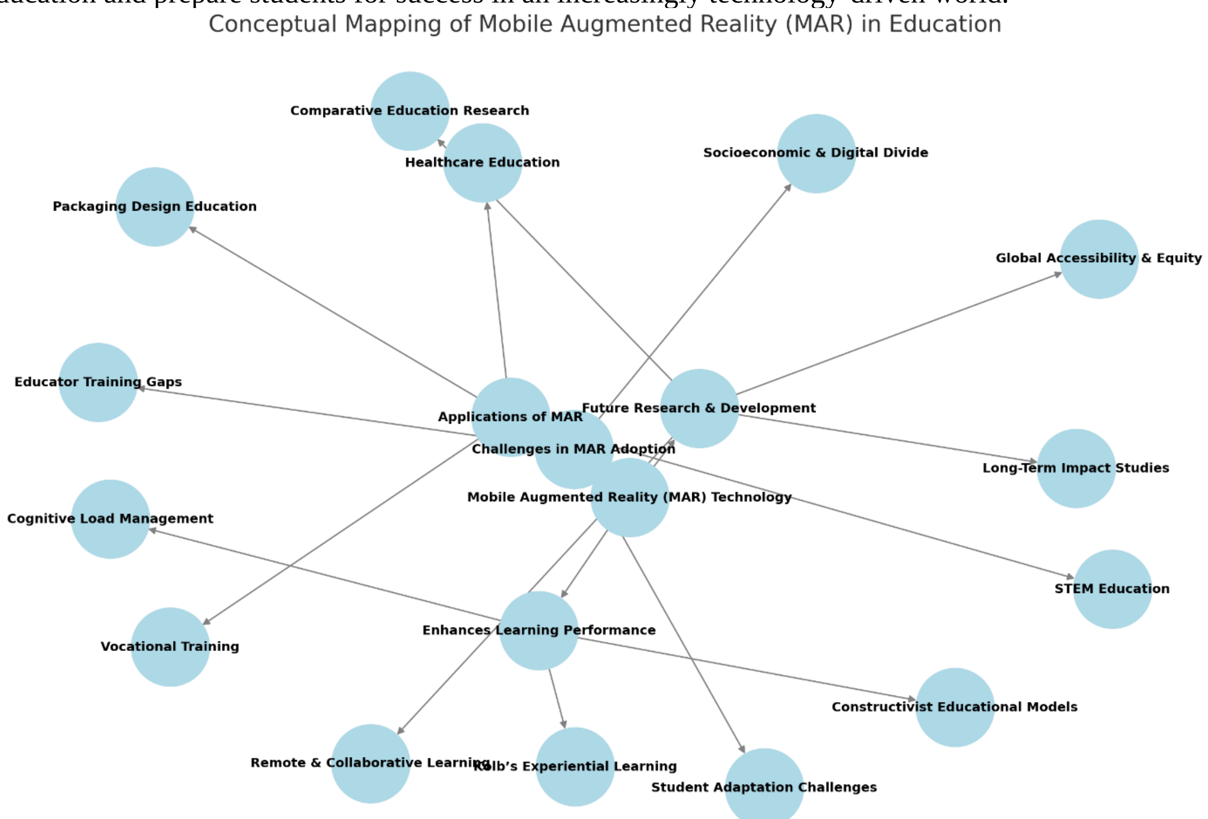

Figure 2 Mobile Augmented Reality (MAR)

The conceptual model provides a visual representation of the role of mobile augmented reality (MAR) in education by emphasizing its key components and relationships. MAR essentially enhances learning outcomes by boosting imagery, creativity, and engagement. Its uses go beyond teaching packaging design; it also helps with hands-on learning and complicated concept visualization in STEM, vocational training, and healthcare. The model also emphasizes the theoretical underpinnings of MAR by connecting

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it to constructivist educational models, cognitive load management, and Kolb's experiential learning, all of which promote active and iterative learning. Widespread acceptance is hampered by obstacles like the digital divide, limitations in teacher preparation, and difficulties with student adaptation. Future options for addressing these obstacles include comparative research, worldwide accessibility initiatives, collaborative learning integration, and longitudinal impact studies. This methodical approach highlights MAR's potential to transform education while pointing out important areas for further study and development.

Recommendation

Based on the findings of this study, several recommendations are proposed to enhance the integration of Mobile Augmented Reality (MAR) technology into packaging design education. These recommendations focus on maximizing MAR's potential to improve student learning outcomes, addressing implementation challenges, and expanding its broader applicability in education. To ensure long-term sustainability, educational institutions should incorporate MAR as a core component of design curricula and adopt cost-effective strategies for device maintenance, software updates, and faculty training. Establishing dedicated MAR learning labs and securing institutional funding for technology upgrades (Wang et al., 2023) can provide students with consistent access to interactive learning tools while reducing the dependency on high-end hardware. Cloud-based MAR platforms can also be leveraged to lower hardware costs while ensuring students can access essential tools from multiple devices (Rakshit et al., 2023).

For effective MAR implementation, comprehensive educator training programs should be developed to ensure instructors can confidently design, integrate, and manage MAR-based lessons. These programs should include hands-on workshops on MAR platforms such as Kivicube, strategies for incorporating MAR into lesson plans, and methods for evaluating MAR's impact on student learning outcomes (Susilawati et al., 2023). Training should emphasize both technical proficiency and pedagogical strategies that align with constructivist and experiential learning theories, ensuring that real-time feedback mechanisms, virtual simulations, and interactive learning experiences enhance student engagement and understanding (Kolb, 1984; Dunleavy & Dede, 2014). Educators should also be trained to use student-centered learning approaches, allowing students to explore MAR-based design solutions at their own pace (Ibáñez & Delgado-Kloos, 2018). To address accessibility challenges, institutions should establish shared resource centers, providing AR-enabled tablets, smartphones, or headsets for classroom use. Additionally, loan programs could allow students, particularly those from underserved backgrounds, to borrow devices for extended periods (Wang et al., 2023). Partnering with local governments and technology providers can further support the cost-effective deployment of MAR solutions, ensuring that students, regardless of financial background, have equitable access to technology-enhanced learning experiences (Rakshit et al., 2023). Open-source MAR applications should also be prioritized to reduce financial barriers and increase adoption in resource-limited educational settings (Jindal et al., 2023).

While this study focuses on packaging design education, MAR's potential extends to architecture, industrial design, engineering, and healthcare education, where spatial visualization and hands-on learning are crucial. For example, in architecture, students can use MAR to explore scaled 3D models of buildings, while in engineering, MAR can simulate mechanical structures and moving components for interactive analysis (Zhao & Song, 2023). The successful application of MAR in these fields highlights its cross-disciplinary potential, encouraging educators to adapt MAR-enhanced learning across diverse academic disciplines. Additionally, collaborative MAR-driven projects between students from design, marketing, and engineering disciplines can mirror real-world professional environments, preparing them for industry demands (Susilawati et al., 2023). To assess the effectiveness of MAR-based instruction, institutions should implement clear evaluation frameworks measuring student engagement, progress, and skill development (Dunleavy & Dede, 2014). Metrics should include quantitative measures such as test score improvements, creativity assessments, and design accuracy, alongside qualitative feedback from students and instructors. Further, longitudinal studies should examine whether MAR-driven learning leads to long-term retention of design skills, ensuring that the technology provides lasting educational benefits (Swara et al., 2023). AI-driven learning analytics could also be leveraged to personalize MAR-based instruction, tailoring content and feedback to individual student needs (Sánchez-Juárez et al., 2023).

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Future development of MAR technology should focus on enhancing interactivity and collaboration features to increase student engagement and teamwork. This includes real-time peer collaboration, multi-user simulations, and AI-driven design feedback to create a more adaptive and interactive learning experience (Liu & Oh, 2022). Cloud-based MAR platforms could facilitate cross-location virtual teamwork, allowing students to collaborate on design projects remotely (Ibáñez & Delgado-Kloos, 2018). Moreover, integrating MAR with complementary technologies like Virtual Reality (VR), Artificial Intelligence (AI), and blockchain could expand its functionality and applicability in education, paving the way for next-generation digital learning environments (Jindal et al., 2023). Educational policymakers should establish frameworks to support MAR adoption by allocating funding for technological infrastructure, integrating MAR training into teacher certification programs, and setting benchmarks for evaluating MAR-based learning outcomes (Dunleavy & Dede, 2014). Collaborative efforts between academic institutions, governments, and industry stakeholders can help co-develop MAR-enhanced curricula, ensuring alignment with professional standards (Susilawati et al., 2023). Furthermore, industry partnerships can provide students with real-world insights into MAR applications, enhancing career readiness through internships, mentorships, and joint design projects (Zhao & Song, 2023).

Further research should explore the long-term impact of MAR on creativity, critical thinking, and problem-solving, as well as comparative studies across multiple disciplines to assess MAR's effectiveness beyond design education. Cross-cultural research should investigate how MAR adoption varies across economic and technological landscapes, ensuring scalability and accessibility for diverse learning environments (Swara et al., 2023). Additionally, studies on MAR's integration with AI-driven adaptive learning, VR simulations, and blockchain-based credentialing could provide insights into its potential to revolutionize digital education (Sánchez-Juárez et al., 2023). These recommendations aim to leverage MAR's full potential to transform design education and broaden its impact across multiple fields. By addressing implementation challenges, fostering collaboration, and establishing effective evaluation frameworks, MAR can become a cornerstone of future educational practices (Rakshit et al., 2023). As institutions, policymakers, and industry leaders work together to expand and refine MAR applications, this technology has the potential to redefine learning, prepare students for digital-era careers, and create more engaging, interactive educational experiences (Ibáñez & Delgado-Kloos, 2018).

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