



## THE APPLICATIONS OF AUGMENTED REALITY FOR ENHANCING MOTIVATION AND SPATIAL SKILLS IN ELEMENTARY MATHEMATICS

Wen Hung Chao

The Department of Culture Creativity  
and Digital Marketing, National United  
University, Miaoli, Taiwan

[nosir.tw@gmail.com](mailto:nosir.tw@gmail.com)

### ABSTRACT

Aim/Purpose	This study aims to investigate the impact of an augmented reality (AR)-based mathematics application on the spatial abilities, academic performance, and learning motivation of 5th-grade primary school pupils.
Background	Elementary students often struggle to understand 3D geometric shapes and spatial concepts due to limited instructional tools. This paper addresses this problem by implementing an AR-based mathematics application that allows students to interact with virtual 3D shapes to enhance their learning experience.
Methodology	The study employed a quasi-experimental pre-test–post-test design to compare the effects of using the AR application with using only traditional physical blocks. The study involved 51 fifth-grade students in Taiwan, divided into an AR experimental group (N=25) and a control group (N=26), with balanced gender representation.
Contribution	This paper contributes to the body of knowledge by demonstrating that AR can significantly enhance elementary students' spatial ability, mathematical achievement, and motivation compared to traditional methods, serving as an equitable pedagogical tool for both genders.
Findings	The results demonstrate that the AR group significantly outperformed the control group in learning achievement (adjusted mean: 90.14 vs. 74.13, $\eta_p^2 = 0.26$ ) and motivation. Regarding gender, both groups showed improvements, suggesting AR provides equitable spatial learning support rather than solely bridging the gender gap.

Accepting Editor Tharrenos Bratitsis | Received: August 9, 2025 | Revised: December 22, 2025;  
January 29, 2026 | Accepted: March 1, 2026.

Cite as: Chao, W. H. (2026). The applications of augmented reality for enhancing motivation and spatial skills in elementary mathematics. *Journal of Information Technology Education: Innovations in Practice*, 25, Article 11.  
<https://doi.org/10.28945/5742>

(CC BY-NC 4.0) This article is licensed to you under a [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/). When you copy and redistribute this paper in full or in part, you need to provide proper attribution to it to ensure that others can later locate this work (and to ensure that others do not accuse you of plagiarism). You may (and we encourage you to) adapt, remix, transform, and build upon the material for any non-commercial purposes. This license does not permit you to use this material for commercial purposes.

Recommendations for Practitioners	Practitioners are encouraged to integrate AR tools to transform abstract geometric concepts into tangible experiences. However, adequate teacher training and a hybrid curriculum combining AR with physical manipulatives are recommended for optimal implementation.
Recommendations for Researchers	The paper recommends that researchers conduct longitudinal studies to examine the long-term retention of learning gains and the “novelty effect.” Additionally, investigating the integration of AR with adaptive learning systems for personalized scaffolding is suggested.
Impact on Society	Integrating AR into education can democratize access to high-quality spatial training. This supports equity in STEM pathways, fosters inclusive learning environments, and contributes to a more technologically skilled future workforce.
Future Research	Future research should explore the long-term effects of AR on students’ learning retention, its impact across different age groups, and how personalized AR experiences can further enhance learning outcomes.
Keywords	spatial ability, mathematics, augmented reality, physical blocks, digital learning materials

## INTRODUCTION

---

Mathematics is fundamental to scientific and technological advancements and is critical in cognitive development. Daily life requires an understanding of geometric and spatial concepts to identify the positions, sizes, and shapes of objects. Sorby et al. (2022) emphasized the importance of spatial capabilities in math learning, highlighting a significant correlation between spatial abilities and math proficiency.

In 2000, the National Council of Teachers of Mathematics (NCTM) outlined goals for geometry education, emphasizing visualization, spatial reasoning, and geometric modeling for problem-solving. However, research by Rohendi and Wihardi (2020) suggests that students are less familiar with three-dimensional shapes and struggle to visualize transitions from 2D to 3D, indicating a need for enhanced educational materials and strategies. Furthermore, Taiwan’s elementary geometry curriculum focuses primarily on plane figures and lacks resources for three-dimensional problem-solving.

To address these challenges, studies advocate environments that promote knowledge building to support mathematical learning (Calor et al., 2022; Dominguez, 2024). The widespread use of information and communication technology (ICT) and mobile devices has led to the development of mobile app-based educational activities. Advances in digital technology integration, such as augmented reality (AR), which combines virtual and real worlds (López-Faican & Jaen, 2020; Piumsomboon et al., 2018; Yilmaz, 2016), have fostered immersive learning experiences and improved mathematical understanding. AR enhances these tools by allowing virtual elements to be superimposed onto real-world settings, thus aiding the teaching of mathematical concepts and spatial transformations.

While previous literature indicates that males tend to outperform females in spatial abilities (Ballatore et al., 2020), few studies have empirically compared AR with physical manipulatives for elementary students’ spatial skills, motivation, and gender equity in mathematics learning (Flavin et al., 2025). This study aims to bridge this gap by investigating the impact of an AR-based math app designed for 5th-grade students on their understanding of geometric volumes and three-dimensional shapes. It compares the learning effectiveness of traditional materials and digital tools, assesses students’ attitudes towards ICT integration, and explores whether diverse instructional strategies can equalize learning outcomes among students with varying math skills and genders.

Research questions based on the educational needs and research gaps, the main research questions addressed in this study are as follows:

**RQ1:** Is the AR app more effective than traditional physical blocks in learning mathematics?

**RQ2:** Can the AR app enhance students' motivation in mathematics?

**RQ3:** Do different genders exhibit improved spatial abilities using various learning aids?

The paper is structured as follows. The next section reviews the relevant literature on spatial ability, gender differences, and AR in education. The research methodology, including the experimental design and instruments used, is then presented, followed by the results of the data analysis. Finally, the findings and implications are discussed, followed by the conclusion and future research directions.

## LITERATURE REVIEW

---

### *SPATIAL ABILITY AND MATHEMATICS LEARNING*

The crucial role of mathematics across fields such as science, medicine, and economics highlights its importance as a fundamental academic discipline. To cultivate lifelong engagement with mathematics, educational systems must foster early appreciation and motivation for the subject, moving beyond rote memorization to emphasize critical thinking and problem-solving skills.

Significant research indicates a strong correlation between spatial ability and mathematical performance. For instance, spatial visualization skills, which are essential for understanding geometry, have been shown to directly influence broader mathematical capabilities, including calculations and problem solving (İbili et al., 2020; Lu et al., 2020). Studies such as that by Atit et al. (2022) have demonstrated that targeted mental rotation training can enhance these spatial skills, thereby improving overall mathematical achievement. The development of spatial abilities can be effectively supported through interactive tools such as computer software and digital simulations (Ye et al., 2023; Yohannes et al., 2023). However, while the importance of spatial skills in mathematics is well established, questions remain about how these skills are distributed across demographic groups, particularly by gender.

### *SPATIAL ABILITY AND GENDER*

The relationship between spatial abilities and gender remains a contested topic. While traditional views posit that men generally surpass women on spatial tasks, recent literature suggests a more complex picture. Historical research, including Guay and McDaniel's (1977) study, found that boys outperformed girls in complex spatial tasks, although both genders performed similarly on simpler tests. Conversely, Ramírez-Uclés and Ramírez-Uclés (2020) observed that boys used mental visualization for problem-solving, while girls preferred drawing figures, which affected their performance on geometric tasks. Furthermore, a substantial study by Silverman et al. (2007) found that males excelled in three-dimensional rotation, whereas females performed better in object position memory. Ganley and Vasilyeva (2011) noted that gender differences are not uniform; they found girls showed a better understanding of basic spatial concepts, while boys excelled in complex spatial reasoning.

Collectively, these studies suggest that gender disparities are likely influenced by the specific nature of the spatial task and the instructional tools used, rather than being an absolute biological inevitability (Nazareth et al., 2019). A comprehensive review reveals that while gender gaps exist, they are not insurmountable. Given these mixed findings on gender and spatial ability, researchers have turned to innovative technologies to explore if new learning methods can provide more equitable learning opportunities (Geary et al., 2023; Lauer et al., 2019).

## ***AUGMENTED REALITY IN SPATIAL ABILITY LEARNING***

To address the challenges in spatial learning and potential gender disparities, Augmented Reality (AR) has emerged as a promising educational tool. The development of digital technology has put interactive media in the limelight (Hidayat & Wardat, 2024). AR is characterized by sensory immersion, guidance, and control, which exert a positive effect on learners' emotions (Shaghaghian et al., 2024; Supli & Yan, 2024). Theoretically, AR aligns with constructivist learning theories and Embodied Cognition (Afnan & Puspitawati, 2024). It allows learners to manipulate virtual objects in a real-world context actively, thereby reducing the cognitive load associated with visualizing complex 3D structures (Altmeyer et al., 2024).

Empirical studies affirm that AR improves spatial learning outcomes, with users demonstrating superior performance in geometry education compared with traditional methods (Elford et al., 2022; Tiwari et al., 2024). These studies also reported increased learner engagement, interest, and satisfaction, underscoring the motivational advantages of AR (Ajit, 2021; Lampropoulos et al., 2023). Moreover, AR promotes collaborative learning, enabling students to exchange feedback in an interactive setting.

In summary, while spatial ability is critical for math achievement and AR has shown potential to enhance these skills, there is a lack of empirical evidence addressing whether AR can bridge the gender gap in spatial reasoning. This study addresses this gap by implementing an AR-based mathematics learning application in elementary classrooms. It aims not only to assess improvements in mathematics outcomes and motivation but also to determine whether AR support can serve as an equalizer for students of different genders compared to traditional methods.

## **DESIGN AND IMPLEMENTATION OF THE BEARD DADDY APPLICATION**

---

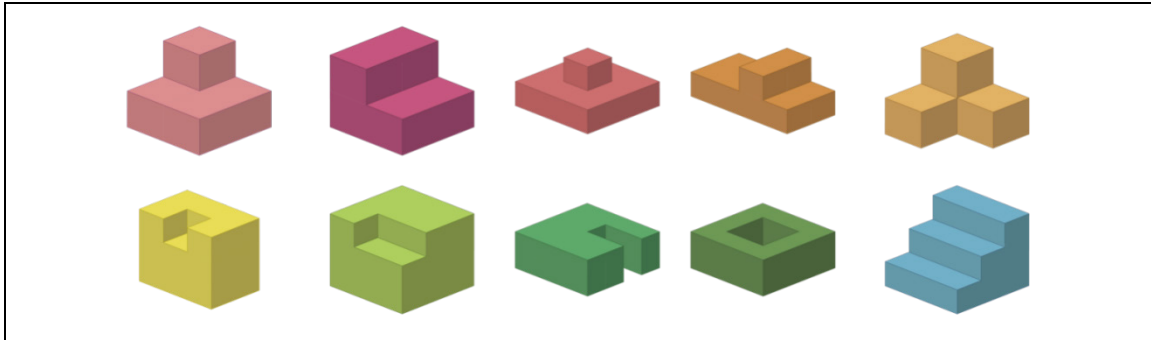
### ***LEARNING MATERIAL DESIGN***

Volume is intrinsically linked to children's lived experiences with physical objects. Developing a full understanding of volume requires cultivating measurement skills and the ability to visualize spatial transformations. However, traditional instruction often overemphasizes memorizing formulas without fostering true comprehension of underlying spatial relationships (Huang & Witz, 2013; Vasilyeva et al., 2013). To address these shortcomings, this study leveraged digital materials to design an interactive learning aid that specifically targets volumetric concepts. The key objectives were: (1) enabling learners to gain a holistic perspective of volume and develop an intuitive spatial sense; (2) exposing students to diverse strategies for solving volume problems; and (3) constructing problem-solving approaches that are conceptually accessible.

The learning materials were developed as digital "flashcards" with volumetric questions modeled after the 5th-grade mathematics textbook. This gamified, card-based format allows for flexibility in adjusting content and difficulty levels based on instructional needs or self-directed learning preferences. Figure 1 shows examples of the materials created. Figure 1(a) shows examples focused on calculating the volumes of various 3D shapes such as cylinders, rectangular prisms, and composite objects. This aimed to develop skills for mentally decomposing complex forms and applying formulas. Figure 1(b) shows sample "learning flashcards" presenting volumetric word problems and visual puzzles. These interactive scenarios challenged students to analyze spatial relationships and develop solution strategies.

This digital format enabled seamless integration with the AR math application at the core of the intervention. When scanned, the flashcards triggered immersive 3D visualizations that allowed students to manipulate virtual objects using interactive features of the AR app, as detailed in the following subsection. By combining structured curricular content with exploratory digital activities, these learn-

ing materials sought to cultivate a deeper conceptual understanding of volume while promoting independent problem-solving abilities. Multimodal design leverages the unique affordances of the AR technology to transform an abstract mathematical domain into an immersive and concrete experiential process.



(a) Volume of various shapes



(b) Learning flashcards

Figure 1. Learning materials examples for volume learning in math

### *APPLICATION IMPLEMENTATION AND FUNCTION*

To facilitate an immersive, interactive learning experience, an AR-based math application was developed using the Unity 3D integrated development environment and Vuforia Software Development Kit. The app emphasizes hands-on engagement with three-dimensional geometric structures through intuitive touch interactions on mobile devices. When students scanned the digital learning flashcards with the app's camera, 2D images were rendered as interactive 3D objects superimposed on a real-world view (Figure 2).

This bridged the physical and virtual realms, allowing learners to transition seamlessly between symbolic mathematical representations and tangible spatial manipulations. The specific interactive functions integrated into the AR application's user interface are outlined in Table 1 and illustrated in Figure 3. These functions include:

- Stacking (3b): Students can drag and stack virtual unit blocks to construct complete 3D composite shapes, fostering an understanding of the spatial structures of objects.

- Removal (3c): Specific components of larger shapes can be removed, prompting students to understand how volume changes through decomposition.
- Rotation (3d): Rotating objects provides viewpoints from all angles to comprehend the structure, orientation, and depth.
- Decomposition (3e): Learners can deconstruct complex shapes into simple constituent solids and scaffold skills using spatial analysis.
- Formula Display (3f): After manipulating the objects, the corresponding volume calculation formulas and potential solutions are presented based on the configuration.

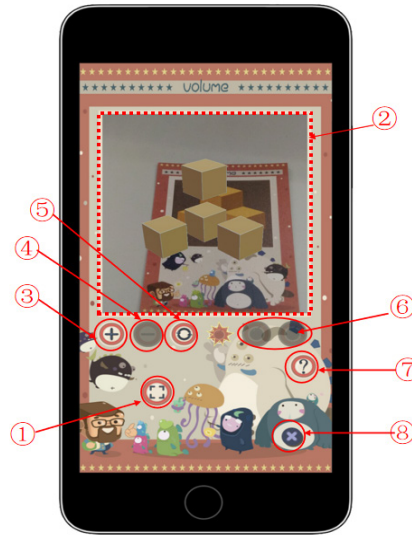


Figure 2. User interface example of the AR math learning app

Table 1. App interface function descriptions

No. (Fig. 2)	Button	Function description	Figure
1	Card scan	Using the camera to read the learning flashcard question	3a
2	3D object area	Rendering the 2D image on the flashcard and presenting it as 3D interactive objects	3a
3	Stacking	Dragging and stacking the virtual blocks to understand the structure of the three-dimensional object	3b
4	Removal	Removing certain block unit(s) on a complete 3D object to understand volume calculations	3b
5	Rotation	Understanding the structure of the three-dimensional object by using the rotation function to see it from all angles	3d
6	Decomposition	A complete three-dimensional object can be decomposed into several smaller objects	3e
7	Calculation formula	Volume calculation formula: depending on the question, there may be 2-3 ways to solve a question	3f
8	End of game	End of learning	-

These dynamic visualizations and construction tools extend beyond the observation of static 3D models. Interactive affordances encouraged learners to adopt a hands-on, inquiry-based approach to explore volumetric properties and relationships. By seamlessly integrating digital and physical learning modalities, the AR application aims to cultivate an intuitive spatial sense grounded in concrete experiences that are fundamental to developing mathematical understanding.

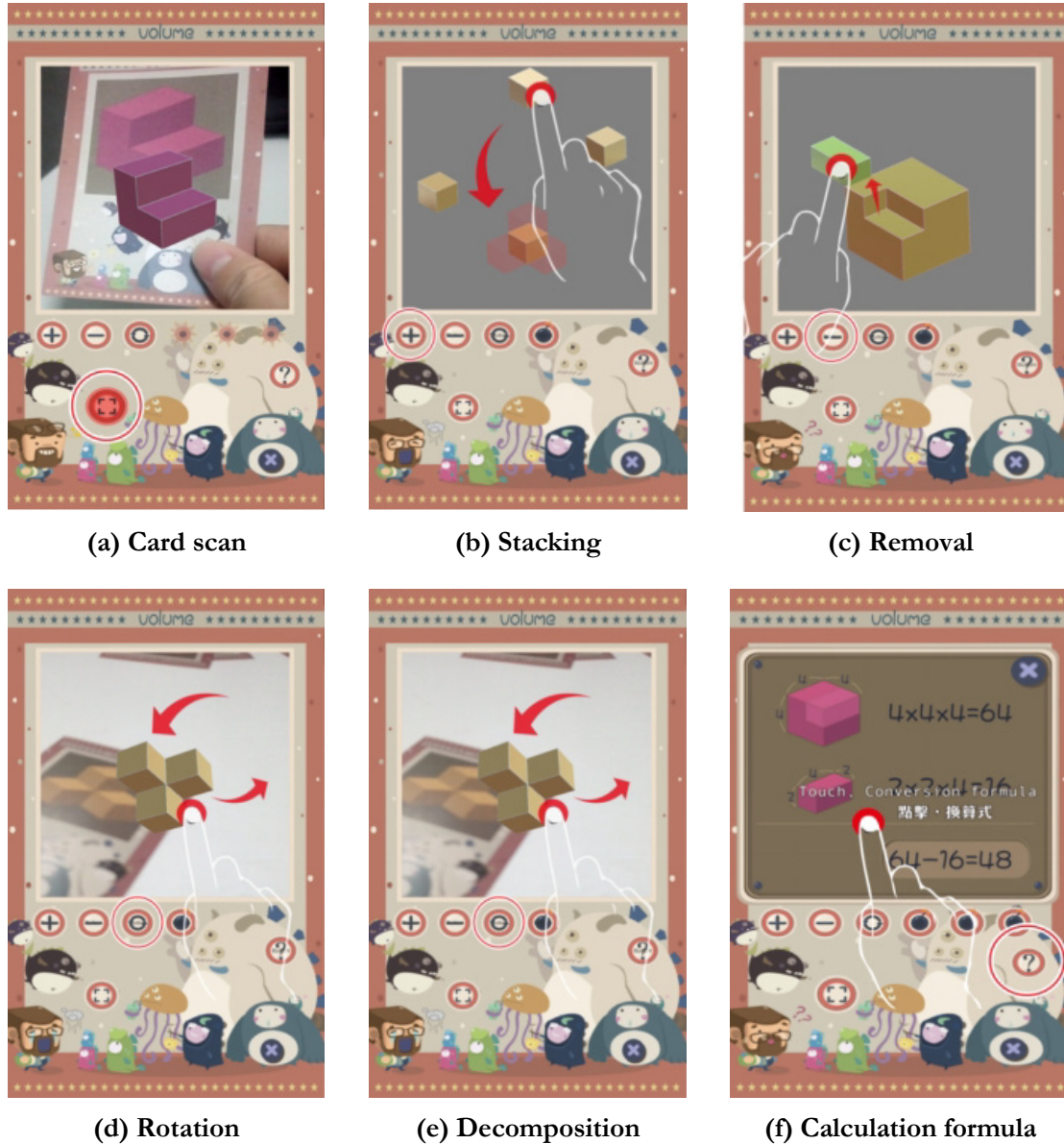


Figure 3. Examples of AR math app interactive operations

## RESEARCH METHODOLOGY

This study employed a quasi-experimental pre-test–post-test design to investigate the impact of integrating an AR math learning application into 5th-grade geometry instruction on volumetric concepts. The effectiveness of the AR approach was compared with that of traditional methods that utilize physical manipulatives (control groups) across multiple dimensions, specifically:

- (1) Students' learning achievement in understanding 3D geometric shapes and calculating volumes
- (2) Changes in students' motivation and attitudes towards learning mathematics.
- (3) Potential gender differences in developing spatial abilities through the respective instructional strategies.

A quasi-experimental design was adopted as students were already assigned to pre-existing, intact classroom groups, precluding random assignment to conditions. However, selecting comparable classes taught by the same instructor helped control for potential confounds and approximated authentic educational settings.

### ***PARTICIPANTS***

Participants were 5th-grade students from an elementary school in Taiwan. Two classes of students were designated as experimental and control groups. A total of 51 students participated, with an approximately equal distribution of males and females in each group, as shown in Table 2. The experimental group consisted of 25 students (15 males and 10 females), while the control group consisted of 26 students (13 males and 13 females). The two classes were selected based on: (1) being taught by the same math teacher, (2) having similar socioeconomic and educational backgrounds per school record, and (3) having no statistically significant differences in prior math performance based on the analysis of previous scores. Random assignment was not feasible because the classes had already been constructed as intact groups by the school, although this had maintained a naturalistic classroom setting. Ethical guidelines were strictly followed. Informed consent was obtained from both the school administration and the students' parents. All student data were anonymized to ensure confidentiality throughout the study.

**Table 2. Number of participants by group and gender**

	<b>Experimental group (A)</b>	<b>Control group (B)</b>	<b>Total</b>
Male	15	13	28
Female	10	13	23
Total	25	26	51

### ***EXPERIMENTAL PROCEDURE***

This study followed a structured procedure comprising three phases: pre-tests, instructional intervention, and post-tests. The experimental flowchart is shown in Figure 4.

- (1) *Pre-tests*: Before the learning intervention, all students in both groups completed achievement pre-tests to assess their baseline knowledge of 3D geometric shapes and volumetric concepts. Additionally, they completed a pre-intervention learning motivation questionnaire to establish baseline attitudinal levels.
- (2) *Instructional Intervention*: The Learning activities focused on the “volume” unit in the 5th-grade mathematics curriculum. Both groups received instruction from the same mathematics teacher over a 2-week period, with three 40-minute classes per week. To ensure intervention fidelity, all students engaged in learning activities for the same duration, and teacher assistance was standardized to provide technical support without offering direct solutions.
  - *Experimental Group*: Students used the interactive AR math app as a supplementary tool. They followed the operational steps outlined in Table 1. For example, regarding the “Card scan” function, students were instructed first to read the volumetric question printed on the flash-card (e.g., “Calculate the volume of this composite shape”) before scanning it to trigger the 3D interaction.

- *Control Group*: Students in the control group used the same set of Learning Materials containing identical volumetric questions. However, instead of using the AR app, they utilized traditional physical plastic blocks to construct the shapes and solve the problems manually in conjunction with their textbooks.
- (3) *Post-tests*: After the unit, all students took post-tests to evaluate their understanding of volume measurement. They also completed post-intervention questionnaires to assess changes in motivation.

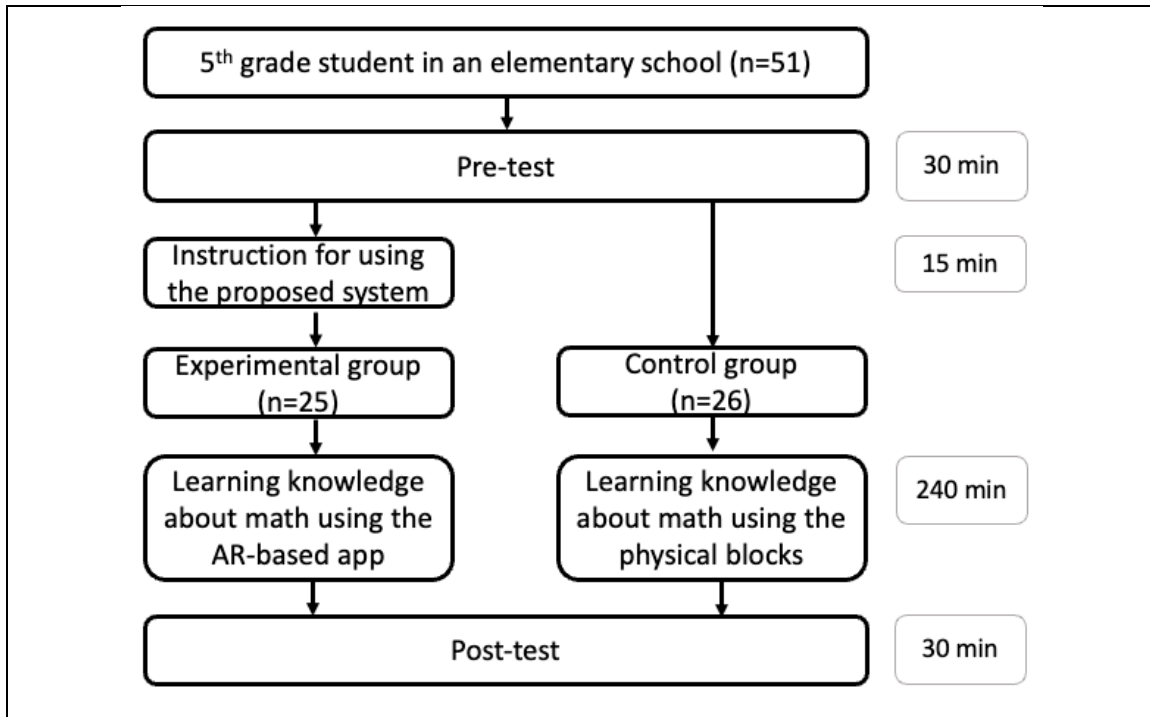


Figure 4. Experiment flowchart

### *DATA COLLECTION PROCEDURE AND INSTRUMENTS*

This study utilized achievement tests and questionnaires to collect data.

#### **(1) Achievement tests**

The achievement tests were co-developed by two experienced mathematics teachers based on the 5th-grade curriculum. Each test consisted of ten questions (totaling 100 points). The pre-test focused on assessing prior knowledge of three-dimensional shapes. The post-test evaluated the ability to comprehend volume measurements and apply spatial reasoning. Sample questions included tasks requiring students to calculate the volume of irregular composite figures.

#### **(2) Learning motivation questionnaire**

A motivation questionnaire was administered before and after the intervention. The items were adapted from Hwang and Chang's (2011) validated learning-motivation scale. The 7-item questionnaire used a 5-point Likert scale to measure three subscales: Interest, Perceived Value, and Desire/Expectation to learn mathematics. Sample items included, "I think learning math is interesting and valuable," and "I want to learn and observe more in math class." The questionnaire demonstrated adequate internal consistency (Cronbach's alpha = 0.79).

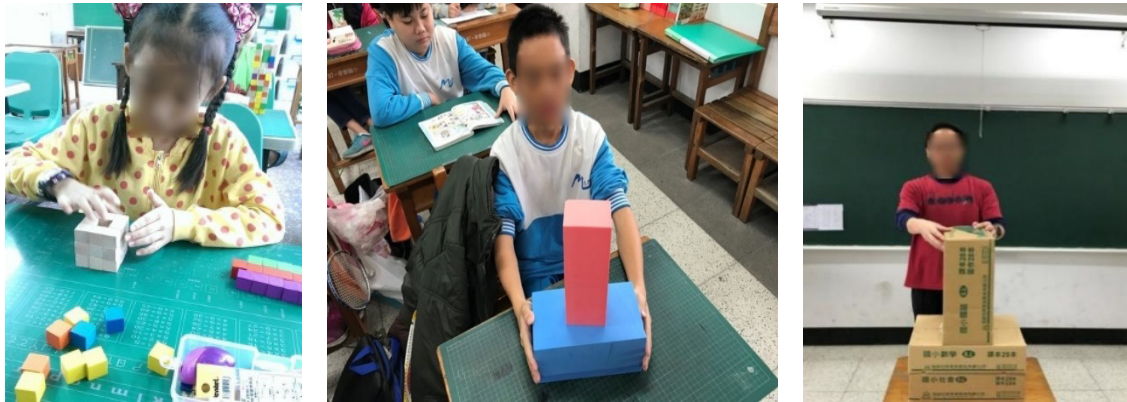
### ***DATA ANALYSIS***

Statistical analyses, including t-tests, ANCOVA, and descriptive statistics, were conducted to interpret the quantitative data. Appropriate validation tests were performed to ensure that the assumptions of the analysis were satisfied, and effect sizes were calculated where applicable.

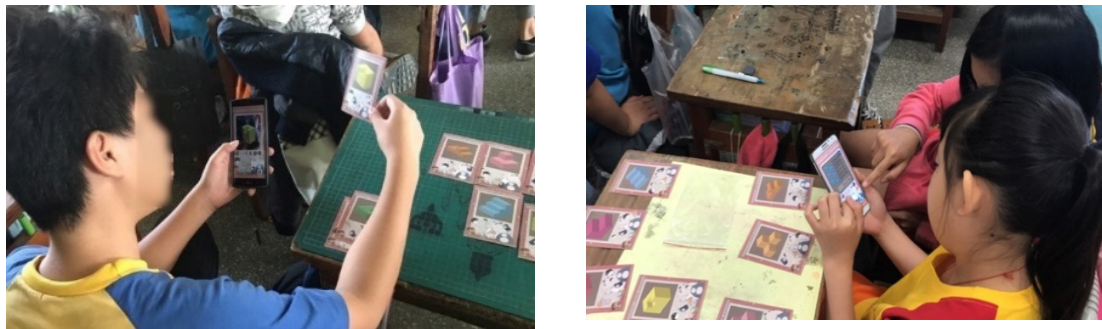
### **FINDINGS**

---

A total of 51 fifth-grade students participated in this quasi-experimental study, with 25 and 26 students in the experimental and control groups, respectively. Over a course of four hours of mathematics instruction on the volumetric concepts unit, the differential learning impacts of the two instructional approaches were investigated. Figures 5 and 6 show the learning scenarios in the control and experimental groups.



**Figure 5. Control group students using physical blocks to assist in their learning**



**Figure 6. Experimental group students using an AR learning app to assist in their learning**

### ***LEARNING ACHIEVEMENT ANALYSIS***

To determine whether the experimental and control groups had comparable prior knowledge, an independent-samples t-test was conducted on pre-test scores. Results showed no statistically significant difference between the two groups ( $t = 1.551, p > 0.05$ ), indicating equivalent baseline mathematical ability.

To assess the impact of the AR learning app versus physical blocks, an ANCOVA was performed on post-test scores, with pre-test scores as a covariate. Prior to analysis, the assumptions of homogeneity of variance and regression slopes were verified and satisfied. Table 3 presents the ANCOVA results. After controlling for pre-existing differences, a statistically significant difference was found in the adjusted post-test means between the two groups ( $F(1, 58) = 20.09, p < 0.01$ ). The analysis yielded a

large effect size ( $\eta_p^2 = 0.26$ ), indicating that the difference was not only significant but also practically meaningful. Students who used the interactive AR app demonstrated substantially greater learning gains in understanding 3D geometric shapes and in calculating volumes than those using traditional physical blocks.

**Table 3. ANCOVA results for post-test mathematics achievement scores**

	N	M	S.D.	Adj. mean	S.E.	F	$\eta_p^2$
Experimental group	25	92.16	13.73	90.14	2.52	20.09**	0.26
Control group	26	72.19	16.70	74.13	2.47		

\*\* $p < 0.01$

### ***ANALYSIS OF MATHEMATICS LEARNING MOTIVATION***

To investigate motivation, an independent-samples t-test first confirmed that there was no significant difference in baseline motivation scores between groups ( $t = -0.767, p > 0.05$ ). Subsequently, an ANCOVA was conducted on post-intervention motivation scores. The assumptions of homogeneity of variance and regression slopes were checked and met.

As shown in Table 4, the results revealed a statistically significant difference in adjusted mean motivation ( $F(1, 58) = 4.80, p < 0.05$ ), with a medium effect size ( $\eta_p^2 = 0.08$ ). Students in the AR group reported significantly higher motivation and more positive attitudes towards mathematics (*adj. mean* = 4.48) than those in the control group (*adj. mean* = 4.23). This suggests that the engaging multimedia AR environment successfully fostered greater interest and perceived value in learning mathematics.

**Table 4. ANCOVA results for post-intervention mathematics learning motivation scores**

	N	M	S. D.	Adj. mean	S. E.	F	$\eta_p^2$
Experimental group	25	4.46	0.39	4.48	0.08	4.80*	0.08
Control group	26	4.24	0.45	4.23	0.08		

\* $p < 0.05$

### ***ANALYSIS OF SPATIAL ABILITY ACROSS GENDERS***

To examine whether learning aids affected spatial ability differently for male and female students, pre-test and post-test spatial scores were analyzed. Baseline analysis indicated no significant gender differences in spatial ability within either the control ( $t = 2.56, p > 0.05$ ) or experimental groups ( $t = 2.556, p > 0.05$ ) prior to intervention.

ANCOVA was conducted to compare post-test spatial scores by gender within each group (Table 5). In the control group, no significant difference was found between males and females ( $F = 0.14, p > 0.05$ ). Similarly, in the experimental AR group, the difference between genders did not reach statistical significance ( $F = 3.24, p = 0.086$ ), although a positive trend was observed favoring females (*adj. mean* = 96.61) compared to males (*adj. mean* = 91.26) with a medium effect size ( $\eta_p^2 = 0.13$ ).

**Table 5. Summary of ANCOVA results for post-test spatial scores by gender**

Group	Gender	N	M	SD	Adj. mean	S.E.	F	p	$\eta_p^2$
Control	Male	13	91.54	7.47	89.25	2.07	0.14	0.711	0.006
	Female	13	88.08	8.55	90.37	2.37			
Experimental	Male	15	91.33	9.54	91.26	2.46	3.24	0.86	0.128
	Female	10	96.50	4.12	96.61	1.30			

## ***DISCUSSION ON GENDER FINDINGS***

Contrary to historical studies suggesting male superiority in spatial tasks (Ramírez-Uclés & Ramírez-Uclés, 2020), our findings indicate that AR technology effectively supported spatial skill development for both genders. While females in the AR group showed descriptively larger gains and higher adjusted means than males, this trend was also present to a lesser extent in the control group. This aligns with recent literature suggesting that gender gaps are not insurmountable and that providing appropriate scaffolding, whether through physical manipulatives or digital visualization, can help equalize learning opportunities (Elford et al., 2022). The immersive nature of AR may offer particular benefits by reducing the cognitive load required for mental rotation, thereby supporting students who might otherwise struggle with abstract spatial tasks.

## **DISCUSSION**

---

### ***ENHANCING ACHIEVEMENT AND MOTIVATION THROUGH IMMERSIVE LEARNING***

This study aimed to evaluate the effectiveness of an AR-based application in teaching volumetric concepts. The findings reveal that students in the AR group significantly outperformed those using physical blocks in learning achievement. Consistent with recent studies by Elford et al. (2022) and Tiwari et al. (2024), our results confirm that AR facilitates a deeper conceptual understanding of geometry. While traditional manipulatives provide tactile experience, they are often limited by physical constraints (e.g., inability to visualize internal structures). In contrast, the AR application allowed students to perform operations like “Decomposition” and “X-ray views” (Figure 3), effectively making abstract mathematical concepts tangible. Theoretically, this aligns with Embodied Cognition and Cognitive Load Theory (Altmeyer et al., 2024), suggesting that manipulating virtual objects in a real-world context reduces the cognitive effort required for mental rotation.

Regarding motivation, the AR group reported significantly higher interest and engagement. This echoes the findings of Lampropoulos et al. (2023) and Ajit (2021), who identified interactivity and gamification as key drivers for student enthusiasm. Unlike passive textbook learning, the AR system provided immediate visual feedback (e.g., automated formula display), which likely fostered a sense of autonomy and competence – crucial elements of intrinsic motivation.

### ***GENDER EQUITY IN SPATIAL REASONING***

A critical objective of this study was to examine gender differences. Historically, research has suggested a male advantage in complex spatial tasks (Guay & McDaniel, 1977; Ramírez-Uclés & Ramírez-Uclés, 2020). However, our findings challenge this notion of biological inevitability. Results indicated that both male and female students in the AR group achieved high spatial scores, with no statistically significant gender gap observed.

Interestingly, female students demonstrated descriptively higher gains than males in both the AR and control groups. This observation aligns with Silverman et al. (2007), who suggested that gender differences often depend on the specific nature of the task (e.g., orientation vs. location memory) and can be mitigated by appropriate scaffolding. While we cannot conclude that AR is the sole factor driving female progress (since the control group also showed positive trends), the results strongly suggest that AR serves as an equitable pedagogical tool. By providing external visualization support, AR may help bypass the “mental rotation bottleneck” that often hinders students with lower initial spatial confidence, thereby ensuring that female learners are not left behind in STEM education.

### ***PRACTICAL IMPLICATIONS AND CHALLENGES***

The success of the “Beard Daddy” app highlights the potential for integrating AR into elementary classrooms. For practitioners, this suggests that AR should be viewed not just as a novelty but as a

scaffold for difficult concepts. However, successful implementation requires addressing practical constraints. Teachers need adequate training to seamlessly integrate technology without disrupting the flow of instruction. Furthermore, technical challenges such as device battery life, lighting conditions for image recognition, and the availability of tablets in underfunded schools remain barriers to widespread adoption. Future curriculum design should consider hybrid models in which AR complements rather than replaces physical manipulatives to balance cost and effectiveness.

### ***LIMITATIONS AND FUTURE DIRECTIONS***

Several limitations should be noted. First, the sample size was small ( $N = 51$ ) and drawn from a single school, limiting generalizability. Second, the intervention duration (two weeks) was relatively short; longitudinal research is needed to determine whether the “novelty effect” of AR fades over time or leads to sustained learning gains. Finally, while this study assessed motivation generally, future research could employ more granular instruments to measure specific constructs such as “spatial anxiety.” Despite these limitations, this study provides robust quasi-experimental evidence that AR can effectively enhance mathematics achievement and motivation while supporting gender equity in spatial learning.

## **CONCLUSIONS**

---

This study provides compelling evidence for integrating AR into elementary mathematics education. The results demonstrate that the “Beard Daddy” application significantly enhances students’ geometric achievement and learning motivation compared to traditional physical manipulatives. By visualizing abstract volumetric concepts through immersive 3D interactions, AR enabled students to develop a deeper conceptual understanding and reduced the cognitive barrier to entry for complex spatial tasks.

Regarding gender equity, the findings offer a nuanced perspective. Contrary to traditional deficit models, our results showed that both male and female students benefited substantially from the AR intervention. While female students demonstrated a positive trend in spatial gains, this improvement was not unique to the AR group. Therefore, rather than claiming AR solely “closes” a gap that may not exist in all contexts, we conclude that AR acts as an “equalizer” or a democratizing tool. It ensures that female students have equal access to high-quality spatial training, thereby supporting their continued engagement and confidence in STEM pathways.

### ***BROADER EDUCATIONAL IMPLICATIONS***

This study suggests that AR can democratize access to spatial reasoning skills, moving beyond the limitations of physical resources. For practitioners and policymakers, the findings imply that investing in AR is not merely about adopting new technology, but about creating inclusive learning environments. However, successful integration requires equipping teachers with adequate training and designing curricula that complement, rather than replace, hands-on activities.

### ***LIMITATIONS AND FUTURE RESEARCH***

This study has limitations, including a small sample size ( $N=51$ ) from a single school and a short two-week duration. Consequently, the long-term retention of these learning gains remains unclear. Future research should move beyond general replication in specific directions:

- (1) Longitudinal studies are needed to examine whether the motivational effects of AR persist after the “novelty effect” wears off.
- (2) Personalized Learning: Investigating how AR can be integrated with adaptive learning systems to provide customized scaffolding for students with different spatial ability levels.
- (3) Cost-effectiveness: Exploring the economic feasibility of large-scale AR deployment compared to traditional manipulatives in under-resourced schools.

In conclusion, despite these limitations, this study underscores AR's transformative potential to revolutionize math pedagogy. By fostering an engaging, equitable, and interactive learning environment, AR holds great promise for nurturing the next generation of STEM learners.

## REFERENCES

---

- Afnan, M. Z., & Puspitawati, R. P. (2024). Exploration of biological concept understanding through augmented reality: A constructivism theory approach. *Jurnal Pendidikan Biologi Indonesia*, 10(3), 1139–1147. <https://doi.org/10.22219/jpbi.v10i3.36896>
- Ajit, G. (2021). A systematic review of augmented reality in STEM education. *Studies of Applied Economics*, 39(1). <https://doi.org/10.25115/cea.v39i1.4280>
- Altmeyer, K., Brünken, R., Kuhn, J., & Malone, S. (2024). The role of cognitive learner prerequisites for cognitive load and learning outcomes in AR-supported lab work. *Education Sciences*, 14(11), 1161. <https://doi.org/10.3390/educsci14111161>
- Atit, K., Power, J. R., Pigott, T., Lee, J., Geer, E. A., Uttal, D. H., Ganley, C. M., & Sorby, S. A. (2022). Examining the relations between spatial skills and mathematical performance: A meta-analysis. *Psychonomic Bulletin & Review*, 29, 699–720. <https://doi.org/10.3758/s13423-021-02012-w>
- Ballatore, M. G., Duffy, G., Sorby, S., & Tabacco, A. (2020). SAperI: Approaching gender gap using spatial ability training week in high-school context. *Eighth International Technological Ecosystems for Enhancing Multiculturality* (pp. 142–148). Association for Computing Machinery. <https://doi.org/10.1145/3434780.3436577>
- Calor, S. M., Dekker, R., van Drie, J. P., & Volman, M. L. L. (2022). Scaffolding small groups at the group level: Improving the scaffolding behavior of mathematics teachers during mathematical discussions. *Journal of the Learning Sciences*, 31(3), 369–407. <https://doi.org/10.1080/10508406.2021.2024834>
- Dominguez, A. (2024). Teaching dynamics to enhance critical thinking and knowledge socialization in the mathematics classroom. *Frontiers in Education*, 9, 1388720. <https://doi.org/10.3389/feduc.2024.1388720>
- Elford, D., Lancaster, S. J., & Jones, G. A. (2022). Exploring the effect of augmented reality on cognitive load, attitude, spatial ability, and stereochemical perception. *Journal of Science Education and Technology*, 31, 322–339. <https://doi.org/10.1007/s10956-022-09957-0>
- Flavin, E., Chung, M., Hwang, S., & Flavin, M. T. (2025). Augmented reality for area measurement reasoning of elementary students. *Educational Technology Research and Development*, 73, 2663–2697. <https://doi.org/10.1007/s11423-025-10502-0>
- Ganley, C. M., & Vasilyeva, M. (2011). Sex differences in the relation between math performance, spatial skills, and attitudes. *Journal of Applied Developmental Psychology*, 32(4), 235–242. <https://doi.org/10.1016/j.appdev.2011.04.001>
- Geary, D., Hoard, M. K., Nugent, L., & Ünal, Z. E. (2023). Sex differences in developmental pathways to mathematical competence. *Journal of Educational Psychology*, 115(2), 212–228. <https://doi.org/10.1037/edu0000763>
- Guay, R. B., & McDaniel, E. D. (1977). The relationship between mathematics achievement and spatial abilities among elementary school children. *Journal for Research in Mathematics Education*, 8(3), 211–215. <https://doi.org/10.2307/748522>
- Hidayat, R., & Wardat, Y. (2024). A systematic review of augmented reality in science, technology, engineering and mathematics education. *Education and Information Technologies*, 29, 9257–9282. <https://doi.org/10.1007/s10639-023-12157-x>
- Huang, H.-M. E., & Witz, K. G. (2013). Children's conceptions of area measurement and their strategies for solving area measurement problems. *Journal of Curriculum and Teaching*, 2(1), 10–26. <https://doi.org/10.5430/jct.v2n1p10>
- Hwang, G. J., & Chang, H. F. (2011). A formative assessment-based mobile learning approach to improving the learning attitudes and achievements of students. *Computers & Education*, 56(1), 1023–1031. <https://doi.org/10.1016/j.compedu.2010.12.002>

- İbili, E., Çat, M., Resnyansky, D., Şahin, S., & Billinghamurst, M. (2020). An assessment of geometry teaching supported with augmented reality teaching materials to enhance students' 3D geometry thinking skills. *International Journal of Mathematical Education in Science and Technology*, 51(2), 224–246. <https://doi.org/10.1080/0020739X.2019.1583382>
- Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2023). Integrating augmented reality, gamification, and serious games in computer science education. *Education Sciences*, 13(6), 618. <https://doi.org/10.3390/educsci13060618>
- Lauer, J. E., Yhang, E., & Lourenco, S. F. (2019). The development of gender differences in spatial reasoning: A meta-analytic review. *Psychological Bulletin*, 145(6), 537–565. <https://doi.org/10.1037/bul0000191>
- López-Faicán, L., & Jaen, J. (2020). EmoFindAR: Evaluation of a mobile multiplayer augmented reality game for primary school children. *Computers & Education*, 149, 103814. <https://doi.org/10.1016/j.compedu.2020.103814>
- Lu, S.-J., Liu, Y.-C., Chen, P.-J., & Hsieh, M.-R. (2020). Evaluation of AR embedded physical puzzle game on students' learning achievement and motivation on elementary natural science. *Interactive Learning Environments*, 28(4), 451–463. <https://doi.org/10.1080/10494820.2018.1541908>
- Nazareth, A., Huang, X., Voyer, D., & Newcombe, N. (2019). A meta-analysis of sex differences in human navigation skills. *Psychonomic Bulletin & Review*, 26, 1503–1528. <https://doi.org/10.3758/s13423-019-01633-6>
- NCTM. (2000). *Professional standards for teaching mathematics*. The National Council of Teachers of Mathematics.
- Piumsomboon, T., Lee, G., Hart, J. D., Ens, B., Lindeman, R. W., Thomas, B., & Billinghamurst, M. (2018). MiniMe: An adaptive avatar for mixed reality remote collaboration. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (pp. 1-13). Association for Computing Machinery. <https://doi.org/10.1145/3173574.3173620>
- Ramírez-Uclés, I. M., & Ramírez-Uclés, R. (2020). Gender differences in visuospatial abilities and complex mathematical problem solving. *Frontiers in Psychology*, 11, 191. <https://doi.org/10.3389/fpsyg.2020.00191>
- Rohendi, D., & Wihardi, Y. (2020). Learning three-dimensional shapes in geometry using mobile-based augmented reality. *International Journal of Interactive Mobile Technologies*, 14(9), 48-60. <https://doi.org/10.3991/ijim.v14i09.13035>
- Shaghaghian, Z., Burte, H., Song, D., & Yan, W. (2024). An augmented reality application and experiment for understanding and learning spatial transformation matrices. *Virtual Reality*, 28, Article 12. <https://doi.org/10.1007/s10055-023-00904-x>
- Silverman, I., Choi, J., & Peters, M. (2007). The hunter-theory of sex difference in spatial abilities: Data from 40 countries. *Archives of Sexual Behavior*, 36, 261–268. <https://doi.org/10.1007/s10508-006-9168-6>
- Sorby, S., Duffy, G., & Yoon, S. Y. (2022). Math instrument development for examining the relationship between spatial and mathematical problem-solving skills. *Education Sciences*, 12(11), 828. <https://doi.org/10.3390/educsci12110828>
- Supli, A. A., & Yan, X. (2024). Exploring the effectiveness of augmented reality in enhancing spatial reasoning skills: A study on mental rotation, spatial orientation, and spatial visualization in primary school students. *Education and Information Technologies*, 29, 351–374. <https://doi.org/10.1007/s10639-023-12255-w>
- Tiwari, A. S., Bhagat, K. K., & Lampropoulos, G. (2024). Designing and evaluating an augmented reality system for an engineering drawing course. *Smart Learning Environments*, 11, Article 1. <https://doi.org/10.1186/s40561-023-00289-z>
- Vasilyeva, M., Ganley, C. M., Casey, B. M., Dulaney, A., Tillinger, M., & Anderson, K. (2013). How children determine the size of 3D structures: Investigating factors influencing strategy choice. *Cognition and Instruction*, 31(1), 29-61. <https://doi.org/10.1080/07370008.2012.742086>
- Ye, H., Liang, B., Ng, O. L., & Chai, C. S. (2023). Integration of computational thinking in K-12 mathematics education: A systematic review on CT-based mathematics instruction and student learning. *International Journal of STEM Education*, 10, Article 3. <https://doi.org/10.1186/s40594-023-00396-w>

Yilmaz, R. M. (2016). Educational magic toys developed with augmented reality technology for early childhood education. *Computers in Human Behavior*, 54, 240-248. <https://doi.org/10.1016/j.chb.2015.07.040>

Yohannes, A., Chen, H. L., & Chang, C. C. (2023). Effect of an interactive e-book on middle school students' mathematics reading and spatial ability. *Educational Technology Research and Development*, 71, 1869–1886. <https://doi.org/10.1007/s11423-023-10225-0>

## AUTHOR

---



**Dr Wen-Hung Chao** received the PhD degree in Digital Media Design from Asia University, Taiwan. He is currently an associate professor in the Department of Culture, Creativity, and Digital Marketing at National United University. His research interests include VR/AR design applications and research, digital game-based learning, and motivation in technology-enhanced learning. He has led several research projects funded by the National Science and Technology Council (NSTC) and collaborated closely with industry partners to develop digital teaching materials, gamified learning systems, and mobile learning platforms.