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Augmented Reality as a Tool for Enhancing Geometry Learning and Improving Mathematical Understanding

Ratchanikorn Chonchaiya[1] and Nattamon Srithammee[2]

ABSTRACT

This study explored the effectiveness of Augmented Reality (AR) technology in enhancing the instruction of introductory geometry at Phra Dabos School. A mobile AR application was developed to support interactive learning in four key topics—perimeter, area, volume, and surface area. The application was developed to improve students' understanding of abstract geometric concepts by transforming them into tangible and engaging experiences through immersive AR technology. Quantitative analysis showed substantial performance improvements, with average test scores rising from 3.70 to 9.04 ($p < 0.001$, Cohen'ss $d = 2.05$). The findings from the assessment with the System Usability Scale (SUS) questionnaire indicated that the application achieved a score of 78.5, which represented a high degree of user satisfaction. Qualitative data from student interviews indicated that users were more motivated to learn geometry and preferred collaboration in solving problems in the augmented reality-supported learning environment—observational data corroborated interview data, with higher engagement and interest evident during the learning process. These findings highlight the potential of AR technology to enhance mathematics learning, particularly in making abstract geometric concepts more explicit and interactive, and highlight the need for further research to develop application approaches that can be scaled up in a variety of educational contexts.

Article information:

Keywords: Augmented Reality, Mathematics Education, Geometry, Educational Technology, Interactive Learning, STEM Education, Digital Learning Tools, Student Engagement

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1. INTRODUCTION

Mathematics is a basic subject that is part of the growth of the logical mind, analytical orientation, and problem-solving capacity required for survival in the 21st century. With the ongoing development of modern society and more reliance on data and electronic technology, numerical literacy has become necessary for educational progress and adaptation to complex real-life situations. Despite its significance, mathematics is often perceived by students as abstract, complex, or irrelevant to real life, which results in declining interest and continued learning challenges [1]-[4].

To remedy these issues, instructors and researchers have been looking for alternative pedagogical methods to make mathematics more accessible and attractive. Information and Communication Technologies (ICT) have shown promise, particularly in enabling personalized, interactive learning environments [5]. Among these, AR has emerged as a powerful tool that overlays digital content onto the real world, enhancing student interaction and helping visualize abstract mathematical concepts in meaningful ways [6]-[9].

Previous studies have demonstrated the potential of AR to improve students' understanding and performance in geometry. A study in Malaysia, conducted within the framework of the Malaysia Education Blueprint 2013–2025, developed an AR-based application to support primary students' learning of basic geometric concepts. The study adopted the ADDIE instructional design model to create a marker-based mobile AR application, which was evaluated through a quasi-experimental design involving 30 Grade 2 students. The results showed increased motivation among students, spatial reasoning, and conceptual understanding, demonstrating the effec-

[1]The author is with the Department of Mathematics, Faculty of Science King Mongkut's University of Technology Thonburi Bangkok, Thailand, Email: ratchanikorn.cho@kmutt.ac.th
[2]The author is with the Department of Information Technology, Faculty of Informatics Burapha University Chonburi, Thailand, Email: natsrithammee@gmail.com

tiveness of AR in bridging gaps between abstract content and visual learning [10]. The research, however, was predominantly carried out during early primary school education and did not explore its use in vocational or specialized educational settings.

Similarly, during the COVID-19 pandemic, Khairiree (2020) explored the integration of AR and The Geometer's Sketchpad (GSP) in teaching transformation geometry in an online learning environment. With schools in Thailand closed for months, this research demonstrated how AR and dynamic geometry software could teach concepts such as translation, reflection, and rotation through interactive lessons accessible via QR codes. The study also involved nationwide teacher workshops and created open-access online modules for broader implementation. Students reported that the combination of AR and GSP enhanced their understanding of geometric transformations and made learning more engaging, despite some preferring face-to-face instruction. The findings emphasize the value of AR in supporting remote or hybrid learning, especially when tackling visually complex mathematical topics [11].

Building upon these findings, the current study investigates how AR technology can be applied in a Thai vocational education context—specifically, at Phra Dabos School, where geometry is essential for practical skill development. Unlike previous research focusing on early primary or lower secondary learners, this study targets vocational students and their understanding of perimeter, area, volume, and surface area—core geometric topics underpinning hands-on technical and trade-based disciplines.

Students at Phra Dabos School often struggle to visualize three-dimensional shapes and connect mathematical formulas with real-world objects. Traditional teaching practices, reliant on 2D diagrams and textbook descriptions, fail to foster the spatial reasoning required in vocational contexts [12]-[14]. To address this, the present study developed a mobile AR application that delivers interactive and immersive learning experiences to make abstract concepts more tangible and relatable. Through AR-enhanced instruction, students can manipulate and explore 3D geometric forms, visualize changes in size and dimension, and better understand the relationships between measurements and physical space.

The research follows a mixed-methods approach, combining quantitative measures of student learning with qualitative feedback on user experience and engagement [15], [16]. The two-fold approach allows for a balanced evaluation of learning outcomes and the perceived usefulness of the technology. The ultimate goal is to establish the pedagogical utility of AR to teach geometry and its capacity to enable inclusive, interactive, and experiential learning in low-resource learning settings. By situating this research within the broader conversation of education technology, this project contributes to the emergent field of AR-augmented mathematics learning. It demonstrates how immersive digital tools can revitalize geometry education, especially for learners who rely on practical, hands-on understanding to succeed in their vocational pathways.

2. LITERATURE REVIEW

Today's learning environment is changing at breakneck rates, and hence, cutting-edge teaching becomes a necessity to deliver more student engagement, greater comprehension, and improved outcomes. Technological integration in classrooms is no longer optional but essential for facilitating more dynamic and personalized learning experiences [3], [5]. A growing body of empirical research supports the transformative potential of educational technology in promoting learner-centered environments [4], [17], [18]. Amongst all these technologies, AR stands out as it can merge virtual information with everyday surroundings, making learning experiences interactive and immersive, revolutionizing conventional pedagogical methods. Recent research has focused on AR's use in STEM education, particularly geometry, where visualizing and spatial reasoning of abstract structures are critical [9], [19]. AR's capability to superimpose three-dimensional objects in the real world provides embodied cognition, allowing students to naturally manipulate and interrogate geometric shapes. Notably, the expanding ubiquity of AR tools—driven by the spread of mobile devices—positions AR as a feasible and scalable solution for mass educational deployment [20], [21]. Nevertheless, notwithstanding the optimism over AR's promises, the literature is inconclusive regarding long-term effects, outcome consistency across disparate learning environments, and best teaching practices in integrating AR and pedagogy. This review aims to synthesize current findings while critically evaluating how AR aligns with established learning theories and identifying areas for future research.

2.1 Challenges in Mathematics Education

Mathematics, particularly geometry, presents persistent learning challenges, despite various reforms in instructional design. Traditional methods relying heavily on rote memorization and static visualizations often fall short in conveying abstract or spatially complex concepts [4], [6]. In geometry, the lack of dynamic and manipulable representations inhibits the development of spatial visualization and deep conceptual understanding, which are foundational to mastering the subject [2], [22].

Moreover, passive learning models fail to motivate students or support diverse learning styles, leading to disengagement and poor achievement [23]. Active learning methodologies, such as collaborative problem-solving and interactive exploration, have demonstrated significantly better outcomes in conceptual understanding and retention [14], [24], [25]. However, the implementation of such strategies often lacks technological augmentation, which could further enhance learner engagement and comprehension.

2.2 AR as a Tool for Active Learning

AR affordances align closely with constructivist and situated learning theories, emphasizing active, contextualized knowledge construction. From a constructivist perspective, AR offers students hands-on, exploratory learning experiences that support personal meaning-making, particularly when interacting with 3D representations of geometric objects [26], [27]. These experiences bridge the gap between abstract mathematical concepts and concrete real-world understanding. Situated learning theory likewise stresses the value of learning by doing in life. AR adheres to this by situating mathematical problems in real contexts where students contextualize geometry using familiar settings. Spatial reasoning capabilities are triggered through embodied interaction such as rotating, zooming, and moving virtual objects, as well as through self-directed search development [7], [28]. There is empirical support for significant spatial ability and geometric knowledge improvement for students learning AR-enabled instruction against traditional instruction [4], [28]. However, the success of AR in supporting active learning largely rests on the quality of its instructional design, usability, and interactivity. AR applications with poor design can divert attention rather than engage, so pedagogically worthy development is imperative. The ARM (Augmented Reality Mathematics) application is a good case designed to help high school students learn three-dimensional geometry. Developed using a Design-Based Research (DBR) approach, the ARM project incorporated an interactive AR mobile application, printable AR markers, and a user guidebook to foster immersive, active learning experiences. The ARM application enabled students to visualize and manipulate 3D geometric objects, enhancing engagement and supporting concept exploration through experiential learning. Field testing and validation exercises with media specialists, instructors, and students established the value of the application in improving geometry problem-solving skills. Quantitative measures using Likert-scale measurements and the n-gain formula indicated a moderate improvement in students' problem-solving capacity. Additionally, qualitative feedback indicated the high usability, friendly interface, and increased student engagement through the tool. Additional enhancements may include adding animated elements and video-based explanations to enrich learning. This study is part of a growing body of work placing AR as a powerful enabler of active learning. By integrating AR within STEAM (Science, Technology, Engineering, Arts, and Mathematics) education, tools like ARM support the cultivation of essential 21st-century skills such as computational thinking, creativity, and problem-solving [29]. The findings affirm the potential of AR to foster conceptual understanding and promote student-centered, interactive learning within authentic, meaningful contexts. AR technology has gained significant interest in education for its application in active learning environments. Uriarte-Portillo *et al.* (2023) explain that AR facilitates interactive, real-time engagement with virtual objects, allowing students to manipulate and explore geometric shapes in dynamic, immersive environments. AR's use in geometry learning has improved students' motivation and understanding of challenging, abstract notions. By overlaying digital information on the physical world, AR transforms traditional learning materials into interactive ones, enhancing students' comprehension of geometric properties. The article highlights the development of ARGeoITS, an Intelligent Tutoring System (ITS) integrated with AR to support geometry learning for middle school students. The system incorporates a fuzzy logic engine that adapts instruction based on student interaction and performance, offering a personalized learning experience. Results indicated that ARGeoITS had a higher effect on student learning outcomes and motivation than a non-adaptive AR tool, ARGeo, demonstrating the potential of adaptive learning systems in supporting geometry learning.

The findings showed that ARGeoITS students reported higher motivation levels in attention and confidence. The ability of the system to deliver instruction according to individual needs made learning more effective and interactive, with a higher understanding of geometric concepts. The study points to the potential of combining AR with intelligent tutoring systems to facilitate active learning, enhance student engagement, and improve academic performance in geometry [30].

2.3 Impact of AR on Mathematics Education

Hwang *et al.* (2022) present the design and evaluation of Authentic GeometryGo (AGG), an AR mobile learning app for facilitating students' geometry learning through real-world measurement activity and peer evaluation. Using mobile phone cameras and sensors, the AGG app allows students to visualize geometric objects around them, with real-time line and angle measurements displayed through AR overlays. The study demonstrated that students in the experimental group (EG) who utilized the AGG app performed significantly better than students in the control group (CG) on post-test examinations, particularly in estimation skills. Study activities such as reading instructional materials and annotating measurements were associated with excellent test scores and improved estimation accuracy [31]. Annotation activities were found to enhance students' reasoning and comprehension of geometric principles. By interacting with embedded geometric figures in their daily surroundings, students were more effective at linking abstract mathematical symbols to perceivable physical surroundings than in conventional paper-based instruction. The research highlights the potential of AR technology to truly support students' visualization, analysis, measurement, and estimation abilities [31]. Empirical evidence also highlights AR's positive impact on students' motivation, engagement, and comprehension of complex mathematical concepts. Interactive 3D life-size models enable learners to comprehend problematic concepts such as surface area, volume, and geometrical transformations that are difficult to visualize using static images or written descriptions [24], [32]. Virtual objects' interaction in real-time also provides immediate feedback, facilitating iterative learning and a better grasp of mathematical relationships. However, most existing research is focused on short-term outcomes, with a noticeable lack of longitudinal studies investigating whether such gains are sustained in the long term. Although motivational gains are frequently cited, there is sparse empirical evidence to link increased engagement with long-term academic success or knowledge transfer. A recent systematic review by [33] recognizes this lacuna, noting that many AR learning solutions are not supported by robust pedagogical frameworks, which reduces their effectiveness. The review calls for future studies on how some design elements—types of interaction, visual realism, and contextual integration—influence learning outcomes in mathematics education.

Most notably, mobile-based augmented reality (MB-AR) has been very promising in developing spatial thinking and student engagement. Rohendi and Wihardi (2020) developed an MB-AR application for students in Indonesian middle school to aid in the learning of three-dimensional (3D) shapes. Created using Unity 3D and Vuforia, the app allows students to manipulate 3D geometric forms with mobile phones and a marker-based "magic book." Addressing difficulties students often have with visualizing surface area and volume, MB-AR allowed students to explore shapes from all angles, facilitating greater conceptual understanding. The study involved expert validation and use with 150 students, and data were collected through classroom observation. The findings reported significant gains in students' ability to analyze geometric properties, construct mathematical arguments, and work through geometry problems. Students also demonstrated enhanced spatial thinking and enhanced engagement. These findings indicate the potential of AR—particularly mobile-delivered AR—to boost math education by embedding abstract ideas and making them more interactive. The research supports AR's capability to improve spatial abilities required for STEM fields [34].

2.4 Integration with Pedagogical Strategies

The actual pedagogical value of AR is realized when paired with evidence-backed methods such as Problem-Based Learning (PBL), gamification, and collaborative learning. AR-facilitated PBL environments force students to apply the principles of geometry to real-world contexts, building critical thinking and applied consciousness [35], [36]. Similarly, gamified AR experiences leverage the motivational power of game elements in sustaining engagement and supporting learning objectives [37], [38].

Designing AR experiences that facilitate discovery learning is also as well-suited to Bruner's theory of instruction and constructionism by Papert, focusing on the learner's active discovery and control. Studies have shown gamified AR fosters heightened attention and persistence with problem-solving, a characteristic key to understanding abstract mathematical concepts [39], [40].

Co-learning environments, peer-to-peer collaboration, and co-construction of knowledge are also offered through collaborative AR software. It is particularly critical to consider emerging 21st-century competencies such as teamwork, communication, and digital literacy [40],[41]. Though promising findings are present, implementation challenges must be addressed regarding equity of access, teacher training, and curriculum alignment.

2.5 Research Gaps and Future Directions

Though Augmented Reality (AR) has demonstrated potential in supporting the learning of geometry—particularly in strengthening student motivation and conceptual understanding—a considerable gap in research remains. Specifically, there is a lack of large-scale longitudinal studies investigating the long-term effect of AR exposure on learning outcomes. While many studies document short-term benefits, it is still unclear whether these gains are sustained over time or effectively transferred to deeper learning and new contexts [24], [31]. Given students' ongoing difficulties in mastering abstract and spatial concepts in geometry, this gap calls for further investigation. Another underexplored area involves the influence of AR design features—such as feedback mechanisms, interaction complexity, and visual realism—on learning and cognition. While prior research has primarily focused on overall AR effectiveness, more profound insight into how specific design elements affect cognitive processes could help tailor AR applications to diverse educational needs [4], [6]. Additionally, limited studies have examined how AR can support students with different learning capabilities, including those with learning disabilities or low spatial ability.

Exploring how AR can offer individualized support would help increase its inclusivity and accessibility [28], [32]. Finally, while AR is often aligned with constructivist and situated learning theories, future research should consider integrating additional theoretical frameworks—such as Active Learning, Collaborative Learning and dual coding theory—to improve instructional design and minimize cognitive overload [27], [42]. Moreover, further investigation is needed on how AR can be embedded into active pedagogical approaches like gamification, Problem-Based Learning (PBL), and collaborative learning environments [35]-[37]. Addressing challenges such as teacher training, curriculum alignment, and equitable access is essential for ensuring the effective and scalable integration of AR in various educational settings [23], [34].

3. APPLICATION DEVELOPMENT

3.1 AR Application Development and Design Process

The creation of the AR Math App Phradabos revolves around delivering an interactive and immersive educational experience for students learning fundamental concepts in geometry. The application utilizes AR features that enable users to scan real-world markers. When the markers are scanned, three-dimensional (3D) geometric objects like cubes, cylinders, and cones are projected into the real world via the device's camera. These models are interactive, and users can manipulate them using touch gestures, enabling a haptic exploration of the mathematical structures. This interaction promotes a deeper connection with the principles of geometry, fostering spatial reasoning and enhancing the learning experience [24], [43].

The Phradabos AR Math App is an interactive e-learning platform for elementary geometry that utilizes immersive 3D models and interactive quizzes to learn key concepts such as area, volume, and surface area. The application employs high-quality 3D models created using industry-standard tools such as Blender and Maya, offering a visually realistic and interactive experience. Through augmented reality technology, the application enables users to visualize virtual geometric shapes within their surroundings via the camera of an Android device, thus connecting theoretical knowledge with practical application [24], [35].

To ensure its seamless functionality and simplicity of user experience, the app was thoroughly tested on devices meeting the ARCore specifications. Testing was of the utmost priority to confirm the app's functionality on various devices and assure users of a proper experience of interactive components and the learning value of AR in a simple and accessible manner.

In developing an application for learning and reviewing mathematics, the topic of finding area and volume is finding area and volume and consists of four topics: finding the perimeter, finding area, finding volume, and finding surface area.

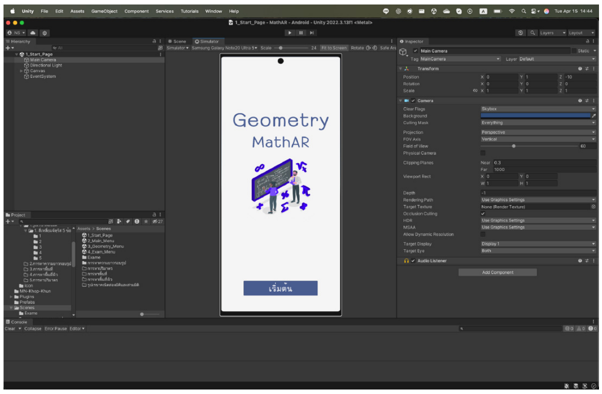

Fig.1: *Overview of Android Application Development.*

Fig. 1 illustrates the development of an Android application focusing on creating an AR-based learning environment for perimeter, area, surface area, and volume calculations.

The user interface, developed with Figma, focuses on user interaction and simplicity and incorporates an augmented reality platform to support interaction with geometric concepts in an efficient manner. The content is structured progressively, beginning with simple geometric shapes and progressing to complex subjects gradually, thereby ensuring a comprehensive understanding at each step [15]. The application of augmented reality supports users' visualization and interaction with geometric figures in real time, promoting experiential learning.

The subject matter of area and volume calculation is categorized into four fundamental parts: finding perimeter, finding area, finding volume, and finding surface area. Five multiple-choice questions were designed for each geometric shape to assess understanding with a close association with the instructional content. The application's features, such as the presentation using 3D models, augmented reality experience, and quizzes, were programmed in Unity, hence providing an integrated and effective learning tool [16], [44].

3.2 The Composition and Operating Features of the Augmented Reality Mathematics Application

The Phradabos AR Math App is an application based on the Android operating system that utilizes the ARCore function to communicate with mobile device sensors. Built on Unity's AR Foundation library, the app has support from the Android and iOS platforms. The development and export on iOS require macOS systems due to platform-specific restrictions [17], [24]. Fig. 2 illustrates the software logical layers. As users interact with the app, the interface communicates with AR Foundation, which bridges to ARCore to access device sensors and execute AR functionality. This structured architecture enables a user-friendly interface, blending technical sophistication with pedagogical appeal. The app effectively combines AR functionality with a user-friendly interface to deliver an enjoyable yet challenging learning experience [18].

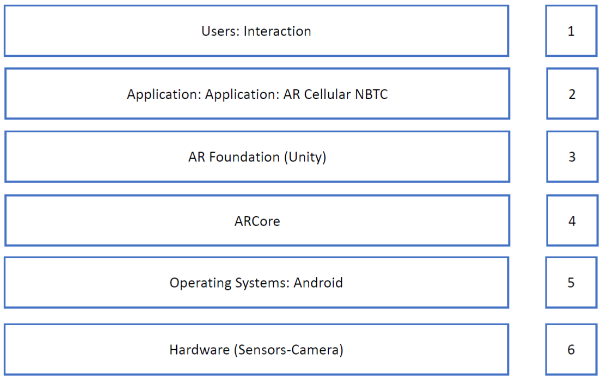

Fig.2: *Software Logical Layers of AR Math App phradabos.*

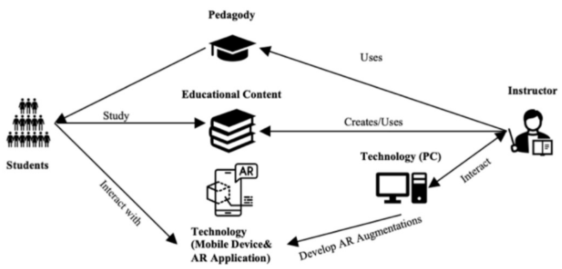

Fig.3: *Pedagogical Framework for AR-Enhanced Learning.*

3.3 Pedagogical Framework for AR-Enhanced Learning

Fig. 3 outlines the pedagogical framework designed to enhance learning through AR technology. This framework integrates students, instructors, and technology to create an immersive and interactive educational environment. Instructors curate and design content using desktop technologies, which are then adapted for delivery via AR applications on mobile devices. This approach allows students to explore interactive 3D models and simulations that make abstract concepts more tangible [35].

The framework is grounded in constructivist and inquiry-based learning principles, emphasizing active engagement and exploration. By interacting with AR content, students build on prior knowledge, establish connections with new concepts, and engage in problem-solving activities that mirror real-world challenges. This aligns with the idea that learning is most effective when students actively construct knowledge through hands-on experiences and reflective practices [43].

By integrating these elements, the AR-enhanced learning framework promotes higher engagement, deeper understanding, and improved retention of STEM concepts. This framework ultimately supports the development of critical thinking and problem-solving skills, transforming traditional education into an interactive, personalized experience suited to the demands of the 21st-century classroom [45], [46].

Fig.4: *Phra Dabos MathAR Application Start Screen.*

Fig.5: *Menu Page Display.*

3.4 Materials and Methodology

The start screen of the Pra Dabos MathAR app, as seen in Fig. 4, displays the name of the application, which takes the user through the most important functions before launching it. At the bottom of the page is a prominent “Start” button, which acts as a gateway into the app. When clicked, the user is taken to the main menu page, as shown in Fig. 5.

Fig. 5 displays the different submenu options: Learning Materials, 2D Geometry, and 3D Geometry. The Questions section is a compilation of quizzes for evaluating the effectiveness of the research. Many of these quizzes take an FAQ-style approach, providing questions at both overview and detail (neck) levels, thus making them particularly suitable for beginners. The application is developed on a proven augmented reality platform for a concentrated, uninterrupted interactive experience.

Fig.6: *Submenu Display Under 2D and 3D Geometry Lessons Section.*

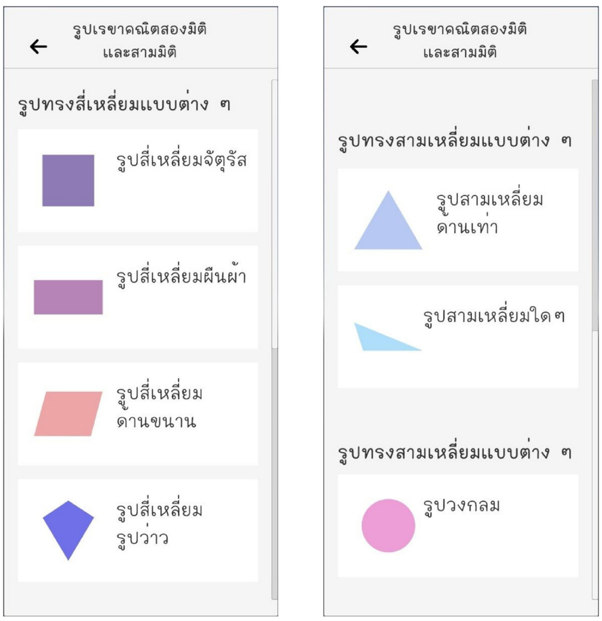

Fig.7: *2D Geometry Shapes Lessons Options.*

Fig. 6 Submenu Display under the 2D and 3D Geometry Lessons Section, offering five options: “2D and 3D Shapes,” “Perimeter Calculation,” “Area Calculation,” “Surface Area Calculation,” and “Volume Calculation”. Additionally, there is an option to navigate back to the previous Submenu to choose other categories. When the users click on “2D Geometry Shape,” they can access some of the many lessons on 2D shapes. In doing this, they learn several geometric shapes according to their need and wish. This system facilitates the users with easy personalization of learning and attention to some specific parts of geometry. Fig. 6 displays several options of different shapes being investigated in depth. The interactive design thus encourages use and enables learners to navigate around the learning content.

Fig. 7 shows how the phone’s camera detects a marker after a user chooses the 3D Geometry Shapes lesson. A 3D shape is shown on the screen after successfully scanning the marker. Users can zoom in and rotate the shape to understand it better. The result of this interaction is depicted in Fig. 7, which is the 3D shape after scanning the marker.

Fig.8: *3D Geometric Shape Displayed After Scanning the Marker.*

The Fig. 10 illustrates four distinct lesson types designed to teach geometry by integrating traditional and AR approaches. The first category, labeled AR 2D Lesson (A), combines two-dimensional geometry concepts with augmented reality technology, thus allowing students to visualize and interact with two-dimensional shapes in an augmented environment, further enhancing their understanding of geometric properties, such as angles and areas. The second category, 2D Lesson (B), is a traditional method of teaching two-dimensional geometry based on static images and text descriptions to transmit theoretical concepts and assist in calculations without any interactive element. Conversely, the AR 3D Lesson (C) brings three-dimensional teaching to a new level, integrating augmented reality software that enables students to interac-

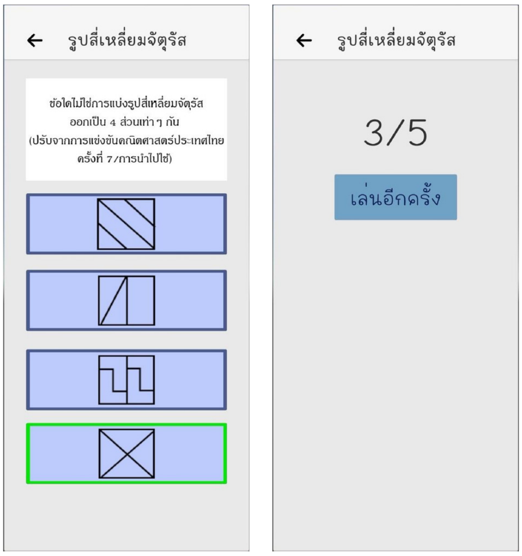

Fig. 9: *Quiz and Results Display.*

tively rotate or rescale three-dimensional geometric shapes, thereby greatly augmenting spatial cognition and comprehension. Finally, the 3D Lesson (D) presents a more traditional approach to three-dimensional geometry learning with static pictures of shapes alongside descriptive text that points out attributes such as surface area and volume. These lesson formats demonstrate a range of teaching methods, with AR-based lessons (A and C) offering interactive experiences to engage students and enhance their understanding of 2D and 3D geometry.

After completing all the lessons, users can take a quiz. As evident from Fig. 4, the users are provided with the 'Quiz' menu, which directs them to a multiple-choice quiz with four available answers to all the questions posed. Following the Quiz, the user's score is shown on the screen. Besides, users can also select 'Play Again' so that they can replay the Quiz and enhance their learning experience. The results of this process are illustrated in Fig. 9 shows the quiz interface and the displayed results.

3.5 Integration of AR Application into Mathematics Pedagogy: A Strategic Framework

Integrating augmented reality (AR) into mathematics instruction requires careful planning. Educators should understand AR's functionalities—such as marker detection and 3D model interaction—and decide the optimal point in the lesson to introduce AR for maximum effectiveness.

Essential mathematical concepts like geometric shapes, area, volume, and perimeter should be taught before implementing AR technology. Once students grasp these basics, AR can enhance visualization and understanding of abstract concepts. Activities should progress from guided discovery of geometric figures using AR to group discussions and hands-on problem-solving in vocational contexts.

Improvement of collaboration is achieved through learning, as the students in groups adopt roles such as a scanner and data recorder, rotating roles for successful experiential learning. It facilitates peer-to-peer interaction, enhancing understanding and communication skills.

It is essential to relate mathematics to application. Applications in real life, like calculating water tank volumes or estimating building materials, highlight the use of math in technical sectors. AR facilitates students to interact with 3D models, enabling improved spatial awareness among potential technicians and engineers.

Evaluating learning should be multidimensional, measuring both theoretical knowledge and application. Formative assessments, participation observation, and tools like Plickers for real-time feedback will be used alongside reflective practices to help students articulate how AR enhances their learning and develops metacognitive awareness.

3.6 Data Collection Instruments

The research team collected quantitative data using a validated 20-item multiple-choice test to assess students' understanding of geometric concepts. The team established the reliability of this test by calculating Cronbach's alpha, as shown in Equation (1), which yielded a coefficient value of 0.85. This high-reliability coefficient reflects strong internal consistency and supports the validity of the test results for measuring the intended learning outcomes.

$$\alpha = \frac{N}{N-1}\left(1 - \frac{\sum_{i=1}^{N}\sigma^2_{Y_i}}{\sigma^2_X}\right) \tag{1}$$

Along with the quantitative metrics, the researchers collected qualitative data through semi-structured interviews with a random sample of 20 student participants. From the interviews, the researchers collected rich, detailed data regarding the students' perceptions, known difficulties, and strengths in using the augmented reality app. The researchers also employed a structured observation checklist to note non-verbal signs of engagement, such as the level of participation, attention, and quality of interaction with the AR technology by the students. The multi-method study allowed the researchers to obtain a broader and more nuanced view of students' engagement and behavior during the learning process. The researchers compared pre-test and post-test scores using a paired t-test to evaluate learning improvement, detailed in Equation (2). This statistical procedure helped quantify the degree of change in student performance resulting from the intervention.

(A) AR 2D Lesson (B) 2D Lesson (C) AR 3D Lesson (D) 3D Lesson

Fig.10: *Example of Detailed View with Video and Additional Information for Geometric Shapes.*

$$t = \frac{\bar{d}}{\frac{S_d}{\sqrt{N}}} \quad (2)$$

With the integration of cognitive tests and experience-based evaluations, the study's data collection research design gave a comprehensive view of the effectiveness of the AR app in facilitating rich learning experiences.

3.7 The principle and structure of the AR Math App phradabos application

The developers created and built the Phradabos AR Math App for the Android platform using a high-performance design optimized for mobile devices. They incorporated ARCore to provide an interface to interact with the native sensors of the device and thereby improve the augmented reality capabilities of the application. The AR Foundation library forms the heart of the app's functional features, and the developers utilized it as middleware within the Unity development environment to facilitate the easy enabling of AR capabilities across various platforms. Despite the application's inherent support for Android and iOS platforms, the development team must leverage a macOS environment to compile and deploy the iOS version due to inherent platform-related restrictions. The team architected the application's software into various logical layers, facilitating operation workflows on Android-based devices, enhancing performance efficiency, and optimizing system-level resource usage. As illustrated in Fig. 2, the app allows users to explore a user-friendly and interactive UI, which the developers designed from scratch to make learning more enjoyable. As a user interacts with the UI in the secondary architectural layer, the system communicates with AR Foundation, which directly links to ARCore. This connection enables the application to utilize various AR functions, such as sensor-based interactions and real-time tracking. Using AR Foundation, the development team achieved compatibility on both leading mobile platforms while maintaining the same level of performance throughout. AR Foundation coordinates the data transfer between the Unity engine and ARCore during user interactions, thus enabling the application to deliver dynamic, contextually aware augmented reality experiences. The seamless integration of AR Foundation and ARCore allows the Phradabos AR Math App to deliver an immersive, engaging learning experience. The application's solid structure integrates interactive technology with learning content, enhancing the learning process and rendering it more interesting and intellectually stimulating. The app's intentional design, technical accuracy, and emphasis on user experience create an efficient learning aid that provokes inquisitiveness and reinforces students' understanding of geometric principles.

3.8 Ethical Considerations

Prior to data collection, the research protocol was reviewed and approved by the Ethics Committee of Research, Innovation and Partnerships Office, King Mongkut's University of Technology Thonburi, approval number KMUTT-IRB-COE-2024-130. All participants and their guardians were informed about the study objectives and procedures, and informed consent was obtained in accordance with ethical research practices.

4. RESULTS

4.1 Data Collection and Analysis

The research team utilized a mixed-methods approach to evaluate the AR app's effect, using quantitative and qualitative data to give a general assessment. The study involved 79 students (aged 18-35) from Phra Dabos School, a Thai vocational institution serving disadvantaged learners with secondary education or lower. Participants typically possessed middle school-level geometry knowledge while pursuing technical trades that demanded practical mathematical application.

4.2 Quantitative Analysis

Fig. 11 compares pre-and post-test scores, revealing a substantial improvement in student performance following the AR intervention. The average pre-test score of 3.70 (SD = 2.48) rose significantly to a post-test average of 9.04 (SD = 2.76), $t(78) = 18.11$, $p < 0.001$. The calculated effect size, Cohen's $d = 2.05$, reflects the strong impact of the AR application on learning outcomes.

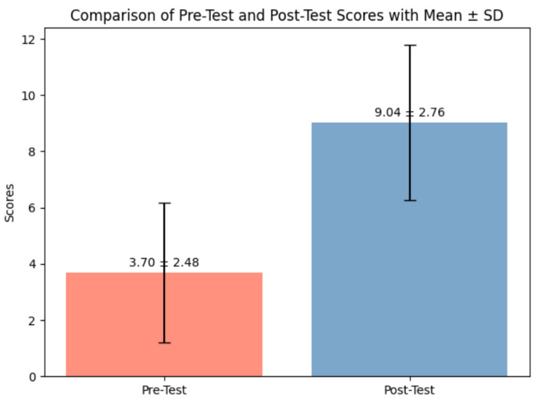

Fig.11: *Comparison of Pre-test and Post-test Scores.*

Students showed the most notable gains in understanding three-dimensional shapes and volume calculations. Their performance on average in these aspects was improved by 25% , indicating that the AR app assisted them in visualizing and comprehending complex spatial concepts that typically are problematic in typical learning environments. The research group also conducted a user satisfaction questionnaire to quantify the students' sentiment towards the AR-based learning experience. As shown in Fig. 12, although many participants had priostudents'e' AR through gaming, sports broadcasts, or virtual environments, most had never encountered AR in educational settings due to limited access to technology and learning opportunities. Students identified the practicality of AR and its effectiveness as a learning tool as key motivators for its adoption. They rated the quality of learning materials and supplementary information the highest, with an average score of 3.87 on a 5-point scale. Other features, including content quality, lesson introductions, and overall user experience, also received favorable feedback, scoring 3.45, 3.60, and 3.87, respectively. These findings suggest that students appreciated the AR experience but saw the potential for improvement in content organization and interface design.

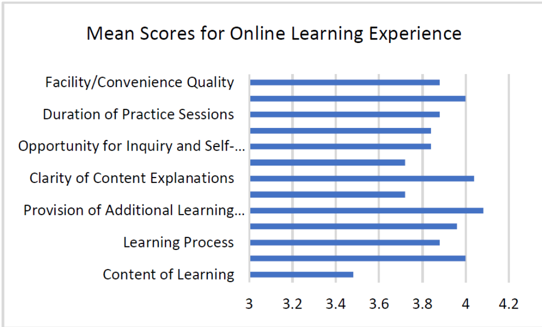

Fig.12: *Results of Online Learning Experience Satisfaction Survey.*

4.3 Qualitative Analysis

The student interviews were also analyzed thematically by the research team, which illustrated some of the learning benefits of the AR application. Enhanced visualizations of math, increased participation, and further opportunities for collaborative learning were all identified by the students. Many reported higher levels of involvement and motivation in AR lessons, illustrating the degree of interactivity motivating them to engage more in learning. Collaborative learning was a common trend. The students would work on problems in groups of two or teams of a few, fostering peer interaction and better teamwork. The AR application supported these collaborative efforts by enabling shared manipulation of virtual content, encouraging students to discuss and explore ideas together. Although some students initially experienced technical challenges—such as difficulties with marker scanning or device compatibility—most resolved these issues with persistence and assistance from peers and teachers. This finding indicates adequate technical support is needed when integrating AR into learning environments. Students also reported that they could apply concepts learned with AR to different math situations, thereby improving spatial reasoning and problem-solving. Such findings indicate that AR technology promises to significantly influence educational outcomes through higher engagement, collaborative learning, and conceptual transfer. However, additional development must address technical problems and improve the overall user experience to promote broader classroom implementation.

5. DISCUSSION

The research results demonstrate a significant potential for AR in increasing students' comprehension of geometry concepts by bringing them fun and interactive learning experiences. The high increase in test scores, from a mean of 3.70 during the pre-test to 9.04 during the post-test, provides strong evidence of AR's effectiveness in achieving academic accomplishment. The effect size (Cohen's $d = 2.05$) calculated also represents the magnitude of this effect, especially in benefiting students who struggle with abstract math concepts such as three-dimensional objects and spatial reasoning. Along with the quantitative improvement, qualitative student feedback highlighted the entertaining and interactive nature of AR-based learning. Students expressed appreciation of the experiential, visual nature provided by the app in that they could actively manipulate dynamic geometric shapes rather than passively looking at static diagrams [14]. Incorporating interactive elements enabled better comprehension of mathematical relationships and promoted collaboration among peers, strengthening communication and critical thinking abilities in collaborative problem-solving [10].

However, using AR in the learning environment poses some challenges. Even though a System Usability Scale (SUS) score of 78.5 confirmed that the app was generally well-liked, some students experienced hindrances related to the complexities of the interface and novelty of the technology. These were particularly evident in those with little prior experience with AR or digital technologies overall. Furthermore, restricting access to augmented reality-supporting devices proved an important setback, particularly in educational environments with poor technological infrastructures.

Educators must consider pedagogical strategy and infrastructural readiness to integrate AR effectively into classroom instruction. Educators can support students by providing adequate scaffolding when they introduce AR, for instance, by giving them time to get used to the application in low-stakes settings before advancing to formal lesson content [42]. This will make the learning process smoother and reduce the cognitive load associated with new technologies. Teachers also need to design AR activities in the context of curricular objectives and active learning encouragement, positioning AR as another tool and not as a substitute for current solutions. Schools should increase support for AR adoption by investing in teacher professional development, upgrading infrastructure technology, and building professional networks for cooperation and knowledge sharing. Incorporating AR into comprehensive curricular models, primarily through interdisciplinary uses, promises to advance its pedagogical significance. In addition, as new technologies like virtual reality (VR) and artificial intelligence (AI) become achievable, educators can consider new ways of incorporating these tools in conjunction with AR to provide personalized, data-driven learning experiences. These forward-looking directions emphasize the importance of ongoing research and progressive refinement, both of which will ensure that AR develops in ways that address the diverse needs of learners and support impactful educational outcomes.

6. CONCLUSION AND FUTURE WORK

This study illustrates how augmented reality transforms geometry teaching by making abstract mathematical notions more concrete and understandable. The augmented reality application effectively aided learning volume, area, and three-dimensional shapes in ways that traditional learning does not accomplish. Quantitative data revealed significant performance improvement, and qualitative results revealed greater student engagement, motivation, and collaboration. Students were drawn to the interactive and immersive quality of the augmented reality experience and showed significant improvement in both engagement level and concept understanding.

Though the results are encouraging, several challenges need to be overcome. Usability problems were apparent, especially for students without AR experience, and more intuitive interface design and guided training procedures are needed. The lack of sufficient AR-enabled devices and teacher preparation indicates more considerable equity and access issues that must be resolved for large-scale implementation.

Our immediate next task will be to systematically integrate this AR app into comprehensive lesson plans specially designed for active learning classrooms. By constructing coherent pedagogical designs with AR as an integral component rather than as an auxiliary tool, we will formulate scalable templates for technology-enabled active learning of mathematics. These lesson plans will include pre-AR activities to activate prior knowledge, guided AR exploration phases, collaborative problem-solving with AR visualizations, and post-AR reflection to consolidate learning—fulfilling an entire instructional cycle that takes advantage of the technology's learning potential.

Future deployments must also involve creating more accessible AR experiences that can scale to fit different teaching contexts with minimal technology. Instead of substituting traditional teaching, AR's worth supplements what is already being accomplished by adding visual and interactive elements that make understanding concepts easier. With mediated instruction and crafted opportunities for reflection, AR can emerge as a viable mechanism for opening up mathematical learning.

The educational possibilities of AR will increase as emerging technologies evolve—primarily through the intersection of AI, adaptive learning streams, and personalized experiences. To realize this potential to their highest, ongoing development and teacher training investment is critical. Creating communities where AR content and best practices can be shared will also rapidly spur innovation and adoption.

Lastly, AR is also a fantastic math instructional tool. It explains complex ideas, makes education engaging, and develops the required skills, like problem-solving and collaboration. With the growth of technology and pedagogical methods, AR can revolutionize the face of mathematics instruction to better serve students in both how and what they learn.

7. RECOMMENDATIONS FOR EFFECTIVE AR IMPLEMENTATION IN MATHEMATICS EDUCATION

7.1 Developing Collaborative Learning Through AR Technology

The qualitative results of this study indicate that students like group work when it is utilized with AR apps. In light of this, educators are urged to design learning assignments that enable substantial interaction among group members—such as activities where students must share information by viewing AR models from different angles. Clearly defined but circular functions like device operator, data recorder, analyst, and presenter need to be created to allow each student to participate in various aspects of the AR-augmented learning process. The quality of group collaboration and the output produced also need evaluation criteria created [7]. States that cooperative learning using AR significantly enhances students' motivation, particularly in attention and confidence.

7.2 Connecting Abstract Concepts with Practical Applications

To enhance the effectiveness of AR-based learning—particularly within technical mathematics contexts—instructors should design modules that explicitly link geometric concepts to real-world applications in fields like engineering and architecture. This can be achieved by the use of case studies of calculations of area, volume, and surface area drawn from construction or industrial settings. Furthermore, field visits or visits by practitioners to lecture on using geometric principles in practice can be employed to reinforce students' contextual knowledge [14]. AR technology significantly improves spatial thinking capability, a STEM student's critical thinking skill.

7.3 Establishing Infrastructure Readiness and Teacher Development

Institutions have to emphasize several key strategies for efficiently utilizing AR in education. First, equitable access has to be provided through offering proper technological tools and crafting resource-sharing frameworks. Second, there must be the provision of practical professional development workshops that equip educators with the skills to employ AR tools and solve common issues confidently. The development of Professional Learning Communities (PLCs) dedicated to implementing AR can motivate collaboration and the sharing of experiences alongside the dissemination of best practices among teachers. Besides, developing precise instructional materials and pedagogical content will facilitate teachers' incorporation of AR in current curricula. These steps will help teachers utilize AR's revolutionary potential to enhance teaching mathematics, focusing on concept understanding, student engagement, and connecting theoretical concepts to practical applications in technical learning environments.

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AUTHOR CONTRIBUTIONS

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References

[1] T. Adolphus, "Problems of teaching and learning of geometry in secondary schools in rivers state, nigeria," *International Journal of Emerging Sciences*, vol. 1, no. 2, pp. 143–152, 2011.

[2] F. Radmehr and P. Vos, "Issues and challenges of 21st century assessment in mathematics education," *Science and mathematics education for 21st century citizens: challenges and ways forward*, pp. 437–462, 2020.

[3] S. Singhal, J. B. Bheda, J. Jogi, P. Rathod and R. Damor, "Impact of ict based tools on teaching-learning system-a case study," *Indian Journal of Educational Technology*, vol. 2, no. 1, pp. 21–30, 2020.

[4] J. Garzón, J. Pavón and S. Baldiris, "Systematic review and meta analysis of augmented reality

in educational settings," *Virtual Reality*, vol. 23, no. 4, pp. 447–459, 2019.

[5] A. Almufarreh and M. Arshad, "Promising emerging technologies for teaching and learning: Recent developments and future challenges," *Sustainability*, vol. 15, no. 8, p. 6917, 2023.

[6] M. Akçayır and G. Akçayır, "Advantages and challenges associated with augmented reality for education: A systematic review of the literature," Educational research review, vol. 20, pp. 1–11, 2017.

[7] E. İbili and S. Şahin, "The effect of augmented reality assisted geometry instruction on students' achiveement and attitudes," Teaching Mathematics and Computer Science, vol. 13, no. 2, pp. 177–193, 2015.

[8] Á. Di Serio, M. B. Ibáñez and C. D. Kloos, "Impact of an augmented reality system on students' motivation for a visual art course," *Computers & education*, vol. 68, pp. 586–596, 2013.

[9] M. Fidan and M. Tuncel, "Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education," *Computers & Education*, vol. 142, p. 103635, 2019.

[10] M. B. Nadzeri, C. C. Meng, I. Ismail and A. Abu Hassan, "The development and evaluation of augmented reality learning application in geometry topic," *International Journal of Academic Research in Progressive Education and Development*, vol. 11, no. 1, 2022.

[11] K. Khairiree, "Online learning and augmented reality: Enhancing students to learn transformation geometry during the covid-19 pandemic," in Proceedings of the 25th Asian Technology Conference in Mathematics, pp. 304–313, 2020.

[12] K. R. Bujak, I. Radu, R. Catrambone, B. MacIntyre, R. Zheng, and G. Golubski, "A psychological perspective on augmented reality in the mathematics classroom," Computers & Education, vol. 68, pp. 536–544, 2013.

[13] G.-J. Hwang, P.-H. Wu, C.-C. Chen, and N.-T. Tu, "Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations," Interactive Learning Environments, vol. 24, no. 8, pp. 1895–1906, 2016.

[14] N. Yannier, S. E. Hudson, and K. R. Koedinger, "Active learning is about more than hands-on: A mixed-reality ai system to support stem education," International Journal of Artificial Intelligence in Education, vol. 30, pp. 74–96, 2020.

[15] A. Field, *Discovering statistics using IBM SPSS statistics*. Sage publications limited, 2024.

[16] M. Tavakol and R. Dennick, "Making sense of cronbach's alpha," *International journal of medical education*, vol. 2, p. 53, 2011.

[17] J. Brooke, "Sus: a retrospective," *Journal of usability studies*, vol. 8, no. 2, 2013.

[18] S. Oueida, P. Awad and C. Mattar, "Augmented reality awareness and latest applications in education: A review," *International Journal of Emerging Technologies in Learning*, vol. 18, no. 13, 2023.

[19] E. Ibili, H. Çatlioğlu, C. İbiş, and G. Aşiksoy, "Enhancing students' interactivity and responses in learning geometry by using augmented reality," *EURASIA Journal of Mathematics, Science and Technology Education*, vol. 15, no. 12, p. em1804, 2019.

[20] S. Sarkar and P. Das, "Design and evaluation of an ar-based learning application (geometria) for geometry education," *Informing Science: The International Journal of an Emerging Transdiscipline*, vol. 26, pp. 81102, 2023.

[21] T. Oktavia, Dafik and A. Supratman, "Augmented reality-based geom etry learning application to improve elementary students' spatial visual ization skills," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 17, no. 24, pp. 117–133, 2023.

[22] J. Gonzalez *et al.*, "The role of dynamic geometry software in enhancing students' spatial abilities," *Journal of Educational Research and Practice*, vol. 10, no. 3, pp. 23–34, 2020.

[23] C. Moore and T. Smith, "Mathematics education and student disengagement: An analysis of contributing factors and strategies for improvement," *International Journal of Mathematical Education*, vol. 45, no. 2, pp. 120–136, 2021.

[24] S. Cai, E. Liu, Y. Shen, C. Liu, S. Li and Y. Shen, "Probability learning in mathematics using augmented reality: impact on students' learninggains and attitudes," in *Cross Reality (XR) and Immersive Learning Environments (ILEs) in Education. Routledge*, pp. 22–35, 2023.

[25] M. Taylor and R. Black, "Active learning in mathematics education: A systematic review of the impact on student performance," *Educational Studies in Mathematics*, vol. 101, no. 2, pp. 105–118, 2019.

[26] J. Lave, *Situated learning: Legitimate peripheral participation.* Cambridge university press, 1991.

[27] D. H. Jonassen, "Modeling with technology: Mindtools for conceptual change," *Educational Technology Research and Development*, vol. 54, no. 4, pp. 105–121, 2006.

[28] X. Xie and H. Wang, "Exploring the effect of augmented reality on students' learning outcomes in geometry education," *Journal of Educational Technology & Society*, vol. 23, no. 3, pp. 56–67, 2020.

[29] H. Nindiasari *et al.*, "The use of augmented reality to improve students' geometry concept problem-solving skills through the steam ap-

proach," *Infinity Journal*, vol. 13, no. 1, pp. 119–138, 2024.

[30] A. Uriarte-Portillo, R. Zatarain-Cabada, M. L. Barrón-Estrada, M. B. Ibá˜ñez, and L.-M. González-Barrón, "Intelligent augmented reality for learning geometry," *Information*, vol. 14, no. 4, p. 245, 2023.

[31] W. -Y. Hwang, R. Nurtantyana, S. W. D. Purba, U. Hariyanti and Suprapto, "Augmented Reality With Authentic GeometryGo App to Help Geometry Learning and Assessments," in *IEEE Transactions on Learning Technologies*, vol. 16, no. 5, pp. 769-779, Oct. 2023.

[32] L. Medina Herrera, J. Castro Pérez and S. Juárez Ordóñez, "Developing spatial mathematical skills through 3d tools: augmented reality, virtual environments and 3d printing," *International Journal on Interactive Design and Manufacturing (IJIDeM)*, vol. 13, pp. 1385–1399, 2019.

[33] V. M. López, "Realidad virtual y aumentada en la educación contem poránea," *Social & Educational Lens*, vol. 1, 2024.

[34] D. Rohendi and Y. Wihardi, ""Learning three-dimensional shapes in geometry using mobile-based augmented reality," *International Journal of Interactive Mobile Technologies*, vol. 14, no. 9, 2020.

[35] M.-B. Ibáñez and C. Delgado-Kloos, "Augmented reality for stem learning: A systematic review," *Computers & Education*, vol. 123, pp. 109–123, 2018.

[36] A. Johnson and R. Lee, "Problem-based learning and its applications in stem education," *Journal of STEM Education*, vol. 21, no. 4, pp. 45–56, 2020.

[37] B. Anderson and Y. Wang, "Gamification in education: A systematic review of its impact on student learning outcomes," *Educational Technology Research and Development*, vol. 68, no. 4, pp. 1243–1265, 2020.

[38] E. Parsons and S. Hall, "Engaging students through gamified learning: A meta-analysis of the impact on academic performance," *Journal of Educational Research*, vol. 115, no. 2, pp. 107–119, 2022.

[39] J. Martin and C. Cox, "The benefits of augmented reality in stem education: A review of recent studies," *Journal of Educational Technology & Society*, vol. 23, no. 1, pp. 56–68, 2020.

[40] P. Edmunds and J. Lee, "Collaboration and communication through augmented reality in stem classrooms," *Computers & Education*, vol. 174, p. 104313, 2022.

[41] J. Han and D. Park, "Collaborative learning through augmented reality: Impact on student engagement in stem education," *Interactive Learning Environments*, vol. 29, no. 3, pp. 333–348, 2021.

[42] R. Moreno, *Who learns best with multiple representations? Cognitive theory predictions on individual differences in multimedia learning.* Association for the Advancement of Computing in Education (AACE), 2002.

[43] J. Quintero, S. Baldiris, R. Rubira, J. Cerón, and G. Velez, "Augmented reality in educational inclusion. a systematic review on the last decade," *Frontiers in psychology*, vol. 10, p. 1835, 2019.

[44] D. R. Vuta, "Augmented reality technologies in education-a literature review," *Bulletin of the Transilvania University of Brasov. Series V: Economic Sciences*, pp. 35–46, 2020.

[45] J. Lever-Duffy, J. McDonald, and A. Mizell, *The 21st-century classroom: teaching and learning with technology.* Addison-Wesley Longman Publishing Co., Inc., 2002.

[46] K. E. Irving, "The impact of technology on the 21st century classroom," *Teaching science in the 21st century*, pp. 3–20, 2006.

Ratchanikorn Chonchaiya received a Ph.D. degree in Mathematics from the University of Reading, the U.K., and a Master's Degree in Mathematics Education from Ramkhamhaeng University, Thailand. He has over 15 years of experience in the Mathematics Educational area. He is currently working at the Department of Mathematics, Faculty of Science, King Mongkut's University of Technology Thonburi (KMUTT). His current research interest includes students' learning and development at various levels and areas of education. His publication topic includes promoting students' mathematical resilience, self-efficacy, and vocational mathematics. He can be contacted at email: ratchanikorn.cho@kmutt.ac.th.

Nattamon Srithammee received the B.Sc. degree in Information Technology and the M.Sc. degree in Data Science from Burapha University, Thailand, in 2020 and 2023, respectively. She is currently pursuing the Ph.D. degree in Computer Science at Tokyo Metropolitan University, Tokyo, Japan. Her research interests include data analysis, user experience (UX) design, virtual reality (VR), and augmented reality (AR). She has professional experience in data stewardship, software development, and research assistance. Her work focuses on the integration of data-driven approaches with immersive technologies to enhance human-computer interaction.