

DESIGN AND USER EXPERIENCE EVALUATION OF MARKER-BASED AUGMENTED REALITY FOR GEOMETRY LEARNING

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Abstract

Three-dimensional geometry requires learners to interpret spatial relationships that are difficult to convey through static two-dimensional media. This study developed and evaluated a marker-based augmented reality (AR) application for Android to support junior-high-school geometry learning. A research-and-development approach using the waterfall software development life cycle guided requirements analysis, design, implementation, and testing. Unity 3D and Vuforia were used to present seven solids, geometric attributes, volume and surface-area formulas, nets, and three quiz levels. Product evaluation combined an adapted ISO/IEC 25010 product-quality assessment and the full User Experience Questionnaire (UEQ) with 65 respondents. Functional tests showed that registered markers generated the correct 3D objects at distances below 30 cm under adequate lighting, whereas unregistered markers produced no object. The UEQ mean scores were 2.24 for attractiveness, 2.05 for perspicuity, 2.09 for efficiency, 1.92 for dependability, 2.20 for stimulation, and 1.76 for novelty; all were classified as Excellent using the UEQ benchmark. The application demonstrated positive user experience and operational feasibility, although its effect on learning achievement was not tested.

Keywords: *Augmented Reality, Marker-Based Tracking, Geometry Learning, Android, Software Quality, User Experience*

1. INTRODUCTION

Augmented reality (AR) integrates computer-generated content with the physical environment and supports real-time interaction with virtual objects. In education, this affordance is especially valuable when learners must inspect spatial relationships or abstract concepts that are difficult to represent through static media. Recent reviews and meta-analyses report generally positive effects on learning performance, motivation, and engagement, while emphasizing that outcomes vary with instructional design, treatment duration, subject area, and implementation conditions (Amores-Valencia et al., 2022; Chang et al., 2022; Kamińska et al., 2023; Bulut and Borromeo Ferri, 2023; Hidayat and Wardat, 2024).

Three-dimensional geometry requires learners to coordinate two-dimensional representations, mental rotation, and relationships among faces, edges, vertices, diagonals, and nets. AR can make these relationships observable by allowing learners to inspect and manipulate 3D models in their physical environment. Recent empirical studies show that AR can support geometric understanding, spatial visualization, memory retention, flow, and engagement across primary and secondary learning settings (Gargrish et al., 2022; Volioti et al., 2023; Tarnig et al., 2024; Wu et al., 2024; Nadzeri et al., 2024; Nindiasari et al., 2024). Broader mathematics-oriented research also highlights the value of interactive visualization, creativity, culturally responsive learning, and spatially embodied activities (Bertrand et al., 2024; Hidajat, 2024; Kaźmierczak et al., 2025; Mandala et al., 2025; Na et al., 2025).

Although recent studies demonstrate the educational value of AR, their evaluation emphases differ: some focus on learning outcomes or product development, whereas others examine motivation, cognitive load, spatial skills, or learner perceptions. Within the literature reviewed for this manuscript, a combined evaluation that reports operational software-quality testing alongside the full UEQ and

benchmark interpretation remains uncommon. Consequently, evidence about technical operation and evidence about perceived user experience are often presented separately.

This study addresses that gap by developing an Android marker-based AR application for seven solid figures and evaluating it through an adapted ISO/IEC 25010 product-quality assessment and the UEQ. The application integrates geometric elements, formulas, nets, and a three-level quiz. The objectives are to develop the application and assess its operational performance and user experience. Its contribution is a standards-informed evaluation of a geometry-learning AR product rather than a causal test of learning effectiveness.



Fig. 1. Classroom field evaluation of the application.

Figure 1 documents the classroom evaluation session in which student respondents used Android devices to scan printed markers and interact with the generated three-dimensional objects. The session provided the operational observations and UEQ responses reported in this study. Accordingly, the figure illustrates the evaluation setting; it should not be interpreted as evidence that the application improved learning achievement.

2. RESEARCH METHOD

This study used a research-and-development approach organized according to a waterfall software development life cycle: requirements analysis, design, implementation, testing, and maintenance. Unity 3D was used to construct and render the 3D objects, while the Vuforia software development kit handled marker registration and recognition. The Android application contains seven solids: cube, cuboid, cone, sphere, cylinder, triangular prism, and triangular pyramid.

Each registered marker activates the corresponding solid and provides relevant geometric information, including edges, face or space diagonals, radii, nets, volume formulas, and surface-area formulas. The quiz module contains easy, medium, and hard levels; each level has ten questions, with 10 points awarded for each correct answer.

Field evaluation was conducted with 65 student respondents. Product testing comprised (1) marker-recognition tests using registered and unregistered markers at distances below 30 cm under adequate lighting; (2) an adapted assessment covering eight software-quality characteristics derived from the ISO/IEC 25010 framework; and (3) the full 26-item UEQ, which measures attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty on a scale transformed from -3 to +3 (Kollmorgen et al., 2025; Schrepp, 2023). The current ISO/IEC 25010:2023 product-quality model contains nine characteristics. Because the instrument used in this study assessed eight characteristics and did not include the additional safety characteristic, the findings are reported as ISO-informed rather than as formal conformity to the 2023 standard (ISO/IEC, 2023).

Descriptive analysis summarized the operational test outcomes and UEQ scale means. The UEQ results were interpreted using the benchmark guidance provided in the current UEQ documentation (Kollmorgen et al., 2025; Schrepp, 2023). Because the study did not employ a pretest-posttest design or a comparison group, the evaluation addresses product operation and perceived user experience, not causal improvement in geometry achievement.

3. RESULTS AND DISCUSSION

The developed application displayed the seven solids and associated learning content. The home screen provides access to instructions, AR scanning, quizzes, and exit functions (Fig. 2). When a valid marker is recognized, the application renders the relevant 3D object and displays formulas and labeled geometric elements (Fig. 3). The net and diagonal features illustrate how two-dimensional faces form a solid and how internal spatial relationships are organized (Fig. 4).



Fig. 2. Main interface of the geometry-learning application.



Fig. 3. Volume and surface-area formulas provided by the application.

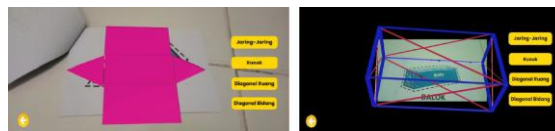


Fig. 4. Examples of a triangular-prism net and cuboid geometric elements.

Registered markers were recognized at scanning distances below 30 cm under adequate lighting, and the correct 3D objects were displayed. Unregistered markers produced no virtual object. These results confirm the intended marker-validation logic under the tested conditions. They should not be generalized to longer distances, low-light environments, or untested Android hardware.

The quiz module provides immediate scoring across three difficulty levels. This feature extends the application beyond visualization by enabling self-assessment, although the current study did not validate item difficulty or measure learning gain.

The UEQ results were 2.24 for attractiveness, 2.05 for perspicuity, 2.09 for efficiency, 1.92 for dependability, 2.20 for stimulation, and 1.76 for novelty. All six scales were classified as Excellent against the applied UEQ benchmark (Fig. 5). Attractiveness and stimulation were the highest-rated dimensions, indicating that respondents perceived the application as appealing and motivating. Novelty was the lowest score, but it remained strongly positive.

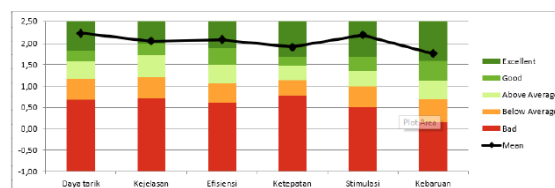


Fig. 5. UEQ scale means and benchmark categories.

These findings are consistent with recent reviews and geometry studies associating AR with engagement, spatial visualization, geometric reasoning, and positive learning experiences (Amores-Valencia et al., 2022; Hidayat and Wardat, 2024; Tarnig et al., 2024; Wu et al., 2024; Kaźmierczak et al., 2025; Mandala et al., 2025; Na et al., 2025). Nevertheless, experimental evidence also indicates that the benefits of AR depend on the device, representation, and task: AR does not necessarily outperform tablet-based interaction for every geometric activity (Walkington et al., 2025).

The present study adds a product-evaluation perspective by pairing operational testing with the full UEQ and benchmark interpretation, consistent with current UEQ guidance (Kollmorgen et al., 2025; Schrepp, 2023). However, criterion-level evidence for the eight assessed software-quality characteristics is not reported in the available manuscript. The results should therefore be interpreted as an ISO-informed product evaluation rather than formal ISO/IEC 25010:2023 conformity. They support operational feasibility and positive perceived user experience, not demonstrated learning effectiveness.

4. CONCLUSION

An Android marker-based AR application for three-dimensional geometry was developed using Unity 3D and Vuforia. Under the tested conditions, registered markers generated the correct objects, unregistered markers produced no output, and the application provided formulas, geometric elements, nets, and quizzes. The UEQ results from 65 respondents placed all six scales in the Excellent benchmark category, indicating a positive user experience. The study therefore supports the application's operational feasibility as an interactive geometry-learning medium. It does not establish improved learning outcomes or formal conformity with ISO/IEC 25010:2023. Future research should report criterion-level software-quality results, document respondent characteristics and sampling procedures, test more devices and environmental conditions, and use controlled pretest-posttest designs.

5. ACKNOWLEDGMENT

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