International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 13; Issue: 1; January 2026
Website: www.ijrrjournal.com
Research Paper *E-ISSN: 2349-9788; P-ISSN: 2454-2237*

Design and Classroom Evaluation of a Marker-Based Augmented Reality Handbook for Magnetic Field Revision in Grade 12 Physics: Evidence from Bac Son High School, Thai Nguyen, Vietnam

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DOI: https://doi.org/10.52403/ijrr.20260142

ABSTRACT

Magnetic field concepts are challenging for secondary students because key features such as field-line direction and three-dimensional spatial patterns are not directly observable. This study developed a low-cost revision resource that combines a printed pocket handbook with a marker-based mobile augmented reality (AR) application for Grade 12 magnetism. When students scan printed markers, the app displays aligned 3D models or short instructional videos to support spatial visualization and independent practice.

The handbook targets core curriculum outcomes, including magnetic interactions, the meaning of magnetic field and iron-filings patterns, magnetic induction, field-line properties, field patterns around common current configurations, and the Earth's magnetic field. A quasi-experimental classroom implementation compared AR-supported revision with conventional revision over two weeks. Learning was assessed with curriculum-aligned tests, and usability was evaluated using a standardized questionnaire. The AR-supported group demonstrated improved learning outcomes and reported high usability, with students highlighting benefits for interpreting field-line direction and comparing field patterns across different conductor geometries. These results suggest that a printed–AR hybrid handbook can be a practical approach for supporting self-study revision in magnetism when AR content is closely aligned with instructional goals and designed to avoid unnecessary cognitive load.

Keywords: Augmented Reality; Grade 12; Marker-Based AR; Magnetic Field; Mobile Learning; Physics Education

INTRODUCTION

Magnetism is a foundational domain in secondary and introductory physics, yet it remains difficult for many learners to master. One reason is representational: magnetic fields are not directly observable, and students must reason with abstractions such as field vectors, direction conventions, and field-line density as a proxy for magnitude. Persistent conceptual difficulties in electricity and magnetism have been documented in the physics education literature, motivating the development of diagnostic instruments and instructional interventions (Maloney et al., 2001).

Within school contexts, exam-oriented revision frequently compresses complex topics into short notes and static diagrams.

While compact revision handbooks can improve access and portability, such resources may provide limited support for spatial visualization. Consequently, students may memorize patterns (e.g., "field lines form circles around a straight wire") without internalizing direction rules, three-dimensional geometry, or comparative reasoning across cases.

Augmented Reality (AR) has been widely discussed as a promising approach for bridging abstract scientific representations with perceptually grounded visualization. AR overlays virtual information onto a real-world view (Azuma, 2017) and is commonly situated within the mixed reality continuum (Milgram & Kishino, 1994). In educational settings, AR can support learning by making invisible phenomena visible, linking multiple representations to real-world referents, and enabling interactive exploration (Wu et al., 2013), (Radu, 2014). Meta-analytic evidence indicates that AR can positively affect learning outcomes, although effects vary with instructional design, intervention duration, and evaluation quality (Chang et al., 2022), (Howard & Davis, 2023). Recent syntheses highlight opportunities and constraints of AR/VR for K–12 STEM learning, including engagement gains alongside operational issues and classroom management constraints (Jiang et al., 2025), (Vidak et al., 2024).

Despite growing evidence, two gaps remain salient for school-based revision practice. First, many AR studies emphasize full digital modules or laboratory simulations rather than short micro-learning experiences integrated into everyday revision. Second, some deployments require extended teacher training, specialized devices, or stable connectivity, limiting scalability. A printed handbook integrated with marker-based mobile AR may address these challenges: it preserves the low-cost portability of printed materials while adding optional interactive visualization at critical conceptual points.

This paper reports the design and classroom evaluation of a printed AR handbook for revising magnetic field knowledge in Grade 12 physics. The handbook is paired with a mobile AR application that displays 3D models or short explanatory videos when students scan designated markers. The intervention was implemented at Bac Son High School (Thai Nguyen, Vietnam) with Grade 12 students, leveraging an AR handbook and application developed for this purpose.

Research objectives. The study addresses three objectives: (1) to design a curriculum-aligned AR handbook that supports Grade 12 revision of magnetic field concepts through marker-triggered 3D and video content; (2) to evaluate the handbook's impact on student learning achievement in a classroom revision context; and (3) to assess usability and learner perceptions of the AR experience using standardized usability measurement.

LITERATURE REVIEW

AR in education and learning outcomes

AR has evolved from early conceptualizations emphasizing real-time overlay of virtual information onto physical contexts (Azuma, 2017) to diverse mobile learning applications. Reviews describe AR as offering unique affordances for contextualized and interactive learning while also posing design and implementation challenges such as cognitive overload, novelty effects, and usability barriers (Wu et al., 2013), (Radu, 2014). Recent meta-analytic work reports overall positive effects of AR on learning outcomes, with effect magnitude moderated by subject area, educational level, treatment duration, and AR affordances (Chang et al., 2022), (Howard & Davis, 2023). In K–12 STEM contexts, systematic reviews emphasize both opportunities (improved engagement and visualization) and constraints (device access, distraction, operational issues) (Jiang et al., 2025), (Vidak et al., 2024).

Multimedia learning and cognitive load

The educational value of AR visualizations can be framed using the Cognitive Theory of Multimedia Learning (CTML), which posits that learners process information through dual channels with limited capacity and that meaningful learning requires active processing. CTML implies that AR may support conceptual understanding by providing integrated visualizations that reduce the need for learners to mentally animate static diagrams. However, CTML also predicts that poorly designed multimedia can overload working memory and reduce learning. Cognitive Load Theory (CLT) similarly emphasizes that instructional design should manage working memory load by reducing extraneous load and optimizing germane load for schema construction (Sweller, 2020). In AR settings, extraneous load can emerge from interface complexity, tracking instability, and split attention between real and virtual elements. Accordingly, an AR handbook should adopt coherence, signaling, and spatial/temporal contiguity principles (Sweller, 2020).

AR for physics learning and magnetism

Physics is a natural domain for AR because many concepts require spatial reasoning and dynamic visualization. Within magnetism instruction, Cai et al. reported that an AR-based learning environment for magnetic field instruction improved students' learning and attitudes compared with traditional tools (Cai et al., 2017). Abdusselam and Karal found that augmented reality and sensing technology (MagAR) supported academic achievement and student views in high school magnetism learning (Abdusselam & Karal, 2020). A recent systematic review highlights both opportunities and challenges of AR in physics teaching, emphasizing the importance of alignment between AR affordances and learning objectives (Vidak et al., 2024).

Usability and acceptance of AR learning tools

Usability can determine whether students will adopt AR tools for self-study revision. The System Usability Scale (SUS) is a widely used standardized questionnaire for quick usability assessment (Brooke, 1996). Interpretive frameworks link SUS scores to qualitative adjective ratings to support communication with educators and stakeholders (Bangor et al., 2009), and prior work discusses SUS factor structure considerations (Lewis & Sauro, 2009). From an acceptance perspective, the Technology Acceptance Model (TAM) suggests that perceived usefulness and perceived ease of use shape intention to use and actual usage behavior (Davis, 1989).

MATERIALS & METHODS

Study context and participants

The study was conducted at Bac Son High School, Thai Nguyen, Vietnam, with Grade 12 students during the magnetism revision period. Participants were recruited from two intact Grade 12 classes (N = 127). One class was assigned to the AR-supported revision condition (n = 64) and the other to the comparison condition using conventional revision resources (n = 63). Participant ages were 17–18 years, consistent with Grade 12 enrollment. All participants had access to an Android smartphone either personally or within their household.

Intervention: Printed AR handbook and mobile application

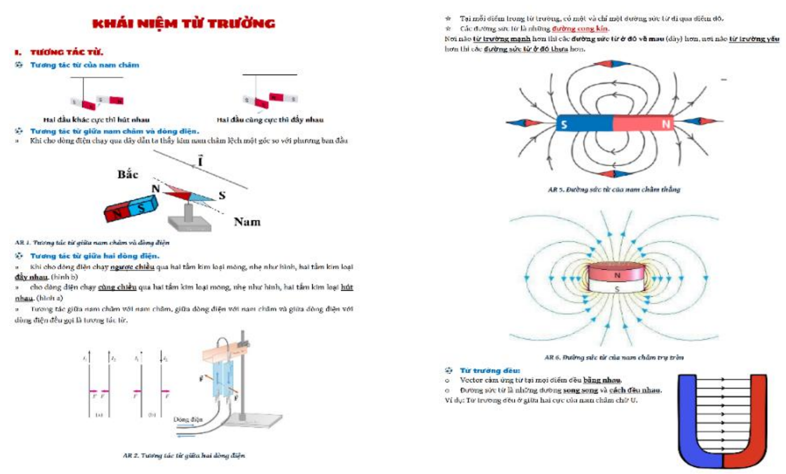
Instructional design rationale

The intervention was designed as a hybrid learning resource that combines a printed pocket handbook with a marker-based mobile AR application. The printed format provides portability, quick scanning of key rules, and easy annotation. The AR layer provides optional interactive visualization or short videos at points where static diagrams commonly fail to support spatial reasoning. This design is consistent with CTML and CLT principles, aiming to reduce unnecessary mental animation and minimize extraneous cognitive load (Sweller, 2020).

Content scope and AR marker mapping

The handbook is aligned with core Grade 12 outcomes on magnetic fields and includes 14 AR markers (AR1–AR14) embedded next to relevant content items. The content covers magnetic interactions; the definition of magnetic field and iron-filings patterns; magnetic induction and field-line properties; field lines of special conductors (straight wire, circular loop, solenoid); and the Earth's magnetic field. The companion project documentation describes the intended learning value and mobile-app workflow (scan a printed marker to display a corresponding 3D model or experiment video).

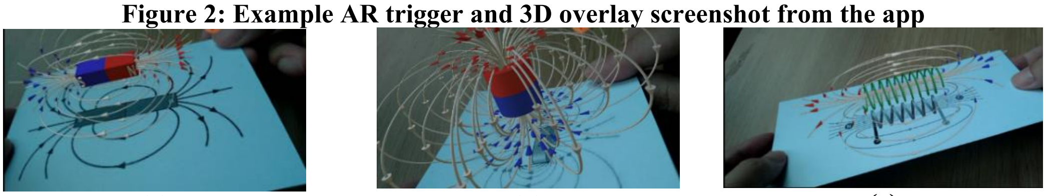
Figure 1: Overview of handbook structure and AR marker locations



AR interaction design

When students open the AR application on an Android phone and scan a marker image in the handbook, the app displays either (i) a 3D visualization (e.g., field lines around a wire/loop/solenoid) that can be observed from different angles or (ii) a short instructional video demonstrating the corresponding concept. Marker-based AR was chosen for practical school deployment because it reduces hardware requirements beyond the smartphone camera and can be used in self-study settings.

Figure 2: Example AR trigger and 3D overlay screenshot from the app



(a) **(b)** **(c)**

Research design and procedure

A quasi-experimental pre-test/post-test design was used. The intervention lasted two weeks and included four guided revision sessions (45 minutes each) plus optional home self-study. Both groups studied the same curriculum topics and were allocated comparable study time; the key difference was access to the AR handbook and app.

Procedure timeline:

1) Orientation (Day 1): the AR group received a 10-minute orientation on how to use the app and scan markers; the comparison group received standard instructions for printed revision materials.
2) Pre-test (Day 1): all participants completed a pre-test on magnetic field concepts (25 items).
3) Revision sessions (Weeks 1–2): students revised magnetism topics during scheduled revision periods; the AR group used the handbook and app, while the comparison group used conventional notes/handouts and textbook diagrams.

4) Post-test (End of Week 2): all participants completed the post-test (parallel form; same blueprint).
5) Survey (immediately after post-test): the AR group completed SUS and short open-ended perception items (Brooke, 1996).

INSTRUMENTS

Learning achievement test

A curriculum-aligned achievement test was developed to assess conceptual understanding and application in magnetic field topics. The test comprised 25 multiple-choice items (score range: 0–25) targeting direction rules, field geometry, and interpretation of field representations. Content validity was supported by alignment to Grade 12 learning outcomes and review by two physics teachers at Bac Son High School.

System Usability Scale (SUS)

Usability of the AR application was measured with the 10-item System Usability Scale (SUS), scored on a 0–100 scale according to standard procedures (Brooke, 1996). Interpretation drew on published guidance linking SUS scores to qualitative adjective ratings (Bangor et al., 2009).

Learner feedback

Two open-ended items captured student perceptions beyond usability (most helpful AR topic and operational difficulties). Responses were summarized using lightweight thematic coding suitable for classroom evaluation.

STATISTICAL ANALYSIS

Data were analyzed using IBM SPSS Statistics 26. Descriptive statistics (mean, standard deviation) were computed for pre-test and post-test scores and SUS. Group differences were examined using independent-samples t-tests for baseline equivalence and ANCOVA for post-test comparison (post-test as dependent variable; group as factor; pre-test as covariate). Within-group improvement was examined using paired-samples t-tests. Effect size was reported as Cohen's d for between-group post-test differences and partial η^2 for ANCOVA (Cohen, 2013). Significance level was set at $\alpha = 0.05$.

RESULT

Participant overview and baseline equivalence

A total of N = 127 Grade 12 students participated (AR group: n = 64; comparison group: n = 63). Baseline performance on the 25-item pre-test was equivalent between groups (AR: 11.9±2.8; comparison: 11.8±2.9; t (125) =0.24, p=0.81).

Table 1. Learning achievement results (25-item test).

Outcome	Group	N	Mean	SD	Test	p-value	Effect size
Pre-test	AR	64	11.9	2.8	t (125) =0.24	0.81	d=0.04
Pre-test	Comparison	63	11.8	2.9			
Post-test	AR	64	19.1	2.6	ANCOVA F (1,124) =18.3	<0.001	partial η^2=0.13
Post-test	Comparison	63	17.2	2.8			

Learning outcomes

Both groups improved from pre-test to post-test, but the AR-supported group demonstrated a larger gain (Δ=7.2 points) than the comparison group (Δ=5.4 points). ANCOVA indicated a significant group effect on post-test scores after controlling for baseline performance (F (1,124) =18.3, p<0.001; partial η^2=0.13). The between-group effect size on post-test scores was d=0.70 (medium-to-large).

Sub-analysis by concept cluster (direction rules; field-line geometry; iron-filings patterns and models; Earth's magnetic field) suggested that AR support provided the strongest advantage for interpreting field-line direction using right-hand rules and for comparing field patterns across conductor geometries.

Usability (SUS) and learner perceptions

Students in the AR group completed SUS after four sessions of use. The mean SUS score was 82.6 (SD=9.1; range: 55–97), corresponding to an "Excellent" usability rating according to Bangor et al. (Bangor et al., 2009).

Table 2. System Usability Scale (SUS) results.

Metric	N	Mean	SD	Min–Max
SUS score (0–100)	64	82.6	9.1	55–97

Qualitative feedback suggested three recurrent themes: (1) visibility of the invisible - AR helped students compare field patterns and direction across cases; (2) just-in-time clarification - markers placed next to concise printed notes enabled quick access to visualization; and (3) operational constraints some students reported lighting or camera focus issues during scanning.

DISCUSSION

The study aimed to design and evaluate a printed AR handbook for Grade 12 revision of magnetic field concepts in a real school setting. The results suggest that integrating marker-based AR visualizations and short videos into a compact printed handbook can support magnetism learning and yield high usability for student self-study.

Interpreting learning effects

The observed performance advantage for AR-supported revision is consistent with meta-analytic evidence that AR can improve learning outcomes when designs are instructionally aligned (Chang et al., 2022), (Howard & Davis, 2023). A plausible mechanism is representational alignment: magnetic fields are inherently spatial, and AR can reduce the need to mentally animate static diagrams by providing manipulable visualization. This explanation is consistent with CTML and CLT predictions about the benefits of well-integrated multimedia and the risks of extraneous cognitive load (Sweller, 2020).

Findings indicating stronger gains for direction-rule interpretation and pattern comparison align with prior AR magnetism studies in which interactive visualization supported understanding (Cai et al., 2017), (Abdusselam & Karal, 2020).

Usability, acceptance, and classroom feasibility

Usability results matter because revision tools are adopted voluntarily in self-study contexts. SUS provides a robust benchmark for interactive systems (Brooke, 1996), and adjective ratings support communication with educators and stakeholders (Bangor et al., 2009). From an acceptance perspective, TAM predicts that perceived usefulness and ease of use shape intention to use (Davis, 1989). Student feedback indicating direct usefulness for difficult topics supports the practicality of the printed–AR hybrid format for exam-oriented revision.

Limitations and future work

Limitations include the single-school setting, quasi-experimental assignment with intact classes, and focus on short-term outcomes. Future research should examine delayed retention, transfer to novel problems, and links between AR usage frequency and learning gains. Iterative refinement of marker design, asset complexity, and offline caching may further improve robustness and reduce operational barriers.

CONCLUSION

This paper presented the design and classroom evaluation of a marker-based AR handbook to support Grade 12 revision of magnetic field concepts at Bac Son High School (Thai Nguyen, Vietnam). The hybrid format—portable printed notes augmented by optional 3D and video explanations—addresses a central challenge in magnetism learning: building accurate spatial mental models of invisible fields. The classroom evaluation indicated improved learning performance for AR-supported revision alongside usability that supports student adoption. Printed AR resources may provide a low-cost and scalable complement to traditional revision materials when AR content is tightly aligned with learning objectives and designed to manage cognitive load.

Declaration by Authors

Acknowledgement: The authors thank the Physics teachers and Grade 12 students of Bac Son High School for their cooperation.

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

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How to cite this article: Hieu Tran Quang, Uyen Hoang Tu, Vy Pham Tra. Design and classroom evaluation of a marker-based augmented reality handbook for magnetic field revision in grade 12 Physics: Evidence from Bac Son High School, Thai Nguyen, Vietnam. *International Journal of Research and Review*. 2026; 13(1): 439-445. DOI: *https://doi.org/10.52403/ijrr.20260142*

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