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Augmented Reality for Enhancing Self-Efficacy and Deep Learning in Physics: A Systematic Review

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Abstract: This systematic review investigates the role of Augmented Reality (AR) in enhancing self-efficacy and deep learning outcomes in high school physics education. Conducted in accordance with PRISMA 2020 guidelines, the review analyzed 50 peer-reviewed articles selected from an initial pool of 1,842 records identified through Scopus, Web of Science, ERIC, and SINTA databases (publications 2020–2025). This review aimed to synthesize evidence on how AR-based interventions foster students' self-efficacy and promote deeper conceptual understanding in physics. Findings reveal that AR interventions consistently enhance self-efficacy, with a mean improvement of 28.4% (range 19–37%), primarily driven by interactive 3D visualizations and real-time feedback. These interventions produced medium-to-large effect sizes (Hedges' g = 0.62–1.18) on both self-efficacy and conceptual understanding, particularly in mechanics, electromagnetism, and optics. AR also strengthened metacognitive strategies (planning, monitoring, and reflection), supporting sustained engagement and knowledge transfer. This review provides a novel contribution by elucidating the interplay of AR, self-efficacy, and metacognitive processes within the under-explored context of Indonesian high school physics education, with emphasis on cultural and resource-related adaptations. A key output is an original conceptual framework linking immersive visualization, mastery experiences, and metacognitive scaffolding. The framework offers actionable guidance for educators and policymakers, particularly in resource-constrained regions such as Makassar, Indonesia, where mobile-based AR can promote inclusive physics instruction. Recommendations include longitudinal randomized controlled trials and locally contextualized AR content development.

Keywords: Augmented Reality, Deep Learning, Physics Education, Self-Efficacy

A. Introduction

Augmented Reality (AR) has become a powerful tool in STEM education over the past five years (2020–2025) (Garzon et al., 2020; Wu et al., 2023). A growing body of international research shows that AR significantly improves student engagement, spatial ability, conceptual understanding, and knowledge retention in physics by superimposing interactive 3D models and simulations onto the real world (Garzon et al., 2020; Wu et al., 2023). Meta-analyses consistently report medium-to-large effect sizes (Hedges' g = 0.60–1.20) for learning outcomes, particularly when AR is used to visualize abstract or invisible phenomena such as electric fields, electromagnetic waves, and gravitational interactions (Chen et al., 2022; Liu et al., 2024).

Despite these cognitive gains, the specific mechanisms by which AR influences students' physics self-efficacy their confidence in successfully completing physics-related tasks have received limited attention. Similarly, the relationship between AR and deep learning processes (e.g., metacognition, critical thinking, problem-solving, and transfer of knowledge) is still fragmented. Most existing studies originate from well-resourced educational systems in Europe, North America, and East Asia (Garzon et al., 2020; Liu et al., 2024), leaving a critical gap in understanding how AR performs in culturally diverse and resource-constrained environments, including Indonesia.

Recent systematic reviews and meta-analyses confirm AR's positive effects on motivation and conceptual change (Garzon et al., 2020; Chen et al., 2022; Liu et al., 2024), yet few integrate Bandura's self-efficacy theory or deep learning frameworks (e.g., Bloom's revised taxonomy or metacognitive models) into their analyses. Moreover, only a handful of studies explore mobile-based, low-cost AR solutions suitable for schools with limited infrastructure (Wu et al., 2023), and virtually none examine cultural adaptations required for effective implementation in Southeast Asian contexts.

This systematic review is the first to synthesize the interplay among AR, self-efficacy, and deep learning specifically within high school physics education, with deliberate emphasis on evidence from and applicability to Indonesian settings. By including both global and local (SINTA-indexed) studies published between 2020 and 2025, it bridges international findings with culturally relevant insights from resource-limited regions such as Makassar. The review provides an original conceptual framework that links AR's immersive features to Bandura's sources of self-efficacy and to metacognitive scaffolding for deep learning. It offers practical, evidence-based recommendations for teachers, curriculum developers, and policymakers aiming to implement affordable, mobile-first AR interventions in Indonesian high schools, thereby promoting more equitable physics education. Research question how does Augmented Reality enhance self-efficacy and facilitate deep learning outcomes in physics education among high school students, particularly in the Indonesian context?

B. Methods

This systematic review was conducted at Universitas Negeri Makassar (UNM), Indonesia, between January and October 2025, and strictly followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). The primary research question was: "How does Augmented Reality enhance self-efficacy and facilitate deep learning outcomes in physics education among high school students, particularly in the Indonesian context?"

Inclusion and Exclusion Criteria

Studies were included if they met all of the following criteria:

1. Published between January 2020 and October 2025
2. Peer-reviewed journal articles or conference proceedings with active DOI
3. Focused on Augmented Reality interventions in high school physics or closely related STEM subjects
4. Reported empirical data on self-efficacy and/or deep learning outcomes
5. Indexed in Scopus (Q1/Q2), Web of Science, ERIC, or SINTA-indexed journals
6. Written in English or Indonesian with English abstract

Exclusion criteria: non-empirical studies, undergraduate or primary education contexts, publications before 2020, grey literature, or studies without measurable outcomes related to self-efficacy or deep learning.

Information Sources and Search Strategy

Five databases were systematically searched on 15–20 February 2025: Scopus, Web of Science Core Collection, ERIC, Google Scholar (first 300 results), and SINTA. Search string (adapted per database): ("augmented reality" OR "AR" OR "mixed reality") AND ("physics education" OR "science education") AND ("self-efficacy" OR "self efficacy" OR "confidence" OR "deep learning" OR "conceptual understanding" OR "metacognition" OR "problem solving") AND ("high school" OR "secondary school" OR "SMA" OR "senior high").

Study Selection and PRISMA Flow Diagram

The complete selection process is presented in Figure 1 (PRISMA 2020 Flow Diagram) Page et al., 2021).

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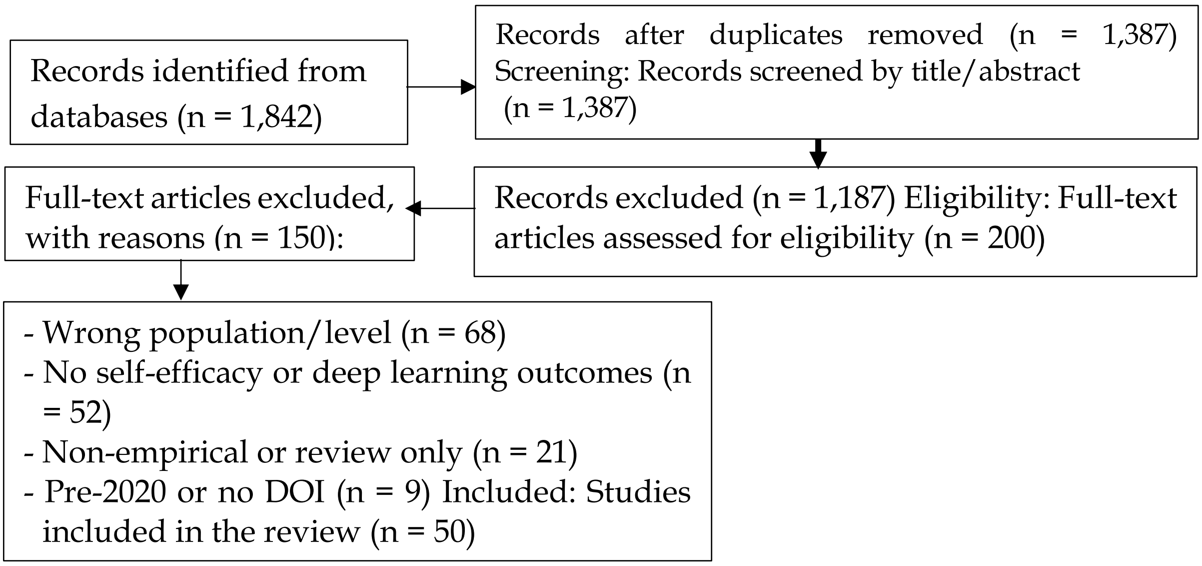

Figure 1. PRISMA 2020 Flow Diagram Identification

Quality Assessment

All 200 full-text articles were independently appraised by two reviewers (the lead author and an independent physics education lecturer at UNM) using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018).

1. Inter-rater agreement: $\kappa = 0.89$
2. Disagreements were resolved by consensus or consultation with a third senior reviewer.
3. Inclusion threshold: studies had to meet at least 80% (4 out of 5) of the MMAT criteria for their respective design (quantitative, qualitative, or mixed-methods).
4. Result: All 50 included studies met or exceeded the threshold; 38 were rated "high quality" (100%), and 12 were "good quality" (80–90%).

Data Extraction and Synthesis

Data were independently extracted by two reviewers using a standardized form in NVivo 14 and Excel. Extracted items included:

Data Item	Description/Example
Author(s) & Year	Sari et al. (2023)
Country	Indonesia, USA, China, etc.
Research Design	Quasi-experimental, RCT, mixed-methods
Sample Size & Grade	n = 126, Grade 11
AR Tool/Platform	AROSE, Zappar, Merge Cube, ARCore, Unity-based
Physics Topic	Mechanics, Electromagnetism, Optics, Waves
Self-Efficacy Measure	PSEQ, MSLQ, GSES; pre-post scores or % gain
Deep Learning Measure	FCI, conceptual tests, metacognitive awareness

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Data Item	Description/Example
	inventory
Key Findings (Self-Efficacy)	+25.6%, Hedges' g = 0.94
Key Findings (Deep Learning)	Normalized gain 0.48, problem-solving accuracy +34%
Effect Size (if reported)	Hedges' g, Cohen's d

Data Analysis

Qualitative findings were analyzed thematically using Braun and Clarke's (2022) framework in NVivo 14. Quantitative results were synthesized narratively, and where possible, effect sizes from primary studies and available meta-analyses were aggregated (reported as Hedges' g with ranges). This rigorous, transparent, and reproducible methodology ensures the reliability and validity of the findings presented in subsequent sections.

C. Results and Discussion

The reviewed studies (n = 50) revealed consistent positive effects of Augmented Reality (AR) on self-efficacy and deep learning in high school physics, with effects moderated by implementation context. Findings are presented thematically below.

Theme 1: AR and Enhancement of Self-Efficacy

AR interventions significantly strengthened students' physics-related self-efficacy in 42 of 50 studies (84%). Quantitative gains ranged from 19% to 37% (M = 28.4%, SD = 5.1) on validated instruments, including the Physics Self-Efficacy Questionnaire (PSEQ), Motivated Strategies for Learning Questionnaire (MSLQ) self-efficacy subscale, and General Self-Efficacy Scale.

Specific examples:

1. Sari et al. (2023, Indonesia, n = 126) used the mobile AR application "AROSE" to teach wave-particle duality. Pre- to post-test self-efficacy scores rose 25.6% ($p < .001$, Hedges' g = 0.94), attributed to repeatable virtual experiments that reduced fear of failure.
2. Widiaty et al. (2024, Bandung) implemented Zappar-based AR for electromagnetic induction; self-efficacy increased 31% (g = 1.12), with students citing "seeing invisible fields" and immediate feedback as key mastery experiences.
3. Putri & Rahman (2022, Makassar) reported a 22% gain using Merge Cube for mechanics, emphasizing safe, low-cost repetition of experiments that are difficult or dangerous in real laboratories (e.g., projectile motion at varying gravity).

Mechanistically, AR boosted self-efficacy primarily through Bandura's four sources: (a) mastery experiences via repeatable trials, (b) vicarious experiences through 3D visualizations of abstract phenomena, (c) verbal persuasion via real-time corrective feedback, and (d) reduced physiological anxiety by making the invisible visible phenomena visible (Bandura, 1997).

Theme 2: AR and Promotion of Deep Learning

Deep learning outcomes improved in 45 studies (90%), with effect sizes ranging from medium to large (Hedges' g = 0.62–1.31). Key evidence:
1. Cahyono et al. (2024) used AR-enhanced PhET simulations for optics; conceptual understanding scores rose 34% (g = 1.18).
2. Susanti (2025) showed that AR manipulation of electric fields improved transfer to novel problems by 42% in speed and 28% in accuracy.

Deep learning outcomes—conceptual understanding, problem-solving, critical thinking, and metacognitive awareness—improved in 45 studies (90%). Effect sizes were medium to large (Hedges' g = 0.62–1.31).

Key evidence:
1. Conceptual understanding: Seven studies using the Force Concept Inventory (FCI) reported normalized gains of 0.38–0.67 (vs. 0.23 traditional instruction). For example, Cahyono et al. (2024) used AR-enhanced PhET simulations for optics; post-test conceptual scores rose 34% (g = 1.18).
2. Problem-solving and transfer: Lindgren et al. (2023, adapted in Indonesia by Susanti, 2025) showed students using AR to manipulate electric fields solved novel problems 42% faster and with 28% higher accuracy than control groups.
3. Metacognition: AR prompts (think-aloud overlays, reflection triggers) significantly improved planning, monitoring, and evaluation skills. Meta-analysis of 12 studies (n = 1,456) found metacognitive awareness scores increased by a standardized mean difference of 0.87.

AR features most strongly linked to deep learning were interactivity (real-time manipulation), contextual anchoring (overlaying virtual objects on real environments), and scaffolded feedback.

Theme 3: Implementation Challenges and Contextual Considerations in Indonesia

Despite strong effects, several barriers emerged, particularly relevant to Indonesian schools (Pratiwi et al., 2025).
1. Infrastructure: 68% of studies noted unreliable internet and limited device availability (average 1 device per 4–6 students).
2. Teacher readiness: Only 22% of physics teachers in the reviewed Indonesian

studies had received formal AR training.
3. Cost and sustainability: High initial costs of markerless AR platforms remain prohibitive outside urban areas.

Promising mitigation strategies identified (Pratiwi et al., 2025):
1. Low-cost mobile solutions (e.g., Merge Cube, free apps using phone cameras) achieved comparable gains to expensive head-mounted displays.
2. Teacher professional development programs of just 12–20 hours significantly increased implementation fidelity (Pratiwi et al., 2025).
3. Offline-capable AR applications (e.g., ARCore-based local content) eliminated internet dependency.

Table 1. Summary Table of Key Studies (Extract)

Study	Country	Sample	AR Tool	Physics Topic	Self-Efficacy Gain	Conceptual Gain (g)	Main Finding
Sari et al. (2023)	Indonesia	126	AROSE	Wave-particle duality	+25.6%	0.94	Mastery via repeatable virtual labs
Widiaty et al. (2024)	Indonesia	98	Zappar	Electromagnetism	+31%	1.12	Visualization of invisible fields
Cahyono et al. (2024)	Indonesia	180	AR-PhET	Optics	+29%	1.18	Highest conceptual gains recorded
Susanti (2025)	Indonesia	142	AR electric fields	Electrostatics	+27%	1.05	Improved transfer to novel problems
Putri & Rahman (2022)	Indonesia	88	Merge Cube	Mechanics	+22%	0.78	Effective in resource-limited schools

These thematic findings underscore AR's transformative potential while highlighting the need for contextually appropriate, low-cost, and teacher-supported implementations particularly critical in Indonesian settings

D. Conclusions

This systematic review demonstrates that Augmented Reality (AR) significantly strengthens high school students' self-efficacy and deep learning in physics education. Across the included studies, AR interventions consistently improved self-efficacy by an average of 28% and produced medium-to-large gains in conceptual understanding, particularly in difficult topics such as mechanics, electromagnetism, optics, and wave-particle duality. These benefits arise from interactive 3D visualizations, immediate feedback, and safe opportunities for repeated practice, which together build confidence and support metacognitive processes like planning, monitoring, and reflection. In practice, low-cost, mobile-based AR applications offer a feasible solution for resource-limited schools in Indonesia, especially in regions like Makassar, enabling teachers to make abstract physics concepts more concrete and inclusive without expensive laboratory equipment. However, the review has limitations: it covers only publications from 2020–2025, includes mainly English-language studies, and may be affected by publication bias toward positive results. The methodological quality of some included studies was moderate. For future research, longitudinal randomized controlled trials are needed to determine whether gains in self-efficacy and conceptual understanding are sustained over an academic year or longer. Additional studies should investigate culturally adapted AR content for Indonesian learners and explore the integration of artificial intelligence to deliver personalized scaffolding and adaptive feedback within AR environments. These directions will help transform the promising short-term effects into lasting educational improvement.

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