The Effectiveness of AR Technology in Chemistry Education: A Meta-Analysis Based on 14 Chinese Studies

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Abstract: *Augmented reality (AR) technology, with its multidimensional visualization and interactive features, offers innovative solutions for presenting abstract concepts in chemistry education. This study conducted a meta-analysis to systematically evaluate the effectiveness of AR technology in chemistry education in China, incorporating 14 empirical studies. The results indicate that AR technology has a significant, moderate positive effect on chemistry learning outcomes (g = 0.502, 95% CI [0.348, 0.656]). Further analysis revealed that educational level was the only variable with a significant moderating effect, while the remaining variables did not show significant heterogeneity.*

Keywords: *augmented reality (AR), chemistry education, meta-analysis*

1. Introduction

Augmented reality (AR) has opened up new avenues for chemistry education by visualizing abstract concepts and simulating experiments. However, its overall effectiveness in classroom instruction in China remains unclear. This meta-analysis systematically reviews empirical studies conducted in China to assess the impact of AR on chemistry learning outcomes and identify key moderating variables, such as educational level and instructional design, thereby providing evidence-based guidance for the effective integration of AR in the Chinese educational context.

2. Method

Based on a systematic search strategy, this study comprehensively collected relevant literature from multiple Chinese and English databases. Following a rigorous screening process and predefined inclusion and exclusion criteria, 14 high-quality studies meeting the criteria were ultimately included, comprising a total of 34 independent effects and 1,199 participants. The included studies were systematically coded across multiple dimensions, including educational level, intervention duration, and learning content, to analyze their characteristics. During the data analysis phase, a random-effects model and Hedges' g effect size were employed for the meta-analysis. Publication bias was comprehensively assessed using funnel plots, Egger's regression test, and Rosenthal's safety margin. The results indicated that no significant publication bias was detected in any of the tests, confirming the robustness and reliability of the meta-analysis findings.

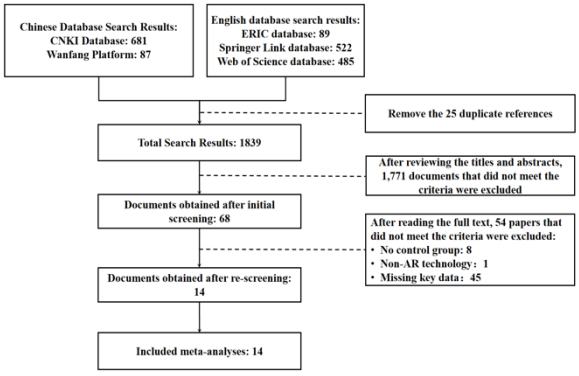

Figure 1 *Literature screening process*

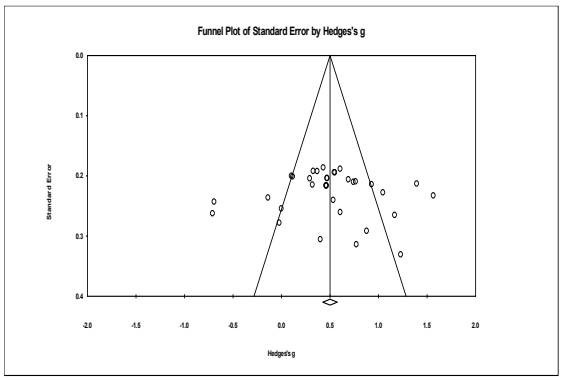

Figure 2 *Forest plot for meta-analysis*

3. Results and Discussion

The meta-analysis results indicate that the use of augmented reality (AR) in chemistry instruction is significantly associated with higher student learning outcomes ($g = 0.502$, $p < 0.05$). This finding aligns with existing research suggesting that AR plays a positive role in chemistry education (Song et al., 2025), further confirming that AR technology has a certain degree of promotional effect in chemistry instruction. Specifically, augmented reality helps learners intuitively understand abstract chemical concepts, thereby enhancing knowledge acquisition and the learning experience (Liu et al., 2023).

Among the moderating variables, only educational stage exhibited a significant moderating effect. The effect size for junior high school students ($g = 0.633$) was significantly higher than that for high school students ($g = 0.284$), indicating that AR has a more pronounced promotional effect on younger learners. According to cognitive development theory, junior high school students are in the formal operational stage and are capable of abstract logical reasoning. However, they face certain challenges in understanding abstract chemical concepts, and their thinking still relies on concrete experiences and intuitive support. The visual representations provided by AR play a crucial role in the learning of students at this stage. In contrast, high school students have already developed preliminary formal operational abilities and are capable of abstract thinking and hypothetical-deductive reasoning; therefore, their reliance on purely intuitive support may be relatively lower.

Although there were differences in other variables—such as source of literature, duration of intervention, class size, learning content, learning outcomes, and teaching methods—none of these differences reached statistical significance. Overall, these results suggest that the effectiveness of AR is influenced by multiple contextual factors, but its positive impact remains generally stable and reliable.

4. Conclusion

This meta-analysis, based on 14 empirical studies conducted in China, systematically evaluated the effectiveness of augmented reality (AR) technology in chemistry education. The results indicate that AR technology has a moderate positive effect on chemistry learning outcomes. Among all moderating variables, only educational level exhibited a significant moderating effect, with the effect being significantly stronger among junior high school students than among senior high school students. In contrast, variables such as source of literature, duration of intervention, class size, learning content, type of outcomes, and teaching methods did not exhibit significant heterogeneity. Overall, AR technology demonstrates clear potential for application in chemistry education, with a particularly strong positive effect on junior high school students.

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References

Liu, Q., Ma, J., Yu, S., Wang, Q., & Xu, S. (2023). Effects of an augmented reality-based chemistry experiential application on student knowledge gains, learning motivation, and technology perception. Journal of Science Education and Technology, 32(2), 153–167.

Song, Q., Li, M., Zhang, Z., & Zhou, Q. (2025). Learning effectiveness of virtual technologies in chemistry using a three-level meta-analysis. Education and Information Technologies, 30(11), 14737–14759.