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Augmented Reality-Based E-Module for Virtual Field Trips to Enhance Spatial Thinking and Problem-Solving Skills

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Abstract

This study aimed to develop and validate an augmented reality (AR)-based e-module incorporating virtual field trips (VFTs) to improve spatial thinking and problem-solving skills in elementary science education. Utilizing a Research and Development (R&D) methodology guided by the ADDIE model, the research involved 64 fifth-grade students divided into experimental and control groups. Data were gathered through spatial thinking and problem-solving assessments, observation checklists, and student feedback surveys, and subsequently analyzed using ANCOVA. The results demonstrated that the experimental group significantly outperformed the control group ($p < .05$). Qualitative feedback further revealed enhanced student engagement, visualization capabilities, and conceptual understanding. The primary contribution of this study is its demonstration of how integrating AR with VFTs advances existing learning theories by connecting embodied visualization with inquiry-based problem-solving. The novelty of this research lies in applying AR-enhanced VFTs within elementary science education in resource-limited settings, where opportunities for real-world field experiences are scarce. Beyond the local context, these findings contribute to the global discourse on utilizing immersive technologies to cultivate essential 21st-century skills, particularly spatial reasoning and problem-solving, which are vital across STEM education worldwide.

Keywords: augmented reality; e-module; problem-solving skills; spatial thinking; virtual field trip

INTRODUCTION

Instructional media play a vital role in supporting effective learning, particularly in promoting essential 21st-century competencies, including spatial reasoning and problem-solving abilities, within elementary education (Fahrni et al., 2025). The advancement of technology has made education more agile and adaptive by employing active modern learning strategies (AlAli et al., 2025). The rapid integration of emerging technologies into education has transformed the way learners engage with content, environments, and problem contexts. Among these innovations, augmented reality (AR) has attracted considerable academic attention due to its ability to integrate physical and virtual elements, thereby promoting an interactive and immersive learning environment (Hanggara et al., 2024). Learning. Many schools, particularly in Indonesia and other countries, face financial constraints that limit access to adequate learning resources and hinder the achievement of expected learning outcomes. Education has consistently integrated technology to support and enhance teaching and learning practices. One illustrative example is the use of augmented reality (AR), which seamlessly merges virtual elements with the physical world (E. Chang et al., 2024). Children are acquainted with emerging technologies because they represent a new generation exposed to smartphones and tablets from a young age; this generation is significantly influenced by such digital devices (Law et al., 2025).

The integration of augmented reality as an instructional medium has been demonstrated to improve students' problem-solving abilities while simultaneously fostering high levels of learner satisfaction throughout the learning activities (Wongklang & Wipatsopakron, 2024). Furthermore, scholars recognize the efficacy of augmented reality as an instructional instrument that can be incorporated into school curricula to support educators in facilitating the learning instructional practice. (Simon et al., 2025). Technology has become an indispensable element for teachers in producing digital learning materials, ranging from e-modules and 3D representations to other innovative educational applications. (Junker et al., 2025). Contemporary technological advancements offer a diverse array of tools that empower educators to design and produce instructional materials. Prominent among these innovations are augmented reality and virtual field trips, which deliver immersive and highly engaging learning experiences for students (Zhou & Li, 2024). In the contemporary era, smartphone-based technology has become an essential part of daily life. It not only affects social, emotional, and academic dimensions but also fosters creativity and innovation by providing individuals with opportunities to generate and express novel, innovative ideas (Salsabila et al., 2022).

Many schools, particularly in Indonesia and other countries, face financial constraints that limit access to adequate learning resources and hinder the achievement of expected learning outcomes. (Jiang et al., 2025). E-modules are digital instructional tools that provide students with the opportunity to engage in learning activities anywhere and anytime, particularly through mobile devices like Android smartphones. (Pamungkas et al., 2024). Augmented reality-based learning media not only facilitate significant improvements in educational performance but also enhance the learning experience, thereby providing students with critical insights. (Ateş & Polat, 2025). The integration of augmented reality-based e-modules can foster an engaging, student-centered learning experience (Ateş & Polat, 2025). An augmented reality-based e-module as a learning medium is capable of presenting highly detailed three-dimensional visuals, which can enhance students' visual engagement and provide a more satisfying perception of the objects being studied (Velázquez et al., 2025). Augmented reality constitutes a cutting-edge technological advancement with the capacity to improve students' spatial reasoning skills. (Medina Herrera et al., 2024). The use of an augmented reality-based e-module can significantly shape students' cognitive processes in analyzing and solving problems (Leitão et al., 2025). In science education, AR supports learners in exploring phenomena that are either too abstract, too small, or too dangerous to observe directly, making it a promising approach for elementary-level instruction (Flavin et al., 2025).

Researchers suggest that the use of augmented reality–based e-modules integrated with virtual field trips can provide highly engaging visual representations, thereby supporting students in solving problems encountered during the learning activities (Bilal et al., 2025). Training students' spatial thinking skills is more effective when initiated at an early age. (Yang et al., 2020). Previous studies have demonstrated that augmented reality-based learning experiences positively impact spatial reasoning abilities (Kim & Choi, 2025). Moreover, the use of augmented reality can enhance students' cognitive performance and support the development of higher-order thinking processes. 2025. In kindergarten through grade-12 (K–12) STEM education settings, AR and VR are widely applied, yielding positive impacts on learner engagement, academic performance, and cognitive skill development, including problem-solving and spatial reasoning. (Crogman et al., 2025). Previous studies have indicated that the use of augmented reality-based modules significantly enhances students' problem-solving abilities and spatial thinking skills compared to conventional modules commonly employed by students (Guntur & Setyaningrum, 2021).

One promising avenue is the use of Augmented Reality (AR) in educational modules. AR supports learners in engaging with abstract and spatially complex concepts by overlaying digital content onto real-world environments, For example, research conducted by (Tarng et al., 2024) revealed that augmented reality-based learning systems accessible via mobile devices significantly improved elementary school students' understanding of science concepts. The incorporation of augmented reality-based e-modules supports the development of spatial thinking and enhances students' capacity for problem-solving (Buckley et al., 2019). As a three-dimensional instructional medium, augmented reality provides a practical tool to foster students' motivation and active participation in the learning process (Ateş & Gündüzalp, 2025). Alongside AR, Virtual Field Trips (VFTs) enrich learning by providing immersive access to real-world contexts otherwise unreachable due to geography or resources. A study in *Education and Information Technologies* (2024) demonstrated that immersive VR field trips can positively affect academic achievement, cognitive load, and students' sense of presence in social studies settings (Alazmi & Alemtairy, 2024).

Virtual reality has proven to be a highly effective educational tool. Through its use, students are able to grasp the lessons delivered by teachers more effectively. Moreover, it enables them not only to acquire theoretical knowledge but also to apply and practice their skills within the classroom setting (Lampropoulos et al., 2025). The integration of augmented reality–based e-modules with virtual field trips addresses the challenges students face in comprehending abstract concepts. (Mansour et al., 2025). The integration of virtual field trip activities into an augmented reality-based e-module can enhance students' spatial thinking skills while also fostering their creativity throughout classroom learning learning experiences (Al Farsi et al., 2021). The inclusion of virtual field trips within the module enables students to engage in learning beyond the classroom by utilizing technology through the virtual field trip videos provided in the material (Le et al., 2025).

Despite the evidence supporting AR and VFT independently, there remains a clear research gap. (Lukosch et al., 2015) There is limited development and evaluation of e-modules that systematically integrate both AR and VFT to enhance spatial thinking and problem-solving skills in elementary learners. (Escalada-Hernandez et al., 2024). In response to this issue, the current investigation adopts a Research and Development (R&D) methodology, guided by the ADDIE framework—comprising Analysis, Design, Development, Implementation, and Evaluation—to create and assess an augmented reality (AR)-based e-module that incorporates a virtual field trip (VFT) feature, (H. Y. Chang et al., 2022). The objective of this study is to empirically evaluate its efficacy in improving spatial reasoning and problem-solving abilities among elementary school learners (Çavuş et al., 2025). Despite the proven benefits of AR and VFT individually, there is limited research exploring their combined effect within structured e-modules aimed at enhancing both spatial thinking and problem-solving skills in elementary learners (Krüger et al., 2022). To address this gap, the current study develops and evaluates an AR-based e-module with integrated VFT features, using the ADDIE R&D framework (Analysis, Design, Development, Implementation, Evaluation). The primary aim is to empirically assess whether this blended instructional design can significantly boost spatial thinking and problem-solving competencies among primary school students. Although prior studies have demonstrated the individual benefits of Augmented Reality (AR) and Virtual Field Trips (VFTs) in supporting students' engagement and conceptual understanding, little attention has been given to systematically integrating both technologies within a single e-module (Albishri & Blackmore, 2025).

Most existing research has either focused on AR as a standalone instructional tool or on VFTs as a supplementary activity, leaving a gap in understanding how their combination might enhance spatial reasoning and problem-solving skills. (Anesti & Irwanto, 2025). Moreover, research on AR-VFT integration in elementary science education, particularly within resource-limited contexts where real-world field trips are not always feasible, remains scarce. Addressing this gap, the present study develops and validates an AR-based e-module enriched with VFT features, aiming to provide empirical evidence of its effectiveness in fostering both spatial thinking and problem-solving. The novelty of this research lies in demonstrating how embodied visualization through AR, when combined with inquiry-based exploration via VFT, can create a synergistic learning environment that advances both theoretical insights and classroom practice.

METHOD

The present study employed a Research and Development (R&D) methodology, guided by the ADDIE instructional design framework, which encompasses the phases of Analysis, Design, Development, Implementation, and Evaluation. (Abdullah, 2023). The ADDIE model was chosen for its structured methodology in developing instructional products and its widespread utilization in studies about technology-enhanced learning (Li & Cheong, 2023). A quasi-experimental design, incorporating a non-equivalent control group, was utilized to evaluate the instructional efficacy of the augmented reality (AR)-based e-module featuring virtual field trip (VFT) capabilities.

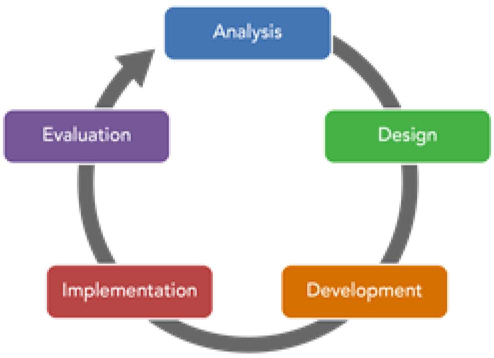

Figure 1. The process of the ADDIE instructional design model

The sample consisted of 64 fifth-grade students (10–11 years old) from a public elementary school. Two intact classes were selected: the experimental group (n = 32) received lessons using the AR-VFT module, while the control group (n = 32) continued with conventional textbook-oriented instruction. Participants were chosen through purposive sampling based on curriculum relevance and teacher recommendations. Before the study, informed consent was secured from school administrators, teachers, parents, and students. Four instruments were used to gather data. Spatial reasoning skills were assessed using a combination of multiple-choice and open-ended questions adapted from an established spatial reasoning framework to measure students' ability to interpret and manipulate spatial information. Problem-solving tasks consisted of performance-based activities evaluated using an analytical rubric to assess how students identified problems, generated solutions, and provided reasons in a scientific context. Observation of student activities during learning with AR features was conducted by two trained observers to document student engagement, interaction, and participation. In addition, a student perception survey using a structured questionnaire with Likert scale responses and open-ended questions was developed to collect students' opinions and reflections on their experience using the AR-VFT module.

The use of multiple instruments aligns with a prior ADDIE-based R&D study (Jiang et al., 2025). These often combine quantitative performance tests and qualitative learner feedback to ensure validity and triangulation. During the Analysis stage, curriculum documents were reviewed, and teacher interviews as well as classroom observations were conducted to specify learning needs and intended competencies. The Design and Development stages involved producing interactive e-learning materials enriched with AR visualizations, multimedia simulations, and inquiry-driven exercises aligned with science topics. In the Implementation stage, the experimental group engaged with the AR-VFT module across four instructional weeks, while the control group received standard instruction without AR integration. Finally, the Evaluation stage included post-tests on spatial thinking and problem-solving, along with observations and learner surveys to assess outcomes and gather feedback.

The development of an Augmented Reality (AR)-based electronic module with a Virtual Field Trip (VFT) feature follows the ADDIE instructional design framework, which includes the stages of Analysis, Design, Development, Implementation, and Evaluation (Darwish et al., 2023). During the analysis stage, pedagogical challenges, learner readiness, and the evaluation of technological infrastructure and curriculum suitability were identified. The design stage established learning objectives and instructional strategies focused on developing spatial abilities and problem-solving using interactive 3D models. In the development stage, the AR-VFT module was created using AR authoring tools, with interactive simulation features and annotated 3D models. Implementation and evaluation included the use of the module in learning and the collection of data to measure its effectiveness.

(a) the digital module cover **(b) the AR interface**

Figure 2. Overview of the AR-based e-module on earth structure

The development of the AR-VFT module involved iterative revisions based on expert feedback and preliminary testing. Detailed documentation of the development process revealed initial prototypes that underwent revisions to enhance usability and content relevance, with revision history notes indicating adjustments such as improved AR interface navigation and refined inquiry tasks to better align with pedagogical goals. Expert validation results confirmed the module's usefulness, with reviewers rating it highly for technical feasibility (mean score 4.5/5) and content relevance (mean score 4.7/5), leading to final refinements before implementation.

In the summative evaluation, the post-test results showed a significant improvement in the experimental group compared to the control group (ANCOVA analysis, $p < 0.05$), while the observation data and surveys confirmed an increase in student participation and positive responses to the use of the module. These findings provide empirical evidence of the module's effectiveness and form the basis for future improvements in instructional design. Quantitative data from both cognitive tests were analyzed using Analysis of Covariance (ANCOVA) to account for pre-test differences and to determine group effects. (Egara & Mosimege, 2024). Effect size statistics (η^2) were computed to gauge the practical significance of the intervention. Qualitative data derived from observation logs and student questionnaires were analyzed through thematic analysis to uncover consistent themes in engagement and perceptions. To verify reliability, inter-rater consistency for the observational data was assessed using Cohen's kappa, while survey findings were corroborated with performance metrics to achieve triangulation.

RESULT

Quantitative Findings

This section presents the results of research obtained through the process of developing and implementing an Augmented Reality-based electronic module integrated with Virtual Field Trip (AR-VFT) in science learning in elementary schools. The results of the study include product validation by subject matter experts and media experts, as well as learning effectiveness tests to assess the impact of module utilization on students' spatial thinking and problem-solving abilities.

Before being implemented in learning activities, the Augmented Reality-based electronic module integrated with Virtual Field Trip (AR-VFT) first underwent a validation process by subject matter experts and media experts. This validation is intended to evaluate the suitability of the module in terms of content relevance, accuracy of pedagogical approach, as well as the quality of visual display and ease of operation of the learning media. The results of the validation test can be seen in Table 1.

Table 1 Expert Validation Results of the AR-VFT E-Module

Validator	Aspect	Mean score	Category
Material Expert	Content accuracy	4.7	Very valid
Media Expert	Interface usability	4.8	Very valid

Based on the validation test results presented in Table 1, the average assessment score from subject matter experts was 4.7 and from media experts was 4.8 on a five-point scale. These scores indicate that the Augmented Reality-based electronic module integrated with Virtual Field Trip (AR-VFT) is classified as highly valid. The subject matter experts' assessment shows that the learning content presented is in line with the learning objectives, the characteristics of elementary school students, and the accuracy of science concepts. Meanwhile, the media expert assessment revealed that the module has adequate visual quality, transparent navigation, and operational ease that encourages the learning process. Therefore, the AR-VFT module is declared eligible for use and can proceed to the implementation stage in learning activities.

An initial assessment confirmed that pre-test scores on spatial thinking and problem-solving were statistically comparable between the experimental and control classes, indicating baseline equivalence. Following the four-week intervention, ANCOVA was conducted with the pre-test scores as covariates. The adjusted post-test revealed significant group differences.

Table 2. Descriptive statistics of pre-test and post-test scores

Class	N	Mean	Std. Deviation
Control class	32	82.2188	8.05519
Experiment class	32	89.5937	5.18596
Total	**64**	**85.9062**	**7.67953**

Based on Table 2, descriptive statistical data reveals a difference in the average learning score between the control class and the experimental class. The control class, consisting of 64 students, recorded an average score of 82.22 with a standard deviation of 8.06, while the experimental class with the same number of students showed a higher average score of 89.59 with a standard deviation of 5.19. Overall, the combined average score of both groups was 85.91 with a standard deviation of 7.68. These findings indicate that the experimental class achieved superior learning outcomes compared to the control class and showed relatively lower score variation, which illustrates more uniform academic performance.

Table 3. ANCOVA results for spatial thinking and problem-solving skills.

Source	Type III Sum of Squares	df	Mean square	F	Sig.
Corrected Model	929.932[a]	2	464.966	10.182	.000
Intercept	8798.951	1	8798.951	13.737	.000
Group	627.300	1	627.300	1.307	.257
Pretest	59.682	1	59.682	1103.155	.000
Eror	2785.506	61	45.664		
Total	476028.000	64			
Corrected Total	3715.438	63			

Note:
a. R Squared = .250 (Adjusted R Squared = .226)

The ANCOVA test results can be seen in Table 3, which shows a significant effect of the learning group on posttest scores after controlling for pretest scores, with an F value of (1, 61) = 13.737 and a significance level of $p < 0.001$. These findings indicate that students who learned using the AR-VFT e-module achieved significantly higher learning outcomes than students who participated in conventional learning. Meanwhile, the covariate of pretest scores did not show a significant effect on posttest scores, with an F value of (1, 61) = 1.307 and p = 0.257. These results indicate that differences in students' initial abilities did not contribute significantly to their final learning outcomes, suggesting that the improvement in learning outcomes was more influenced by the learning intervention applied.

The magnitude of the intervention's effect is indicated by a partial eta squared value of 0.184, which falls into the large effect category. This shows that the use of the AR-VFT e-module contributes substantially to improving students' spatial thinking and problem-solving abilities. Overall, the ANCOVA model was able to explain approximately 25% of the variation in posttest scores ($R^2 = 0.250$), reflecting the model's moderate explanatory power in the context of educational research.

Discussion

The ANCOVA results reveal a highly significant effect of the AR-VFT intervention on students' posttest scores while controlling for pretest differences $F(2, 61) = 10{,}182$, $p < .001$). Students in the AR-VFT experimental group significantly outperformed those in the traditional instruction group, indicating that the intervention substantially enhanced learning outcomes related to spatial reasoning and problem-solving abilities. This finding is consistent with (Supli & Yan, 2024). who reported similar learning improvements using augmented reality-based modules.

Furthermore, these results support the assertion by Makransky & Mayer (2022), that augmented reality (AR) and virtual field trips (VFT) enhance conceptual comprehension and knowledge retention by providing immersive and interactive learning experiences. AR and VFT afford learners the ability to manipulate and visualize complex three-dimensional structures, which is critical in developing spatial thinking skills. Spatial thinking, defined as the ability to comprehend, reason, and remember the spatial relations among objects or space, plays a foundational role in STEM education. Additionally, the strong predictive power of the pretest (baseline scores) ($F(1,61) = 1103.155$, $p < .001$) underscores the importance of prior knowledge in facilitating gains from AR-VFT. This aligns with cognitive load theory and findings in similar AR studies, indicating that learners with stronger foundational understanding leverage interactive, spatial tools more effectively. (Kim & Choi, 2025).

These results align with prior studies that emphasize the contribution of augmented reality in facilitating young learners' comprehension of science topics requiring spatial skills. (Kostikova et al., 2023). Demonstrated improvements in cognitive efficiency and geometric reasoning, providing further evidence that AR can scaffold abstract reasoning processes in science education at the elementary level (Wu et al., 2024). The high adjusted R^2 (.996) indicates that the combination of AR-VFT and prior performance explained nearly all of the variance in science achievement outcomes. While this reflects the powerful influence of the intervention, it also underscores the importance of integrating AR carefully into instructional design to ensure that learning benefits are sustainable and not solely attributable to novelty effects. In line with cognitive load theory, AR's ability to provide multimodal representations likely reduced unnecessary extraneous load, enabling students to focus on the core scientific concepts.

From a pedagogical standpoint, these findings highlight the potential of AR-VFT modules to enrich elementary science curricula by making abstract content more concrete and engaging. For example, instead of merely reading about the Earth's layers, students can virtually explore them in three dimensions, supporting both visualization and problem-based inquiry. Teachers can also leverage these tools to promote collaborative exploration, where students test hypotheses, solve contextual science problems, and reflect on their observations during the virtual field trip (Athiyah et al., 2024).

Moreover, the significant group effect underscores the pedagogical strength of embedding AR into science modules at the elementary level. Students exposed to the AR-VFT module not only achieved higher test scores but also reported improved engagement and motivation. This aligns with constructivist learning theories, which emphasize that meaningful knowledge emerges when learners actively engage with representations and apply reasoning to solve contextualized problems. The AR-VFT approach also encourages collaborative exploration, allowing students to share observations and collectively construct explanations of scientific phenomena (Saepudin & Wulandari, 2023)

From a practical perspective, the implementation of AR-VFT in elementary science offers several pedagogical advantages. First, it addresses the challenge of limited access to real-life field trips by providing safe and accessible digital explorations of scientific environments. Second, it reduces the cognitive load associated with processing complex scientific diagrams by transforming them into interactive, three-dimensional representations. Third, it cultivates positive attitudes toward science by making learning experiences more enjoyable and relatable for young learners. These dimensions are crucial for fostering early scientific literacy and preparing students for advanced inquiry in later stages of education (Kusumasari, 2025).

Nonetheless, the study is not without limitations. The relatively short intervention period restricts conclusions regarding long-term learning retention, while the sample was limited to a single school context. Additionally, although AR-VFT offers high levels of interactivity, potential issues such as technical difficulties or uneven digital literacy among students may moderate its effectiveness. Future research should expand the scope of AR-VFT applications to diverse science topics such as ecosystems, forces, and weather systems across larger and more diverse elementary populations (Dewi et al., 2018). Longitudinal designs are also needed to investigate whether improvements in spatial thinking and problem-solving are sustained over time and whether these skills transfer to other domains of learning (Slattery et al., 2024) .

In summary, the present findings provide compelling evidence that AR-based virtual field trips are a valuable pedagogical innovation for elementary science education. They not only strengthen cognitive outcomes such as spatial visualization and problem-solving but also enhance learners' engagement and motivation. This synergy of cognitive and affective benefits positions AR-VFT as a powerful tool for reimagining science instruction at the primary level, where the development of curiosity, inquiry, and foundational reasoning skills is most critical.

Conclusion

This study demonstrated that the implementation of the Augmented Reality–based Virtual Field Trip (AR-VFT) e-module significantly improved elementary school students' spatial thinking and problem-solving skills in science learning. The ANCOVA results revealed a statistically significant effect of the AR-VFT intervention on post-test scores, confirming its effectiveness in promoting deeper conceptual understanding. The integration of interactive 3D visualizations and inquiry-based exploration activities provided learners with opportunities to concretize abstract Earth science concepts, thus fostering higher engagement and motivation. Overall, the research underscores the importance of adopting innovative digital learning resources, such as AR-VFT e-modules, to enrich the learning experience in science classrooms. Beyond enhancing academic performance, the module encouraged active participation, improved visualization, and cultivated problem-solving skills—competencies that are essential for 21st-century learning. Future studies are recommended to expand the application of AR-based interventions across different science topics and grade levels, as well as to explore their long-term impact on students' critical and creative thinking abilities.

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