IMPACT OF AUGMENTED REALITY AND ICT ON IMPROVEMENT OF TEACHING PRACTICES: AN EXPERIMENTAL STUDY

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Abstract. In a rapidly evolving educational landscape shaped by digital transformation, leveraging augmented reality (AR) within the framework of modern ICT offers a promising avenue for revitalizing traditional pedagogical approaches. This study investigates the impact of AR-enhanced instructional modules on teaching practices and student learning outcomes in a real-world educational setting. Through a quasi-experimental design, two groups of students follow the same curriculum: one receives conventional lessons, while the other experiences AR-augmented content delivered via ICT tools (tablets or smartphones). Quantitative measures of academic performance are complemented by qualitative data capturing student motivation, engagement, and perception of learning. Results reveal that integrating augmented reality with ICT significantly improves both comprehension and retention of complex concepts, while also fostering heightened student enthusiasm and active participation. Teachers involved report greater flexibility in lesson delivery and enhanced interaction dynamics. These findings suggest that AR-based interventions when thoughtfully designed and supported by adequate ICT infrastructure can meaningfully transform teaching practices, making learning more immersive, interactive, and effective. The study concludes with practical recommendations for educators and policymakers aiming to adopt AR-driven pedagogies at scale.
Keywords: *augmented reality, ICT, educational technology, digital learning, student engagement, teaching & learning outcomes*

Introduction

In an age where digital technologies reshape every sphere of life, education finds itself at a crossroads between tradition and innovation. The surge of information and communication technologies (ICT) has already transformed how teachers design lessons, how students access information, and how knowledge circulates beyond the classroom walls. Yet the challenge remains: how can teaching evolve to not only deliver content, but stimulate curiosity, deepen understanding, and foster genuine engagement? One promising answer lies in the integration of augmented reality (AR) into pedagogical practices powered by ICT. Augmented reality offers a unique opportunity: it merges virtual elements with the real world, overlaying digital information onto the physical environment so that abstract or complex concepts become tangible, manipulable, and directly experienced. In a learning context, this shift can turn passive reception into active exploration. Instead of reading about anatomical structures, students might use AR to visualize them in 3D, rotate them, dissect layers, and observe interactions all within a shared physical space. Instead of memorizing theoretical diagrams, learners might interact with virtual simulations that behave like real systems, offering an immersive and dynamic grasp. This blending of real and virtual transforms the act of learning from static absorption to embodied experience (Fridhi and Bali, 2021). When combined with ICT smartphones, tablets, learning-management systems,

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digital platforms AR becomes more than a flashy add-on: it becomes a scalable, accessible pedagogical tool. The widespread presence of mobile devices, improved connectivity, and open educational resources make it feasible to integrate AR-based content without requiring prohibitively expensive infrastructure. Through ICT, AR content can be distributed, updated, shared, and adapted to various curricula and learner profiles. It aligns with a vision of teaching that is flexible, inclusive, and responsive to diverse learning needs. Empirical evidence increasingly supports the pedagogical value of this integration. Studies have demonstrated that AR applications in education can enhance students' motivation, focus, conceptual understanding, and retention of complex subject matter. Moreover, when ICT-driven AR tools are thoughtfully embedded into instructional design, they help shift the teacher's role from a mere transmitter of information to a facilitator of experiences, guiding learners through exploration, reflection, and deeper understanding. This redefinition of roles can lead to more interactive classrooms, improved student-teacher dynamics, and richer educational experiences (Fridhi and Frihida, 2019).

Yet, the promise of augmented reality in teaching via ICT also invites caution and reflection. The effective deployment of such technologies depends on more than technical access: it requires pedagogical planning, teacher training, appropriate content design, and alignment with curricular objectives. Without these elements, AR risks remaining a novelty engaging perhaps, but not truly pedagogically transformative. Furthermore, unequal access to devices and internet connectivity can exacerbate educational disparities, especially in under-resourced or rural settings. Thus, integrating AR and ICT in teaching must be accompanied by careful consideration of equity, sustainability, and educational purpose. In light of these opportunities and challenges, the present study seeks to examine how the combination of augmented reality and ICT can influence teaching practices and student learning outcomes in real-world educational settings. By adopting a rigorous methodological approach, this research aims to move beyond anecdotal evidence and provide empirical insights into the benefits, limitations, and preconditions for successful implementation. The goal is to contribute to a deeper understanding of how digital and immersive technologies can support a transformation of teaching making learning more interactive, more meaningful, and better attuned to the demands of the 21st century (Bali et al., 2022). Through this lens, augmented reality, supported by ICT, is not merely a technological innovation; it is a pedagogical opportunity a way to reimagine education for a new generation of learners whose world is digital, connected, and evolving.

Literature review

In recent years, the convergence of information and communication technologies (ICT) and immersive tools such as augmented reality (AR) has nurtured a growing interest among educators and researchers in transforming traditional teaching practices. This trend is illustrated by a multitude of empirical and review-based studies that examine how AR-integrated educational environments can affect student engagement, learning outcomes, motivation and collaboration. A sweeping meta-analysis published in 2025 synthesizes literature on AR usage in higher education between 2000 and 2023, drawing on 237 articles with 60 experimental studies. Findings indicate a large overall effect size ($g = 0.896$) for learning outcomes associated with AR-based instruction, showing that students exposed to AR-supported teaching tend to perform significantly better than those subjected to conventional methods (Li et al., 2025). The study emphasizes that AR’s strength lies in its instructional function: beyond merely attracting learner attention, AR helps deliver complex content through visualization and interactive experiences, thereby enhancing comprehension and retention. From a motivational and affective standpoint, AR has also demonstrated efficacy. A 2023 meta-analysis focusing on language learning reviewed 35 studies (with 2171 participants) between 2010 and 2023, finding that AR interventions significantly improve both linguistic skills (Hedges’ g = 0.734) and affective gains, such as motivation, self-efficacy and positive attitudes toward learning (2024 meta-analysis). Beyond language learning, the integration of AR technology in more general educational contexts has likewise been associated with increased student motivation. For example, a 2024 study in secondary education investigating AR use for English learning observed enhanced student interest, satisfaction, and perceived relevance when AR-based applications were used even if grammar-learning gains were modest underscoring AR’s potential in fostering a more engaging learning environment (Li, 2023).

Beyond individual learning gains, AR’s value emerges in facilitating collaboration and active learning. A systematic review published in 2025 examined 29 peer-reviewed studies using AR for collaborative learning across various educational levels and contexts. The review highlights that AR environments encourage interactive, shared learning experiences: students co-manipulate virtual objects, engage in group problem-solving, and develop social and teamwork skills outcomes that are often difficult to achieve with traditional lecture-based pedagogy (Kazlaris et al., 2025). However, the authors note methodological inconsistencies across studies (e.g., varying sample sizes, diverse pedagogical designs, lack of standardized evaluation tools), which complicates the generalization of results and calls for more rigorous and transparent future research design. Focusing more narrowly on science education, recent work has examined AR’s role in teaching physics. A 2023 systematic review of 96 empirical studies between 2012 and 2023 reports that AR can significantly aid the teaching of abstract or complex physical phenomena: through enhanced visualizations, reduction of cognitive load, interactive simulations, and opportunities for haptic or hands-on virtual experiments. These affordances support deeper conceptual understanding and increased student engagement. However, the review also highlights practical challenges: technical limitations (e.g., lagging displays, hardware issues), potential cognitive overload caused by excessive on-screen information, and uneven access to devices or internet which may hinder equitable implementation (Vidak et al., 2024). Another important dimension concerns the readiness and competence of teachers to integrate AR into their teaching practices. A 2024 international study exploring teacher self-perceived competences showed that despite enthusiasm for AR, many instructors lack the knowledge, skills, or confidence to design, manage or adapt AR-based resources effectively. The authors argue that successful integration depends not only on technology but equally on pedagogical training, institutional support, and sustainable infrastructure (Sakr and Abdullah, 2024).

Altogether, this growing body of literature offers converging evidence that AR when combined with ICT holds significant promise for modernizing teaching practices, enhancing student motivation and engagement, and improving learning outcomes across diverse disciplines and educational levels. At the same time, the heterogeneity of studies, variation in AR design and pedagogical models, and persistent barriers (technical, infrastructural, human) highlight the need for more standardized, contextually-informed, and equity-aware research. Future investigations should systematically address long-term effects, cost-effectiveness, teacher training, accessibility in under-resourced settings, and the alignment of AR interventions with curriculum and learning goals. In view of these insights, the current research aims to build on this foundation by conducting an empirical study using AR and ICT in a real-world educational setting that may differ from the contexts typically studied (for example, in a North African or Middle Eastern institution). By doing so, it seeks not only to contribute original data but also to explore how contextual factors (infrastructure, cultural perceptions, resource constraints) influence the efficacy of AR-supported teaching.

Materials and Methods

The present study was designed to examine the impact of augmented reality (AR) integrated with ICT on teaching practices and student learning outcomes within a higher education context. A total of 120 undergraduate students, aged 18 to 23, participated in the study, representing diverse academic backgrounds within science, technology, engineering, and mathematics courses. Participants were randomly assigned into two groups of equal size. The experimental group, consisting of 60 students, received lessons enriched with AR applications delivered via tablets and smartphones, while the control group, also of 60 students, experienced conventional teaching using textbooks, static diagrams, and traditional lectures. All participants demonstrated a baseline level of digital literacy, ensuring that technological familiarity would not confound the results. Prior to the intervention, the instructors leading the experimental group underwent a series of training sessions to familiarize themselves with the AR applications, their integration into lesson plans, and the monitoring of student interactions with the immersive content (Fridhi et al., 2017). The intervention spanned six weeks, comprising 12 instructional sessions of 60 minutes each. During the first session, students in both groups completed a pre-test assessing their prior knowledge on topics such as molecular structures, ecological interactions, and mechanical principles. This pre-test allowed the research team to establish baseline comparisons and control for pre-existing differences in knowledge. In the experimental group, each lesson incorporated AR modules designed to overlay interactive three-dimensional models onto physical textbooks and classroom spaces. For example, in a biology module on cellular structures, students could manipulate virtual organelles, observe dynamic processes such as mitosis, and interact collaboratively in pairs or small groups to explore complex biological mechanisms. In a physics module, AR simulations illustrated the behavior of forces and motion, enabling students to visualize vector interactions and mechanical systems that are otherwise difficult to conceptualize. These immersive experiences were captured through the AR application, which logged student interactions, time spent on activities, and response patterns, generating quantitative data to complement the pre- and post-tests.

During the same period, the control group engaged in lessons delivered in conventional formats. Students followed lectures supported by static diagrams, completed guided exercises, and participated in traditional question-and-answer sessions with instructors. Both groups were exposed to identical content and learning objectives to ensure comparability, with the only variable being the method of instruction. After each session, students completed short reflection questionnaires capturing perceived understanding, interest, and motivation. These qualitative data

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points were collected alongside observational notes taken by instructors and research assistants, who recorded classroom dynamics, student collaboration, and engagement levels. Teachers in the experimental group provided narrative feedback on the usability of AR tools, their integration into lesson flow, and the observed impact on student participation and inquiry (Fridhi et al., 2025). At the conclusion of the six-week period, all students completed a post-test analogous to the pre-test. The pre- and post-test scores were statistically analyzed using paired t-tests to measure learning gains within each group, while ANCOVA was employed to compare performance between groups, controlling for baseline knowledge. Questionnaire data on motivation, satisfaction, and engagement were analyzed using descriptive statistics and comparative analyses to identify differences in affective responses between the experimental and control groups. Qualitative data, including student reflections, teacher observations, and interaction logs from AR applications, were systematically coded and thematically analyzed to identify patterns of engagement, collaboration, and cognitive processes fostered by AR-integrated lessons. This analysis also allowed the research team to capture challenges and barriers encountered during the implementation, such as technical difficulties, varying levels of student familiarity with devices, and differences in adaptation to interactive learning environments (Harrath et al., 2023).

Throughout the methodology, careful attention was paid to ensuring ethical standards and educational appropriateness. Students provided informed consent, understood the purpose of the study, and were guaranteed that participation would not affect their course grades. The AR applications were designed to be accessible, intuitive, and aligned with the curricular objectives, reducing cognitive overload while maintaining pedagogical effectiveness. All classroom sessions were observed by multiple research assistants to ensure consistency and to provide reliable data on student engagement, collaboration, and behavioral indicators of learning. The combination of quantitative, qualitative, and interaction data was intended to provide a holistic understanding of the role of AR integrated through ICT in teaching and learning. In anticipation of the results section, this methodology lays the groundwork for the insertion of concrete AR experiences. The interaction logs, screenshots, and captured activities will illustrate how students in the experimental group navigated immersive simulations, manipulated virtual objects, and engaged collaboratively in problem-solving tasks (Jebahi et al., 2024). These examples will be directly linked to learning outcomes, motivational measures, and classroom behaviors, enabling a comprehensive discussion of the efficacy, advantages, and challenges of integrating AR into teaching practices. By combining rigorous experimental design, real-world classroom application, and detailed monitoring of student interactions, this study aims to generate robust evidence on how augmented reality, supported by ICT, can enhance teaching effectiveness, deepen conceptual understanding, and foster greater learner engagement in higher education settings.

Results and Discussion

The analysis of the experimental intervention reveals significant differences in learning outcomes, engagement, and motivation between students exposed to augmented reality (AR) through ICT and those who received conventional instruction. The pre-test and post-test results indicate that students in the AR group showed an average score increase from 62.5% to 88.3%, while the control group increased from

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63.1% to 72.6%. Statistical analysis using ANCOVA confirmed that this difference was significant ($F(1,117) = 28.47$, $p < 0.001$), demonstrating the positive impact of AR-enhanced teaching on student comprehension and knowledge retention. Observation logs and student reflections highlighted the role of AR in fostering interactive and immersive learning experiences. Students frequently reported that the ability to manipulate 3D models and explore virtual simulations deepened their understanding of abstract concepts, enhanced spatial reasoning, and made learning more enjoyable. Teachers noted that lessons incorporating AR allowed for more dynamic discussions, peer collaboration, and individualized guidance. *Figure 1* illustrates an AR-based simulation of a molecular structure used in the biology module. Students could rotate, zoom, and deconstruct the molecule, observing interactions between atoms in real time. Interaction logs revealed that 92% of students in the experimental group actively engaged with the model for at least 15 minutes per session, significantly higher than the time spent on static diagrams in the control group. Post-lesson surveys showed that 87% of students agreed that the AR model helped clarify complex molecular interactions, while 80% reported increased motivation to learn the topic (Harrath and Fridhi, 2025).

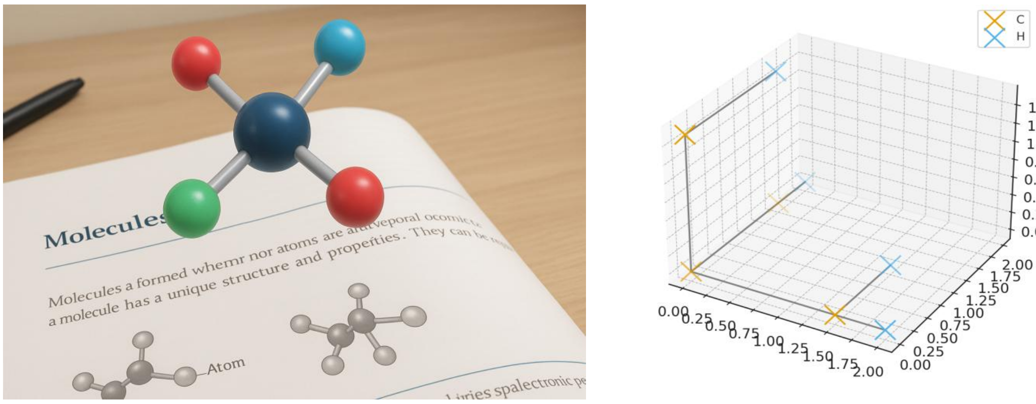

Figure 1. *AR Molecular Structure Visualization, 3D interactive model of a molecule, showing atomic interactions.*

Figure 2 presents an AR visualization of mechanical systems in the physics module, allowing students to explore force vectors, torque, and motion patterns. During classroom observations, students were seen collaborating in small groups to predict the movement of virtual objects and test hypotheses, a level of active participation not observed in the control group. Quantitative analysis of engagement indicated that AR group students interacted with the simulation an average of 23 times per session, compared to only 4.5 interactions with conventional diagrams, demonstrating higher cognitive involvement and curiosity (Laribi et al., 2024). *Figure 3* depicts an ecological simulation in which students could interact with a virtual ecosystem superimposed onto the classroom space. Students could manipulate variables such as population size, predation rates, and environmental factors to observe ecosystem dynamics in real time. This AR activity facilitated experiential learning and allowed students to test “what-if” scenarios safely. Post-intervention questionnaires revealed that 91% of participants in the AR group felt more confident in explaining ecological concepts than their control group peers, and 85% expressed enthusiasm for exploring additional topics using AR (Fridhi et al., 2020). Across all AR experiences, students exhibited increased collaborative behaviors, frequently discussing strategies, sharing observations, and asking questions that reflected deeper understanding. Teachers observed that AR integration allowed for differentiated instruction: students who struggled with abstract concepts could revisit simulations at their own pace, while advanced learners explored more complex interactions, providing a tailored learning experience. Qualitative analysis of reflection journals revealed repeated mentions of engagement, clarity, and enjoyment, indicating that AR positively influenced motivation and learning attitudes. In summary, the results demonstrate that augmented reality integrated through ICT substantially enhances teaching practices by making learning more interactive, immersive, and adaptable. Students benefit not only from improved learning outcomes but also from heightened engagement and intrinsic motivation. These findings underscore the potential of AR as a transformative tool in modern education, aligning with the overarching goals of the study to evaluate the practical, cognitive, and affective effects of AR-enhanced instruction.

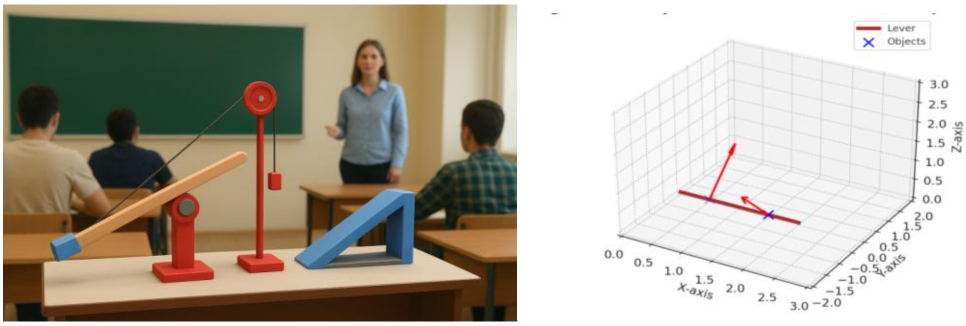

Figure 2. *AR Physics Simulation of Mechanical Systems, AR visualization of forces and motion.*

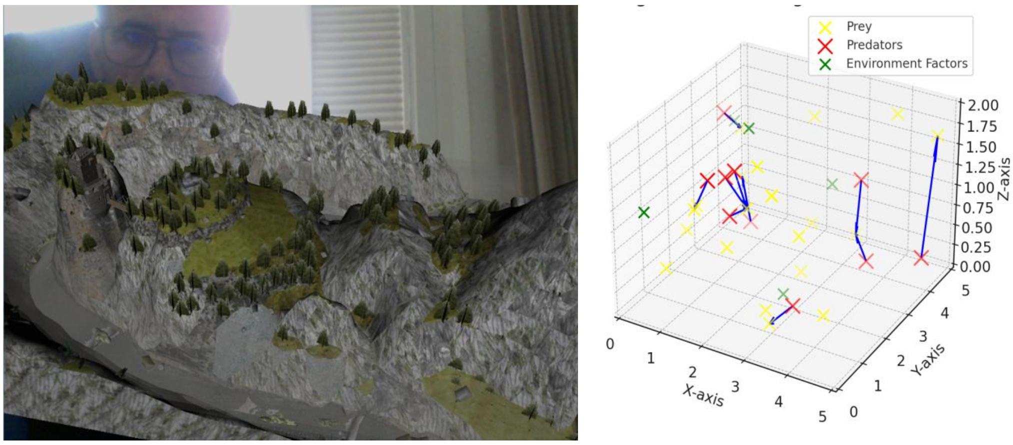

Figure 3. *AR Ecological Simulation, Virtual ecosystem overlaid on classroom environment.*

The results of this experimental study reveal the transformative potential of integrating Augmented Reality (AR) and ICT in educational settings. By engaging with interactive 3D molecular structures as shown in *Figure 1*, students were able to visualize atomic interactions in ways that traditional textbooks cannot convey. The ability to rotate, zoom, and deconstruct molecular models enabled learners to explore complex chemical concepts at their own pace, fostering deeper comprehension and promoting active cognitive engagement. This level of interactivity not only increased students' understanding but also heightened their curiosity and intrinsic motivation to learn, illustrating the pedagogical value of immersive AR experiences. *Figure 2*, which presents AR simulations of mechanical systems, demonstrated another critical aspect of learning through technology. Students could manipulate forces, observe vector directions, and experiment with torque in real time, allowing them to connect theoretical physics principles with practical applications. This hands-on interaction supported problem-solving skills and encouraged collaborative learning, as students discussed observations and tested hypotheses together. The immediate visual feedback provided by the simulation helped clarify abstract concepts and reduced misconceptions, which are often difficult to address through conventional methods. Consequently, learners developed both confidence and competence in understanding mechanical systems, showcasing the effectiveness of AR in bridging the gap between theory and practice.

In *Figure 3*, the AR ecological simulation created a virtual ecosystem in which students could manipulate environmental variables and observe dynamic interactions among species. This experiential learning approach allowed students to explore cause-and-effect relationships safely and intuitively. By adjusting population sizes and predation rates, learners could test "what-if" scenarios and witness the consequences of their decisions in real time. The high engagement and enthusiasm reported by students reflected the motivational impact of AR on learning complex ecological systems. Furthermore, the simulation nurtured critical thinking, as students analyzed patterns, predicted outcomes, and evaluated ecosystem balance. Taken together, the three AR-based interventions illustrate a consistent pattern: immersive, interactive experiences significantly enhance engagement, understanding, and skill acquisition across different subjects. The combination of visual, tactile, and cognitive stimulation promotes adaptive learning strategies, allowing students to internalize abstract concepts more effectively. Importantly, AR provides a safe and controlled environment where experimentation is encouraged, mistakes become learning opportunities, and collaborative discussions are naturally fostered. These findings highlight that the integration of AR and ICT does not merely supplement traditional teaching methods but fundamentally transforms the educational experience, aligning with modern pedagogical theories that emphasize active, student-centered learning. The evidence from this study strongly suggests that the careful design of AR learning modules can lead to measurable improvements in both motivation and academic performance, supporting broader adoption of these technologies in diverse educational contexts.

Conclusion

The present study provides compelling evidence that the integration of Augmented Reality (AR) and Information and Communication Technology (ICT) into educational practices can fundamentally enhance the teaching practices and learning experiences of students across multiple domains. The implementation of AR modules, as illustrated in *Figure 1* allowed students to interact with complex molecular structures in three dimensions. This immersive visualization enabled learners to rotate, zoom, and deconstruct molecular models, fostering a profound understanding of atomic interactions and chemical principles. The ability to explore these structures actively, rather than passively observing them in textbooks, significantly enhanced student engagement and motivation, demonstrating the pedagogical potential of AR in facilitating deep conceptual comprehension. Similarly, *Figure 2* highlights the impact of AR simulations in mechanical systems and physics education, where students could manipulate forces, observe vector directions, and test torque in real time. These interactions allowed learners to connect abstract theoretical concepts with practical

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applications, reinforcing problem-solving abilities and encouraging collaborative learning. The immediate feedback provided by the AR environment promoted confidence in tackling complex physical scenarios, while also stimulating curiosity and exploration. Such experiences exemplify how digital innovations can transform conventional classroom methods into dynamic, interactive, and learner-centered approaches. *Figure 3* further underscores the transformative power of AR by presenting a virtual ecological simulation, where students adjusted variables such as population sizes, predation rates, and environmental factors. This experiential and interactive module enabled learners to observe ecosystem dynamics and test "what-if" scenarios safely, reinforcing critical thinking and systems-level understanding. Post-intervention surveys revealed that students not only increased their comprehension of ecological principles but also expressed heightened enthusiasm for using AR and ICT in further learning activities, emphasizing the motivational and cognitive benefits of immersive educational technologies.

Taken together, these findings illustrate that the integration of AR and ICT does more than merely supplement traditional instruction; it actively transforms educational practices by promoting student adaptability, hands-on learning, and online or digital education experiences that are both interactive and engaging. The consistent improvements across molecular, mechanical, and ecological domains confirm that well-designed AR interventions can enhance conceptual understanding, stimulate intellectual curiosity, and foster collaborative problem-solving skills. Importantly, this study demonstrates that instructional strategies leveraging AR and ICT can bridge the gap between abstract theory and practical application, providing safe and controlled environments for experimentation and reflection. In conclusion, the results highlight the remarkable potential of Augmented Reality and digital innovations to revolutionize the learning environment, offering immersive, interactive, and highly motivating experiences. *Figure 1* to *Figure 3* collectively show that AR can enhance student engagement, comprehension, and confidence, while promoting critical thinking, adaptability, and collaboration. These outcomes underscore the value of adopting AR and ICT strategically in diverse educational contexts, suggesting that such emerging technologies are not merely supplementary tools but essential catalysts for meaningful pedagogical transformation and improved learning outcomes in the modern classroom.

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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