

Virtual and Augmented Reality Technology in Education and Entertainment: Current Trends and Future Outlook

Tien Chi Huang ^{1,*} , Jian Wei Tzeng ¹ and Nen Fu Huang ²

¹ Department of Information Management, College of Information and Distribution Science, National Taichung University of Science and Technology, Taichung 40343, Taiwan; tjw@nutc.edu.tw

² Department of Computer Science and Information Engineering, Southern Taiwan University, Tainan 710, Taiwan; president@stust.edu.tw

* Correspondence: tchuang@nutc.edu.tw

1. Introduction

Extended reality (XR)—including virtual reality (VR), augmented reality (AR), and mixed reality (MR)—has moved perceptibly in recent years from being a “showcase technology” to becoming an instructional medium expected to earn its place in curricula and professional training. In applied sciences education in particular, XR is increasingly judged not by how immersive it looks, but by whether it improves learning conditions that traditional formats struggle to provide: safe rehearsal for hazardous procedures, experiential access to rare or costly scenarios, and intelligible representations for abstract or microscopic phenomena. Put differently, XR is no longer the visiting celebrity in the classroom; it is being asked to become a reliable colleague [1,2].

This Special Issue was conceived to examine that transition with scholarly discipline: How does XR contribute to learning outcomes and learner experience (including immersion), and how do these contributions vary by domain, pedagogy, and learner characteristics? After rigorous peer review, the issue presents 12 published contributions that collectively span systematic synthesis and methodological guidance, professional and vocational simulations, science learning and teacher preparation, and innovative or inclusive applications that broaden participation and reconsider what “effective” instruction means across diverse learners and settings.

A notable feature across the issue is a gradual shift from “Can XR work?” toward “Under what design conditions, for whom, and with what evidence?” Several studies provide outcome comparisons (e.g., VR vs. textbook, MR vs. slides, and VR across delivery formats), while others foreground user experience and feasibility as necessary preconditions for sustainable adoption (e.g., usability, motion sickness, onboarding, and perceived immersion). Importantly, these papers also invite restraint: some report perception-based benefits without claiming performance gains, some propose strong potential while acknowledging the need for longer-term validation, and some remind the field that novelty, cognitive load, and learner differences can meaningfully shape conclusions. This balance—innovation with methodological humility—provides an appropriate foundation for a closing editorial.

2. Thematic Overview of the Special Issue

To support coherent interpretation, the 12 papers can be integrated under four themes. While each theme highlights distinct contexts, their deeper contributions are cumulative: they collectively clarify what XR is good at, what it is not automatically good at, and what researchers must do to make claims that are both useful and defensible.



Received: 9 January 2026

Accepted: 11 February 2026

Published: 27 February 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

2.1. Theme 1: Theoretical Frameworks and Reviews

Two papers establish the conceptual and methodological backbone of the issue.

The systematic review by Huang and Tseng (Contribution 1) synthesizes empirical XR studies in applied sciences education across 2010–2024, reporting both the distribution of XR modalities (VR, AR, and MR) and the outcomes most often observed. Beyond its descriptive contribution, the review’s value is strategic: it characterizes the field as promising but uneven, with recurring constraints—cost, space, discomfort, small samples, and limited longitudinal evidence—that complicate generalization and implementation. In other words, the review normalizes an important truth for XR scholarship: “more immersive” does not automatically mean “more educational,” and claims must be anchored in design and evidence rather than enthusiasm.

Complementing this macro view, Miguel-Alonso et al. (Contribution 2) tackle a micro-level validity concern: the novelty effect in immersive VR learning environments. Their tutorial and validation study operationalize onboarding as an instructional intervention—structured, modular, and grounded in principles from Mayer’s Cognitive Theory of Multimedia Learning—to help learners become fluent with VR interactions and reduce confounds introduced by unfamiliarity. The paper’s practical implication extends beyond VR tutorials per se: it positions interaction literacy as a prerequisite for fair evaluation. If learners spend cognitive resources figuring out controllers, any measured “learning effect” may actually be an interface effect—or, worse, a novelty artifact.

Together, Contribution 1 and Contribution 2 implicitly propose a higher standard for XR research: (i) situate claims within what the broader evidence base can support, and (ii) design learning environments such that observed outcomes are attributable to pedagogy and content rather than first-time awe or interaction friction.

2.2. Theme 2: Professional Skills and Vocational Training

Four studies demonstrate XR’s appeal in skill-oriented contexts where safety, realism, and repeatability are central—but they also reveal how evidence quality can vary depending on what is measured and how comparisons are made.

Ba-Hattab et al. (Contribution 3) examine a VR dental simulator (with haptics) for endodontic access cavity preparation among undergraduate students in two institutions (Qatar and Turkey). With a sample of 60, the study reports broadly positive learning experiences and perceived skill-related benefits (e.g., a majority of learners endorsing VRDS as helpful for fine motor skill improvement), while also documenting realism judgments and recommendations for simulator improvement. The contribution here is appropriately bounded: the study does not overclaim clinical competence gains; instead, it provides evidence that students perceive VRDS as a valuable supplement to conventional mannequin-based training and identifies design targets for improving fidelity and usability. In professional education, this kind of evidence is consequential because learner trust and perceived authenticity often determine whether simulation time translates into deliberate practice.

Lee and Ma (Contribution 4) address a different high-stakes domain: chemical accident response training. Their work develops an operator training simulator that enables mutual cooperation between roles (e.g., field operator and control room) using an infrastructure that combines a pilot plant, a distributed control system, and AR-mediated communication. Conceptually, this is a strong step beyond individual procedural rehearsal toward distributed coordination—precisely the competence profile demanded in real industrial incidents. At the same time, the paper models a key editorial lesson about evidence boundaries: the authors discuss substantial “training effect” and cost/time advantages, but these comparisons are primarily derived from instructional-efficiency reasoning (e.g., training

time reduction) and assumptions associated with experiential-learning retention claims, rather than controlled outcome trials with performance measures. Thus, the value of contribution 4 lies in system design and training logic, while its impact claims should be read as proposed potential requiring rigorous validation.

Liker et al. (Contribution 5) contribute a learner-analytic perspective in maritime engineering education by segmenting students based on perceived immersion (PIMM) in an HMD-based VR engine room simulator. Their K-means cluster analysis identifies “Immersionists” and “Conformists,” showing that the group reporting higher immersion also reports significantly higher perceived learning benefits, future behavioral intentions, and satisfaction. This study reframes immersion as a differentiating learner experience variable—one that may influence acceptance and perceived value even when objective performance measures are not the focus. It also underscores a practical implication for training programs: implementation may benefit from adaptive approaches that recognize learner heterogeneity (e.g., prior VR exposure, comfort, susceptibility to discomfort) rather than assuming uniform uptake.

Finally, Kobayashi and Nagao (Contribution 6) extend “skills training” into a domain where feedback is traditionally difficult to standardize: photography. Their VR Photo Training System provides practice opportunities in a virtual space and integrates machine-learning models to evaluate aesthetic, compositional, and color-related properties of user-taken photos, including a feature that provides composition advice. Importantly, the authors explicitly acknowledge that the study does not confirm improvement in participants’ real photography skills and call for longer-term user experiments to test training efficacy. Within the Special Issue, contribution 6 therefore represents an enabling direction: XR paired with automated assessment can scale formative feedback, but claims about learning gains must be earned through longitudinal outcome studies.

Across these vocational and skill-oriented papers, a coherent insight emerges: XR’s practical value is strongest when it closes a training gap that is otherwise difficult to address (risk, cost, access, and feedback), but the credibility of “effectiveness” depends on whether studies measure performance, perceptions, transfer, or efficiency—and whether the comparison logic is empirical or inferential (Contributions 3–6).

2.3. Theme 3: Science Education and Visualization of Abstract Concepts

Three studies foreground XR’s capacity to represent “unseeable” processes and support conceptual understanding, while also illuminating how instructional format and design quality shape learner judgments and adoption intentions.

Tarng and Pei (Contribution 7) present VR teaching modules for quantum mechanics designed to make wave–particle duality experientially legible through interactive virtual experiments. In a controlled teaching experiment with 60 high school students (VR vs. textbook), the VR group demonstrates higher learning effectiveness, and questionnaire results indicate high learning motivation and low cognitive load associated with VR-based visualization of abstract concepts. The study’s contribution is notable for combining performance evidence with motivational and cognitive-load measures—an alignment that supports a more coherent interpretation of why learning gains may occur (i.e., reduced abstraction burden through interactive visualization).

Ewais et al. (Contribution 8) describe two immersive VR simulations—a DNA laboratory and a crime scene investigation—developed for a forensic molecular biology course. The study compares learners’ perceptions under online vs. face-to-face instructional modalities and examines factors influencing intention to adopt VR-based training. Results suggest that both modalities can support comprehension of core concepts, with limited differences across formats; where differences appear, they relate to selected perceptions (e.g., content

relevance and overall impression), while correlations indicate that content relevance and multimedia qualities (visual quality, animation realism, navigation/interaction) are associated with comprehension, immersive learning experience, and future use intentions. This paper's deeper implication is methodological: "VR effectiveness" should not be treated as a monolith. Design quality (and perceived relevance) functions as a plausible mediator for learner acceptance and perceived learning value—and these relationships may persist regardless of whether delivery is online or in-person.

Czok and Weitzel (Contribution 9) address science education from the vantage point of teacher preparation, analyzing an AR game-based learning environment with German pre-service teachers. Their 2×2 intervention logic distinguishes the effects of "AR" and "GAME" features rather than conflating them. The results show significant gains over time in both knowledge and computer self-efficacy across all intervention groups, with no interaction effect indicating differential gains attributable to AR or game-based components. This is a strategically important null finding: it warns against attributing learning gains to XR features without careful experimental disentanglement. At the same time, the observed self-efficacy gains reinforce a plausible program-level benefit: structured exposure to technology-enhanced learning—whether AR, game-based elements, or both—may build teachers' confidence to integrate digital tools into practice.

Taken together, these science-focused papers suggest that XR's contribution is not merely "better visualization," but designed experiential access—where interactivity, relevance, and multimedia quality influence both learning-related perceptions and the likelihood of sustained adoption (Contributions 7–9). They also caution that the right comparison question is often not "XR vs. traditional," but "Which design mechanism actually accounts for the observed gains?" (Contribution 9).

2.4. Theme 4: Innovative Applications and Inclusivity

The final theme showcases XR's capacity to broaden participation, embody learning, and interrogate the conditions under which immersive technologies may—or may not—outperform conventional instruction.

Capallera et al. (Contribution 10) provide one of the issue's most compelling contributions to ecological validity through a VR simulator designed with social educators to train teenagers with intellectual disabilities in urban mobility tasks. Conducted over seven months across five institutions (with follow-up post-tests), the study reports that several participants achieved high success rates in post-testing, and a subset became completely autonomous in real-world travel (on foot or via public transport). The significance here is not rhetorical: it directly addresses the central promise often claimed for XR—transfer to real-world functioning—using a design that is longer-term, educator-informed, and attentive to stability over time in self-reported impact measures. At the same time, the study's conclusions are framed cautiously and appropriately: learning and transfer outcomes vary by individual, and system feedback from educators remains essential for refinement. In the landscape of XR research—often dominated by short interventions—Contribution 10 stands out as an example of what "implementation-grade evidence" can look like.

Kim et al. (Contribution 11) introduce Logogram VR, a treadmill-coupled VR edutainment system for learning Hanja (a logographic writing system). The design operationalizes embodied cognition by linking character meanings to actions and movement in a gamified VR environment. Evaluations indicate that users experience the system as enjoyable and engaging, with limited motion sickness, and that the embodied approach may be particularly suitable for adolescents; the authors also note that adults may require additional support to use the system effectively. This paper contributes an innovation logic: XR's educational value can be built not only through representation (seeing), but through structured

perception–action coupling (doing), provided the interaction demands are calibrated to learner capabilities.

Petruse et al. (Contribution 12) add a comparative lens, contrasting MR instruction using HoloLens 2 with conventional PowerPoint slides for learning the human muscular system. With 115 participants randomly assigned and matched on IQ and prior knowledge, the study reports nuanced results: overall performance differences between methods are modest, and the effectiveness of the method appears to vary by age group, with MR more suitable for younger participants and traditional instruction marginally more effective for older learners. The paper’s interpretive discussion suggests that cognitive load and familiarity may help explain these patterns. As a contribution to the Special Issue, Contribution 12 functions as a corrective to techno-determinism: immersive technology can improve learning under some conditions, but it can also impose interaction and processing demands that change who benefits and when.

Collectively, Theme 4 makes a broader scholarly point: the field’s frontier is no longer simply “more immersion,” but “more inclusivity, better fit, and clearer evidence of transfer.” XR may be transformative precisely when it is designed for populations and objectives that conventional approaches underserve (Contributions 10–12).

3. Synthesis and Implications

Across the 12 papers, several integrative insights emerge—each grounded in what the studies actually measure and claim, without extending beyond the available evidence.

- (1) XR’s educational value is increasingly framed as a design problem, not a device problem [2,3].

Multiple contributions treat XR effectiveness as contingent on instructional architecture: onboarding and interaction fluency (Contribution 2), embodied action mappings (Contribution 11), relevance and multimedia quality as adoption-linked design features (Contribution 8), and the careful separation of AR and game-based mechanisms (Contribution 9). This converges with the systematic review’s message that outcomes are generally positive but heterogeneous, and that methodological and contextual constraints limit broad generalization (Contribution 1). The implication is straightforward: future XR scholarship in applied sciences must prioritize design accountability—explicitly stating which design mechanisms are expected to influence which learning processes.

- (2) “Learning outcomes” in XR research are multi-layered, and papers in this issue occupy different layers.

A helpful way to interpret the issue is through three evidence layers:

Performance evidence (e.g., knowledge test gains and controlled comparisons): exemplified by quantum mechanics VR modules (Contribution 7) and MR vs. slides in anatomy learning (Contribution 12).

Experience and acceptance evidence (e.g., satisfaction, immersion, intention to reuse): prominent in the forensic VR simulations (Contribution 8), immersion-based segmentation in maritime VR (Contribution 5), and the novelty-effect tutorial validation (Contribution 2).

Transfer and functional autonomy evidence (real-world behavior change): most clearly represented by the long-term VR mobility training for teenagers with intellectual disabilities (Contribution 10).

These layers are complementary but not interchangeable. A paper showing high immersion and satisfaction (Contributions 2 and 5) does not necessarily demonstrate improved performance, just as a study reporting performance gains (Contribution 7) does not automatically guarantee long-term transfer or sustained adoption [4]. Editorially, the Special Issue’s collective contribution is not that XR “works” in a single universal sense,

but that XR research is increasingly capable of specifying which layer of value is being tested and why.

- (3) Learner differences are not noise; they are part of the causal story.

Several studies directly or indirectly show that learner characteristics may condition XR outcomes: perceived immersion segments learners into groups with different perceived benefits and intentions (Contribution 5); age appears to moderate the effectiveness of MR vs. traditional instruction (Contribution 12); adolescents may find embodied logogram learning particularly suitable (Contribution 11); and learners experiencing intense cybersickness can have reduced performance and enjoyment even when onboarding is well designed (Contribution 2). These findings collectively argue against a “uniform user” assumption. For applied sciences education—where learner populations include adolescents, university students, professionals, and diverse special-needs groups—this has practical consequences: XR implementations should anticipate variability and design for it (e.g., optional supports, adaptable pacing, and alternative interaction schemes) rather than treating discomfort or low immersion as edge cases.

- (4) XR is most defensible when it solves a genuine access problem—risk, rarity, or abstraction—but claims still require careful operationalization.

The strongest contextual justifications across the issue align with classic “XR advantage zones”:

High-risk/high-cost training (chemical accident response, maritime engine room operations, clinical dental simulation) (Contributions 3–5).

Abstract or invisible science concepts (quantum mechanics, molecular biology procedures, microplastics education, and teacher preparation) (Contributions 7–9).

Inclusion and functional learning (urban mobility autonomy for teenagers with intellectual disabilities) (Contribution 10).

Yet the editorial stance must remain evidence-sensitive. For example, the chemical accident simulator’s design rationale is compelling, but its comparative “training effect” argument partially relies on inferential comparison logic rather than controlled performance measures (Contribution 4). The photography training system provides an advanced feedback mechanism but explicitly notes that skill improvement has not been empirically confirmed (Contribution 6). These are not weaknesses so much as research-stage markers: the Special Issue reflects a pipeline from system development and feasibility toward more robust impact evaluation.

4. Future Directions

The papers in this Special Issue collectively suggest several research priorities that are both forward-looking and methodologically conservative.

- (1) AI–XR convergence: from immersive content to scalable feedback and personalization.

Two trajectories are already visible within the issue. First, the systematic review explicitly anticipates AI-enabled XR systems that are more adaptive and scalable (Contribution 1). Second, the VR photo training system demonstrates a concrete instance of AI-supported formative feedback within XR via machine-learning evaluation and recommendations (Contribution 6). Future research should move beyond feasibility toward validated learning impacts by asking: How accurate and instructionally aligned are AI-generated feedback signals? Under what conditions do they improve learning outcomes or transfer? And what validation protocols are needed—especially in applied sciences where errors can be consequential?

- (2) Methodological upgrades: controlling novelty, measuring durability, and making transfer the default aspiration.

Miguel-Alonso et al. (Contribution 2) make a compelling case that onboarding and novelty control are necessary to interpret results fairly. The next methodological step is to pair such controls with longer-term designs that examine retention and transfer. Capallera et al. (Contribution 10) provide a model of extended intervention and follow-up in a high-stakes functional domain. For future XR learning studies, “does it last?” and “does it transfer?” should increasingly become standard questions rather than optional extensions.

- (3) Learner-adaptive XR: leveraging profiling, scaffolding, and alternative interaction pathways.

Segmentation by perceived immersion (Contribution 5) and age-moderated comparative outcomes (Contribution 12) both suggest that adaptive XR—whether through configurable interaction complexity, optional supports, or differentiated pathways—may be more educationally responsible than one fixed design. Importantly, adaptation should not be viewed solely as personalization for engagement; it is also a strategy for equity and validity, helping ensure that measured outcomes reflect learning rather than differential interface burden.

- (4) Social and collaborative immersion: moving from individual simulation to coordinated competence.

The chemical accident operator training simulator foregrounds mutual cooperation and role-based coordination (Contribution 4), while the forensic molecular biology simulations situate learners in guided environments with structured tasks and assessments (Contribution 8). Future XR research in applied sciences should expand from individual performance to collective competence: communication, shared situational awareness, and team decision-making under constraints. These are precisely the capacities that many applied science professions require, yet they are often under-measured in XR education studies.

- (5) Human factors as first-class variables: cybersickness, cognitive load, and usability are not peripheral [1,3].

The issue repeatedly highlights the practical limits that can derail XR value: cybersickness and flow challenges (Contribution 2), cognitive-load concerns and age-related differences (Contribution 12), and usability support needs across age groups (Contribution 11). Rather than treating these as “implementation issues,” future XR studies should model them as explanatory variables—measured, reported, and designed around—so that findings become more actionable for both researchers and educators.

Author Contributions: T.C.H.: writing—original draft preparation; J.W.T. and N.F.H.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We sincerely thank all authors who contributed to this Special Issue for advancing the scholarship and practice of XR in applied sciences education. We are equally grateful to the anonymous reviewers whose careful, constructive feedback strengthened the rigor and clarity of each published work. Finally, we acknowledge the Applied Sciences editorial team for their consistent support throughout the peer-review and publication process.

Conflicts of Interest: The authors declare no conflicts of interest.

List of Contributions:

1. Huang, T.-C.; Tseng, H.-P. Extended Reality in Applied Sciences Education: A Systematic Review. *Appl. Sci.* **2025**, *15*, 4038.
2. Miguel-Alonso, I.; Rodriguez-Garcia, B.; Checa, D.; Bustillo, A. Countering the Novelty Effect: A Tutorial for Immersive Virtual Reality Learning Environments. *Appl. Sci.* **2023**, *13*, 593.
3. Ba-Hattab, R.; Helvacioğlu-Yigit, D.; Anweigi, L.; Alhadeethi, T.; Raja, M.; Atique, S.; Daas, H.; Glanville, R.; Celikten, B.; Orhan, K.; et al. Impact of Virtual Reality Simulation in Endodontics on the Learning Experiences of Undergraduate Dental Students. *Appl. Sci.* **2023**, *13*, 981.
4. Lee, J.; Ma, B. An Operator Training Simulator to Enable Responses to Chemical Accidents through Mutual Cooperation between the Participants. *Appl. Sci.* **2023**, *13*, 1382.
5. Liker, L.; Bari, D.; Perić Hadžić, A.; Banar, D. Profiling Students by Perceived Immersion: Insights from VR Engine Room Simulator Trials in Maritime Higher Education. *Appl. Sci.* **2025**, *15*, 3786.
6. Kobayashi, H.; Nagao, K. VR Training System to Help Improve Photography Skills. *Appl. Sci.* **2023**, *13*, 7817.
7. Tarnag, W.; Pei, M.-C. Application of Virtual Reality in Learning Quantum Mechanics. *Appl. Sci.* **2023**, *13*, 10618.
8. Ewais, A.; Mystakidis, S.; Khalilia, W.; Diab, S.; Christopoulos, A.; Khasib, S.; Yahya, B.; Hatzilygeroudis, I. Virtual Reality Immersive Simulations for a Forensic Molecular Biology Course-A Quantitative Comparative Study. *Appl. Sci.* **2024**, *14*, 7513.
9. Czok, V.; Weitzel, H. Impact of Augmented Reality and Game-Based Learning for Science Teaching: Lessons from Pre-Service Teachers. *Appl. Sci.* **2025**, *15*, 2844.
10. Capallera, M.; Piérart, G.; Carrino, F.; Cherix, R.; Rossier, A.; Mugellini, E.; Abou Khaled, O. ID Tech: A Virtual Reality Simulator Training for Teenagers with Intellectual Disabilities. *Appl. Sci.* **2023**, *13*, 3679.
11. Kim, G.; An, E.; Kim, S. Logogram VR: Treadmill-Coupled VR with Word Reflective Content for Embodied Logogram Learning. *Appl. Sci.* **2023**, *13*, 1627.
12. Petruse, R.E.; Grecu, V.; Gaki, M.; Gutierrez, J.M.; Mara, D. Exploring the Efficacy of Mixed Reality versus Traditional Methods in Higher Education: A Comparative Study. *Appl. Sci.* **2024**, *14*, 1050.

References

1. Jensen, L.; Konradsen, F. A Review of the Use of Virtual Reality Head-Mounted Displays in Education and Training. *Educ. Inf. Technol.* **2018**, *23*, 1515–1529. [[CrossRef](#)]
2. Radianti, J.; Majchrzak, T.A.; Fromm, J.; Wohlgenannt, I. A Systematic Review of Immersive Virtual Reality Applications for Higher Education: Design Elements, Lessons Learned, and Research Agenda. *Comput. Educ.* **2020**, *147*, 103778. [[CrossRef](#)]
3. Makransky, G.; Petersen, G.B. The Cognitive Affective Model of Immersive Learning (CAMIL): A Theoretical Research-Based Model of Learning in Immersive Virtual Reality. *Educ. Psychol. Rev.* **2021**, *33*, 937–958. [[CrossRef](#)]
4. Parong, J.; Mayer, R.E. Learning Science in Immersive Virtual Reality. *J. Educ. Psychol.* **2018**, *110*, 785–797. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.