Land Forces Academy Review
Vol. XXX, No. 2(118), 2025

EMERGING AND DISRUPTIVE TECHNOLOGY AS MULTIPLIER FOR MILITARY TRAINING: EXPLORING THE DEVELOPMENT OF A HYBRID SYNTHETIC TRAINING ENVIRONMENT

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ABSTRACT

Emerging and disruptive technologies, such as immersive training technologies, create new opportunities and transform industries by introducing innovative ways to learn, work, and interact. Currently, Extended Reality (XR) technologies including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are transforming military training by offering interactive and immersive simulations to create training scenarios. By employing immersive training technology, trainees can gain hands-on experience in a safe and controlled environment that enhances their tactical skills, situational awareness, and decision-making abilities. This article explores the implementation of immersive training technologies alongside commercial off-the-shelf solutions (COTS, gaming software) such as DrillsVR, Gun Disassembly, and virtual simulation systems such as VirtualBattlespace3/VirtualBattlespace4 (VBS3/VBS4) to develop a Hybrid Synthetic Training Environment that supports the need for military training. The primary focus was to explore the effectiveness of XR technology in training sessions with that of traditional training methods, highlighting benefits such as cost savings, flexibility in training, and improved operational combat readiness. The findings advocate the integration of XR technology and COTS to modernize military education and create more flexible and effective training sessions designed to meet specific goals.

KEYWORDS: Augmented Reality, Extended Reality, Mixed Reality, Virtual Reality, Virtual Simulation Systems, Virtual Training Environment

1. Introduction to Immersive Training Technologies

Immersive Training Technologies (ITT), as part of the landscape of emerging and disruptive technologies, are used in many activity domains to create a framework for supporting the synthetic training experience. In today's digital age, when immersive technologies disrupt traditional training methods, Extended

DOI: 10.2478/raft-2025-0023
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Reality (XR) technologies, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), have emerged as essential tools across a variety of sectors to enhance professional training, training, and exercises in the military field or operational instructions in the technical domain. These emerging technologies offer immersive, interactive, and customizable training simulations that help users improve their tactical, technical, and cognitive skills.

The NATO Modelling & Simulation Centre of Excellence (MS CoE) defines the ITT as *"the state-of-the-art tool to support education, training, and senior leader decisional support"* to be employed to create a *"synthetic environment where the training audience will be attending a blended asynchronous/synchronous training and exercises"*. The intention of MS CoE is to use ITT in order to *"support rapid prototyping to train personnel through a Virtual World environment, based on gaming technology (preferably open source) integrated via next generation I\O systems and the use of Intelligent Agents driven by Artificial Intelligence"*. Calian Defence states that advanced technologies transform traditional military training and ITTs are *"tailored to deliver an engaging, realistic training experience to improve learning retention before putting skills to the test in live training"*.

XR technologies not only accelerate learning and enhance efficiency but also enable personalized training tailored to users' skill levels. This provides dynamic and adaptive scenarios that closely mirror real-world situations, leading to more realistic and performance-focused training. The Digital Futures Institute of Columbia University considers that immersive technology *"offers interactive and immersive three-dimensional environments that extend learning beyond the physical classroom to engage students in an unprecedentedly imaginable way"*.

The integration of XR in education and training aligns with the trends of Industry 4.0, where digitalization and advanced technologies work together to improve the efficiency and safety of training processes. XR refers to all real and virtual combined environments and human – computer interactions generated by computer technology and wearable sensors (Doolani et al., 2020). Recent studies have shown that XR technologies allow for training in a controlled environment, minimizing the risks associated with traditional methods, especially in complex situations such as operating industrial or medical equipment or enhancing medical education (Asoodar et al., 2024). In addition, experts in modeling and simulation from the military field are focusing their experiments on XR technologies. Utilizing XR immersive simulations in military training could lead to notable improvements in the development of new military capabilities, decision-making processes, and situational awareness among participants. Recent studies have emphasized the benefits of XR in reducing training costs, increasing flexibility, and streamlining educational processes through the incorporation of artificial intelligence (AI), data analytics, and multimodal interaction technologies (Chuah, 2018).

Figure no. 1 shows, in a broad picture, XR technology as part of emerging and disruptive technologies, its different application's fields, and the linkages among VR-AR-MR technologies. The implementation of these immersive technologies has led to a step forward in revolutionizing many industries, such as entertainment, education, military training, healthcare, and manufacturing, by providing innovative ways to visualize, interact, and gather feedback from data and specific working environments.

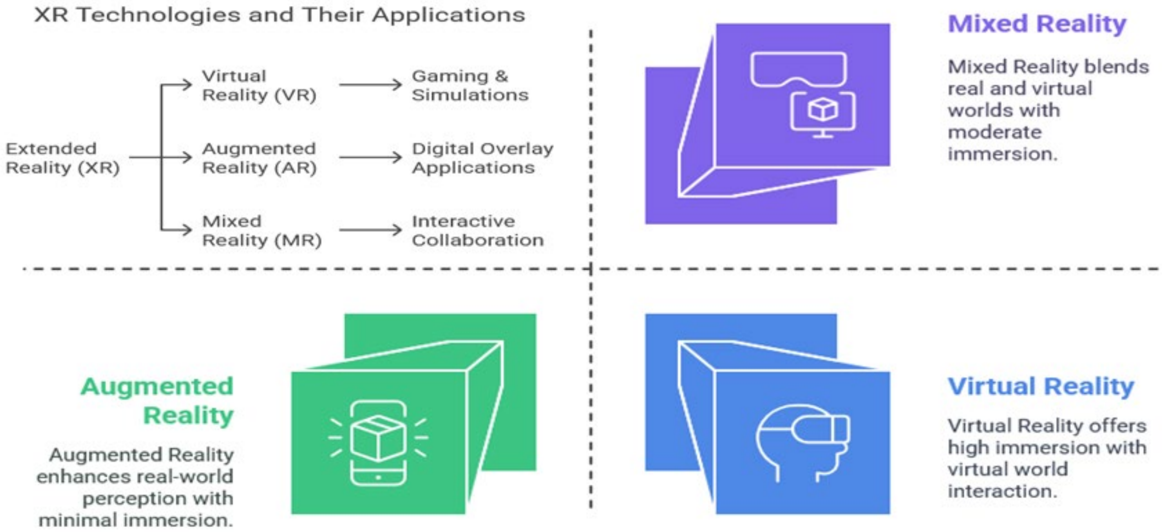

Figure no. 1: *Emerging and Disruptive Technologies – XR technology classification*
(Source: Authors' compilation)

The above figure provides a clear understanding of how the unified concept of XR technology serves as an overarching technology that encompasses all features of the other three immersive technologies. VR provides a completely immersive experience, AR adds digital elements to the real world, and MR allows smooth interactions between digital and physical components.

2. Methodology, Materials and Technical Infrastructure to Be Used in the Proposed Training Framework

From a perspective of military education and operational training and exercises, in order to bolster operational readiness, this article explores the influence of XR during training sessions and is focusing on XR integration with other gaming software and virtual simulation systems such as Virtual Battlespace (VBS). Our exploration of creating a suitable training framework is linked to a hybrid approach that combines emerging and disruptive technologies (XR, VR, AR, and MR), commercial-of-the-shelf (COTS) solutions (software belonging to the gaming industry), and dedicated virtual simulation systems (VBS3 and VBS4).

Cognitive task analysis, along with direct and indirect observations from specific use cases conducted in immersive environments, were used as the research methodologies. We analyzed the capabilities and implementation possibilities of innovative technologies that could be employed for military training and exercises. As a result, a training methodology for Urban Operations (UO) tactical training focusing on small unit leadership at the squad and platoon levels was developed. This study also focused on two research objectives to answer the following research questions.

• Which technical solution can be used as training capability in a safe and controlled synthetic training environment?

• What is the appropriate framework for achieving the training objectives in UO tactical training to enhance combat readiness?

To address the research questions related to training framework exploration, the main focus was to provide an approach for creating a Hybrid Synthetic Training Environment (HSTE). HSTE encompasses XR, COTS, and VBS3/VBS4 virtual simulation systems. In fact, this kind of training approach is a proof-of-principle training solution, and its suitability and feasibility will be proven after running training sessions and exercise rehearsals. To achieve the training objectives, instructors and military planners can adjust the training framework to adapt to each group of trainees' level of training.

2.1. Technical Equipments and Emerging Technologies

To create a training framework, a mix of cutting-edge hardware, tailored software platforms, and tactical simulation scenarios is required. XR integration creates a more effective training experience that offers a manageable, scalable, and interactive environment, specifically designed for complex operational scenarios. This approach is vital for understanding the distinctions and connections between these technologies, highlighting their potential applications in military training, where realistic and interactive simulations are essential for replicating suitable training scenarios. In this context, we aimed to conceptually define these training technologies.

- Augmented Reality enhances the real world by overlaying digital elements such as images, sounds, and 3D objects, thereby improving how users perceive their environment. Notable examples include the 3D terrain overlay in AdaViewer on HoloLens 2 and applications, such as Google Lens.
- Mixed Reality merges the aspects of AR and VR, facilitating real-time interactions between digital and physical objects to create a blended interactive environment. A notable example is Microsoft HoloLens, which allows users to manipulate 3D objects within their surroundings.
- Extended Reality is a broad term that includes all immersive technologies, such as AR, VR, and MR. It emphasizes their development and merging to offer improved experiences in different areas, including education, military training, healthcare, and industry.

The associated tools and equipment can be combined to create immersive training scenarios that can improve practical and tactical skills in a safe and controlled environment. These scenarios not only mimic real-world situations, but also enable the assessment of soldiers' abilities without the dangers linked to traditional training methods.

The VBS3 and VBS4 simulation systems from Bohemia Interactive Simulations have already been used as training solutions in virtual environments. Virtual simulation systems are known for their capacity to deliver complex, interactive, and realistic scenarios. These systems allow the creation of various tactical situations, including combat simulations, coordination exercises, and training for quick decision making.

2.2. Hardware, Software and Virtual Simulation Platforms Used for Proposed Training Solution

- VR headsets: HP Reverb G2 and Oculus Quest 2 can be employed for combat simulations and tactical engagement scenarios, offering a wide field of view and high resolution for an immersive experience.
- AR glasses: Microsoft HoloLens 2 was used to overlay the operational information and provide interactive visual guidance, aiding equipment maintenance, navigation, and terrain analysis.
- Motion-capture sensors (MoCap): MoCap systems have been used to track user movements in XR scenarios, thereby improving posture and tactical precision.
- Haptic devices: Haptic gloves and vests equipped with sensory feedback are integrated to simulate physical interactions with virtual objects and to enhance the realism of the experience.

The following platforms and software can be employed to develop and conduct training scenarios:

• VBS3 and VBS4 (Virtual Battlespace, virtual simulation systems): These virtual training platforms allow the simulation of intricate military scenarios, creating realistic terrain and tactical engagement situations under various conditions. In addition, great embedded simulation systems analysis tools of VBS could be used for After Action Review (AAR).

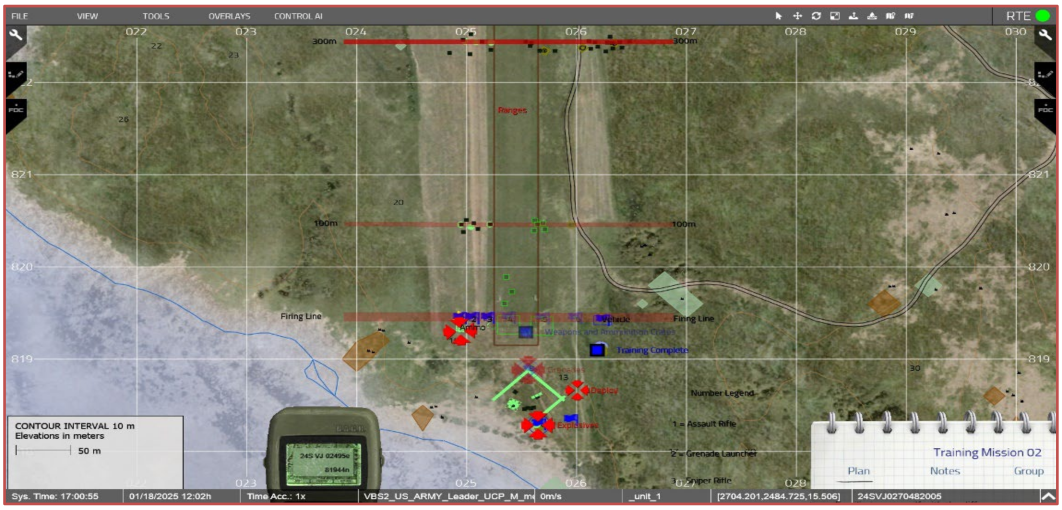

Figure no. 2: *Firing lines, unit positioning, and tactical objectives created for a training scenario on VBS3*
(Source: VirtualBattlespace3 simulation system)

• DrillsVR and GunDisassembly: As COTS solutions, this software could provide an education and training framework for handling, assembling, and maintaining military weaponry, minimizing the risks associated with real equipment. DrillVR, which enhances training through virtual reality, was designed to improve coordination and rapid reactions in simulated tactical scenarios, offering an interactive and lifelike environment. The Gun Disassembly application can be used to learn and practice the assembly and disassembly of firearms. This software offers a comprehensive understanding of the weapon components and their mechanics.

Figure no. 3: *Interactive models of AK-47 and HK G36E in Gun Disassembly 2 used as educational simulation application*
(Source: noble-empire.com)

• Graphics engines – Unity and Unreal Engines: These are used to create and customize XR training environments, enabling the development of detailed and interactive simulation scenarios. Unity and Unreal Engine act increasingly as foundational software for global game development and offer a suite of integrated solutions that are central to developing, testing, and deploying games across various platforms (Berezovskyi, 2024).

• AI statistical and analysis systems can complete the whole framework: Software AI-based can be employed to automatically track user progress and dynamically adjust the difficulty level training based on the user's performance.

To create engaging, immersive, and interactive experiences, the hardware that can be employed includes HP Reverb G2 VR headsets, which provide high resolution and low latency, making them perfect for precision training, and HoloLens 2 augmented reality glasses, which enable virtual elements to be superimposed onto the real world. This setup allowed for interactive presentations and coordination training exercises that seamlessly integrated the physical and virtual realities.

3. The Proposed Solution – A Roadmap to a Training Framework

The above-mentioned technologies allow customization of training exercises to meet the specific needs of each training session while also helping to reduce costs and minimize risks associated with traditional training methods.

1. Hybrid Synthetic Training Environment

1.a Gaming approach: Theoretical and practical training, using:

• DrillVr (or alternate solutions)

• World of guns: Gun Disassembly (or alternate solutions)

1.b Virtual environment approach: Practical training based on specific tactical scenarios, using:

• XR (AR, VR, MR)

• VBS3, VBS4

2. Shooting Range Training Environment

2.a Reduced scale shooting range: Indoor/outdoor practical skills training

• Airsoft training

2.b Real shooting range: Shoot house, Live firing range training

• Live firing exercises tailored to meet specific tactical scenarios training objectives

All of these training solutions can lead to setting up a training framework presented in Figure no. 4.

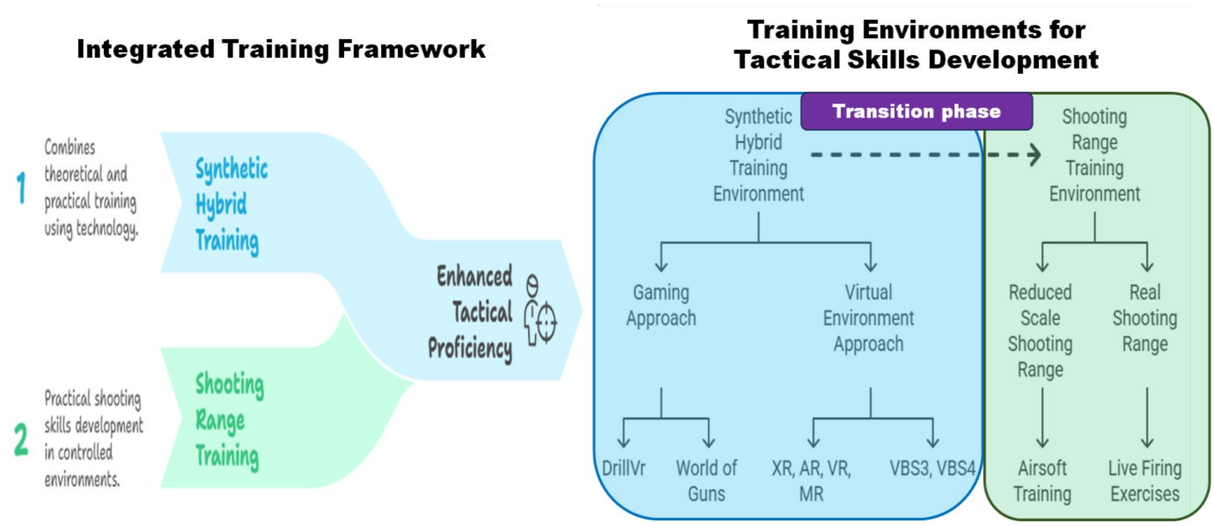

Figure no. 4: *The proposed Training Framework*
(Source: Authors' compilation)

3.1. The Development and Implementation of HSTE

The setup of the Hybrid Synthetic Training Environment, illustrated in Figure no. 4, begins with the gaming approach and continues with simulation platforms that generate the necessary scenarios. These platforms allow for the integration of specialized applications, ensuring detailed interactions with specific objects and procedures. After establishing the software infrastructure, the simulation environment is connected to technologies to enhance the visualization and interaction with digital elements. This phase includes the development of models and scenarios that can be accessed through various interactive environments. Connections are made between the core platforms and training environments, enabling users to actively engage in learning and training processes.

The interaction between the user and virtual environment is fine-tuned through ongoing testing and adjustments. The functionality and realism of the simulated actions are assessed, and scenarios are enhanced to deliver an experience that closely resembles reality. This process involves refining the graphic details, responses to commands, and control mechanisms. Ultimately, the virtual environment is ready for training sessions, where participants could practice and learn through realistic simulations. For virtual training to be successful, there must be a gradual shift toward practical exercises and real-world scenarios. This training framework reflects a systematic approach that emphasizes the gradual creation of training scenarios and the development of knowledge and skills during different stages of training.

3.2. Training Methodology for Use Case – Squad and Platoon Training for Urban Operations

The training scenario starts with an introduction to the weapon inventory system, enabling participants to check their gear at any time and switch or reload ammunition from available supplies. After this phase, participants moved through multiple training stages. The training scenario is structured in several stages, each with clear objectives. Then, treinees learn to operate various types of weapons within the VBS3/VBS4 virtual simulator systems, thereby honing essential skills for managing equipment in a controlled setting. From personal firearms to vehicle-mounted weapon systems, each participant has the chance to improve their skills in a systematic way.

A. *Training Exercise Objectives*:

- Development of a comprehensive and immersive military training solution that enhances squad and platoon marksmanship, tactical communication, and proficiency in urban operations using emerging and disruptive technologies.
- Trainining of participants in tactical maneuvers, room clearing, weapon handling, and decision-making under stress in confined spaces through a simulated environment.

B. *Training Goals*:

- Enhancing marksmanship skills at both squad and platoon levels
- Improving tactical movement and coordination in urban environments
- Developing situational awareness and decision-making under stress
- Practicing communication protocols and command hierarchies.

C. *Training Solution Concept*: COTS solutions and core components integration.

- DrillVR: Used for basic and advanced marksmanship training
- Gun Disassembly: Used for detailed weapon handling and maintenance training.
- Virtual Reality: Creates fully immersive scenarios for marksmanship and tactical drills.
- Augmented Reality: Overlays critical information (e.g., objectives and enemy positions) onto the physical world.

▪ Mixed Reality: Blends physical and virtual elements for realistic weapon handling

▪ Extended Reality: Combines all immersive technologies for dynamic training scenarios

▪ Virtual Battlespace Simulation Systems (VBS3/VBS4): Provide advanced simulations for squad and platoon level military operations.

D. *Training Roadmap* (roughly 2 months/ training session):

Phase 1: Preparation (Weeks 1-2)

- System setup: Installation and configuration of VBS3 and VBS4 simulation systems, setting up phase of immersive technology hardware (VR, AR, MR, XR), and integrating COTS solutions.

- Systems calibration and testing: run pilot simulations to ensure system functionality and fine-tune the realism of virtual environments and weapon systems.

Phase 2: Individual Training (Week 3)

- Marksmanship fundamentals and advanced shooting techniques (familiarization with virtual systems): Provide training on how to use VR headsets, AR glasses, and MR devices; conduct orientation sessions with World of Guns for weapon familiarization (weapon maintenance and handling training) and DrillVR (individual shooting drills and accuracy improvement).

- Introduction of dynamic shooting drills and stress-based scenarios.

Phase 3: Squad Training (Weeks 4-5)

- Team-based marksmanship: Conduct live-fire and virtual drills focusing on communication and covering fire; practice coordinated shooting and maneuvering in a simulated environment.

- Urban operations introduction: Use of VBS3/VBS4 to simulate urban settings with interactive, mission-based scenarios; introduce tactical movement in urban terrain, focusing on room clearing and building entry.

Phase 4: Platoon Training (Weeks 6-7)

- Large-Scale Tactical Operations: Transition to platoon-level exercises for large-scale coordination, practice mission planning, leadership roles, and execution of objectives.

- Urban combat scenarios: Use of VBS3/VBS4 for realistic urban combat and hostage rescue training. The integrated AI of the simulation system could help planners provide realistic crowd behaviors.

- Simulation of entire military operations, including urban infiltration and extraction, from briefing to debriefing.

Phase 5: Advanced Urban Operations (Week 8)

- Mixed reality scenarios: Blend real-world training environments with virtual elements using MR/XR technologies; create complex urban scenarios with live actors and virtual threats.

- Complex mission rehearsal: Implement high-intensity scenarios with VBS3/VBS4, focusing on multi-story building operations and coordinated assaults, introducing environmental stressors, such as low light, loud noises, time constraints, and low radio commo traffic.

Phase 6: AAR and continuous improvement (Week 9)

- Performance metrics: Measure marksmanship, response times, communication effectiveness, mission success rates, utilization of analytic tools within VBS3/VBS4, and immersive technologies to track progress.

- Feedback and iterative training: Conduct debriefings with XR and VBS-based playback of training sessions and iterative training scenarios to address weaknesses and reinforce strengths.

- Adjust training modules based on identified gaps and performance data.

An intermediate stage, such as an Airsoft training range session, can be implemented to facilitate a smooth transition from a virtual training environment to practical training. In this setting, participants can train under conditions that closely resemble reality, while still being safe. Using replica weapons and shooting at targets from shorter distances enables trainees to apply the knowledge gained in the virtual environment, fostering the development of vital skills such as accuracy, equipment control, and quick decision-making.

At the end of each training session, the participants have to receive the assessment and feedback on their performance. Instructors will offer recommendations for skill enhancement, and participants will have the opportunity to retrain in areas where they need more practice. Through this immersive experience, participants gain the skills to handle various weapon systems effectively, preparing them for real-world tactical situations.

4. Conclusions

The proposed training framework using a Hybrid Synthetic Training Environment as a solution to integrate the latest XR immersive technologies, COTS solutions, and virtual simulation systems can be a feasible, robust, and adaptable training platform. By focusing on squad and platoon marksmanship and urban operations, this solution ensures that military personnel are well-prepared for real-world military operations. The training roadmap offers a structured approach, from individual skill development to complex urban warfare simulations, to enhance readiness and operational effectiveness.

To enhance learning further, interactive demonstrations must be included in the process. Participants walked through the steps to assemble and disassemble the weapons, focusing on precision at each stage. The simulations create a safe environment in which trainees could practice applying tactical and mechanical principles without the risks involved in handling real weapons.

The training solution allows for rapid scenario changes and the introduction of diverse and challenging environments. Real-time monitoring and data analysis of the simulators offered valuable insights, enabling instructors to tailor virtual training to meet the specific needs of each participant. Nevertheless, the adoption of these technologies comes with challenges such as the high costs of equipment and infrastructure, the learning curve for instructors, and the necessity for advanced technical support. Addressing these issues is essential for further expanding their application in educational and military settings.

The incorporation of emerging and disruptive technologies such as Virtual Reality, Augmented Reality, and Mixed Reality plays a significant role in developing increasingly realistic and effective training scenarios within the defense industry. In addition, the Artificial Intelligence Agents could be employed in support of training planners in order to automate the analysis and statistical processes. The rapid advancement of innovative technologies in the training sector means that any new solution must undergo thorough testing and be integrated into a specific training framework to ensure the effectiveness and fulfillment of educational and training objectives.

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