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Extended reality in education and training: Enhancing trustworthiness

Asif Zaman *, Mushfiqur Rahman Abir and Sawon Mursalin

Computer Science & Engineering, American International University-Bangladesh, Bangladesh.

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Abstract

Extended reality (XR) technology, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), has the potential to revolutionize education by providing immersive and interactive learning experiences. However, to ensure successful implementation and adoption of XR in education, it is crucial to establish trust among all stakeholders. This paper presents a comprehensive framework for enhancing trust in XR technology in education and Training. The framework addresses key considerations such as transparency, privacy, ethical use, user training, research, collaboration, accessibility, continuous improvement, risk mitigation, and long-term sustainability. By implementing this framework, educational institutions can build a foundation of trust that fosters the effective integration of XR in education, leading to improved learning outcomes and engagement.

Keywords: Extended Reality; Trustworthiness; Transparency; Education and Training

1. Introduction

Over the past decade, extended reality (XR) technology has emerged as a promising tool in various domains, including education. By blending virtual and physical elements, XR offers unique opportunities for immersive and interactive learning experiences (1). The use of XR in education has shown a potential to engage students, promote active learning, and enhance knowledge retention (2).

The adaptation of extended reality (XR) technology in education holds significant importance in transforming traditional learning approaches and creating immersive, engaging, and effective educational experiences. XR provides students with opportunities to explore and interact with virtual environments, simulations, and three-dimensional content, enabling them to grasp complex concepts and theories in a more intuitive and experiential manner. By offering a multi-sensory and interactive learning environment, XR enhances student engagement, motivation, and information retention, fostering a deeper understanding of the subject matter. Additionally, XR facilitates personalized and adaptive learning experiences, catering to diverse learning styles and individual needs. It also enables remote and distance learning, expanding educational access and bridging geographical barriers. Moreover, XR technology promotes collaboration, critical thinking, problem-solving, and creativity skills, essential for the 21st-century workforce. By integrating XR into the education system, educators can unlock new avenues for innovative pedagogical practices and cultivate a future-ready generation of learners who are equipped with the skills and competencies needed to thrive in a rapidly evolving digital world.

Trust plays a fundamental role in technology adoption, particularly in the context of education where the well-being and development of learners are of utmost importance. Stakeholders, including students, parents, teachers, and administrators, must have confidence in the ethical use, privacy, security, and overall efficacy of XR technology. Addressing their concerns and establishing trust is essential to ensure that XR technology is embraced and leveraged to its fullest potential.

* Corresponding author: Asif Zaman

This paper presents a comprehensive framework for enhancing trust in XR technology in education and Training. The framework aims to provide educational institutions with a systematic approach to building trust and confidence in the use of XR. By addressing key considerations such as transparency, privacy, ethical use, user training, research, collaboration, accessibility, continuous improvement, risk mitigation, and long-term sustainability, this framework serves as a guide for educational institutions to establish a solid foundation of trust.

2. Literature Review

Education is a fundamental pillar of society, playing a crucial role in shaping individuals' knowledge, skills, and attitudes. Traditional educational approaches often rely solely on textbooks, lectures, and static visual aids, which can limit students' engagement and experiential learning opportunities (3, 4)

By simulating real-world environments, extended reality (XR) technologies enable students to explore concepts and phenomena that may be challenging or unfeasible to experience in conventional classroom settings (5). For example, virtual reality (VR) can transport students to historical events, distant planets, or microscopic worlds, providing them with firsthand experiences and fostering deeper understanding. AR, on the other hand, overlays digital content in the real-world environment, enabling students to interact with virtual objects and annotations in a contextualized manner. This technology can enhance visualizations, facilitate hands- on learning, and promote active engagement by bringing abstract concepts to life. Students can visualize complex structures, dissect virtual organisms, and explore interactive historical maps, all within their physical surroundings. Extended reality combines virtual and real elements, allowing students to engage with digital content while staying connected to the physical world

(6). XR technologies offer opportunities for collaborative learning, as multiple users can interact with shared virtual objects in real time. Students can collaborate to solve problems, conduct virtual experiments, or create collaborative projects, which can enhance their teamwork and communication skills. The integration of XR in education holds significant promise for addressing the limitations of traditional instructional methods. By offering immersive and interactive experiences, extended reality (XR) technologies have the potential to enhance student engagement, motivation, and knowledge retention (7). They can cater to diverse learning styles, accommodate individual places, and offer personalized learning pathways. Moreover, XR can bridge the gap between theory and practice, allowing students to apply their knowledge in authentic and realistic contexts. Despite the increasing interest and potential of XR in education, there are still challenges that require attention. These include the cost and accessibility of XR technologies, the need for adequate teacher training and professional development, and the development of effective pedagogical approaches for integrating XR into the curriculum (8). This literature review aims to explore the current state of research on the use of extended reality in education, examine its benefits and challenges, and identify future directions for leveraging XR technologies to enhance teaching and learning experiences. By analyzing scholarly articles, research papers, and conference proceedings, the aim is to provide a comprehensive understanding of the potential and implications of XR in the field of education.

2.1. Analyzing Technical Aspects of XR System

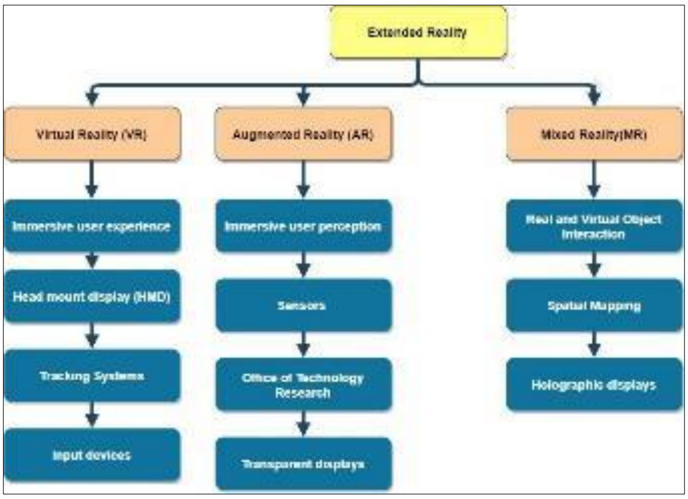

Figure 1 Key Technical aspects of Extended Reality

Virtual reality (VR), augmented reality (AR), and mixed reality (MR) are only a few of the immersive technologies that fall under the broad category of extended reality (XR). Through interactive, immersive experiences that blend components from both realities, XR can close the gap between the actual and virtual worlds. For XR to integrate the physical world with the virtual world, there are some crucial key technical aspects. Figure 1 shows those technical aspects of XR.

2.2. Virtual Reality

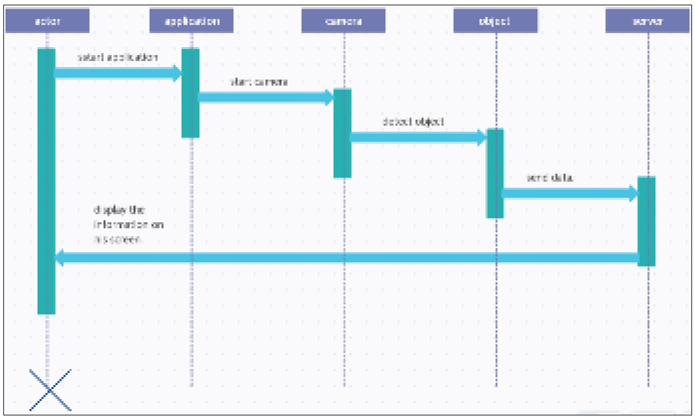

Figure 2 VR Simulation Flowchart to Connect with the Virtual World

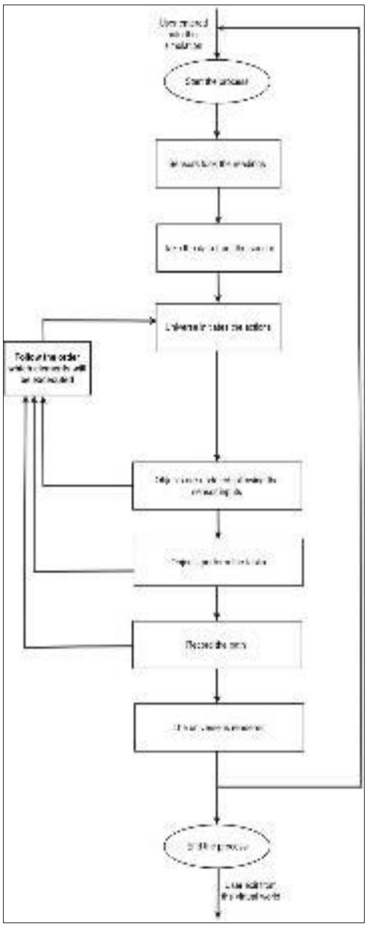

Figure 3 AR Working Simulation Flowchart

Virtual Reality (VR) provides users with a fully immersive experience by creating a simulated environment. Users wear head-mounted displays (HMDs), which include integrated displays, motion detection sensors, and audio output devices. These HMDs track the user's head and body movements, enabling real-time interactions with the virtual world. Additionally, handheld controllers or other input devices are used to interact with objects in the virtual environment.

A VR headset device or other reality technology is used in virtual reality to virtualize the world (27) entirely. It simply implies that the VR equipment controls VR users and that VR enhances a fictitious experience. VR is a different, entirely artificial environment that was produced digitally. Users of VR feel engrossed, as though they are in a new environment, and behave similarly to how they would live in the real world. This experience is enhanced by specialized multisensory devices like immersion helmets, virtual reality headsets, and omnidirectional treadmills, which combine the senses of sight, hearing, touch, movement, and natural contact with virtual things.

To render the virtual universe through a VR simulation is the bridge between the natural and mirror worlds. Through the VR simulation, the users from the real world can interact with the Metaverse in real-time.

According to WorldToolKit Reference Manual (R9) The entire simulation follows a flow to do the processes simultaneously, as shown in figure 2.

2.3. Augmented Reality

Augmented Reality (AR) enhances the user's perception of the real world by overlaying virtual content onto their surroundings. This can be experienced through smart glasses, smartphones, tablets, or specialized headgear. AR devices utilize sensors such as cameras, GPS, and depth sensors to accurately place virtual content in the user's environment. Transparent displays, such as smart glasses, enable users to view both the real and virtual elements simultaneously.

With augmented reality, a real-world environment may be improved or replaced with a simulated or virtual one using a reality technology (such as a smartphone with an AR mobile app) (29). AR improves both the actual world and the virtual world (28). Users of AR have control over both their physical and virtual presence.

The most popular software and applications for augmented reality run smoothly on mobile devices (30). They help users to access a digitally augmented world in a few simple processes. All they have to do is turn on the cameras on their smartphones, look around them through the phone's screen, and rely on augmented reality software to improve the experience. Digital overlays are used for this in a variety of ways-

- The presence of labels
- Superimposing digital images, 3D models, and other data
- Real-time instructions are inserted into navigation applications
- Changing hues according to environmental changes
- Using filters on Snapchat, Instagram, and other platforms, users can alter their appearance or surroundings (31).
- Figure 3 simulates the AR working procedure.
- Mixed Reality
- Mixed Reality (MR) combines both VR and AR, allowing users to interact with both the real and virtual

worlds. XR enables real and virtual objects to interact, with virtual objects responding to physical encounters or being anchored to real-world objects. XR systems use depth-sensing cameras or other sensors to create a 3D map of the environment, enabling virtual objects to accurately interact with surfaces and objects in the real world. Advanced optical technologies can also be employed to display virtual objects such as holograms, which can be observed from different perspectives.

Real-world and virtual (digital) objects can interact in mixed reality thanks to the combination of elements from AR and VR (32). Mixed reality (MR), which unifies these two ideas, is a technology that unifies VR and AR. The idea behind MR is to create virtual objects that let users interact with the 3D environment while immersed in a virtual world with VR or overlaid with virtual content with AR (33). Because the hardware is relatively simple and accurately reflects reality, like glasses, AR offers a more realistic solution, but it is only appropriate for brief content (34). On the other hand, VR involves physical fatigue despite covering the entire field of vision, having an immersive feeling, and being appropriate for long-form content. In some situations, MR is being explored as a solution that can be converted to AR and VR with a single device since it combines these benefits and drawbacks. The extended reality, or XR, is a concept that refers to VR, AR, and MR. Indirect experiences mediated by computers are made possible by XR in virtual commerce or v-commerce (35).

2.4. Advancements of XR

The rapid advances of Extended Reality have spurred innovation across diverse industries, transforming the way we learn, work, and entertain ourselves. As XR technologies continue to evolve and mature, their potential to shape a more interconnected and immersive world remains limitless, promising further advancements that will revolutionize various aspects of our lives. This section explores some of the notable advances of XR in contemporary research.

2.5. Non-Fungible Tokens

Digital assets known as non-fungible tokens (NFTs) signify ownership of items like photos, social media postings, movies, artworks, etc. However, NFTs are not limited to pictures, paintings, and movies; they also represent the tokenized form of real-world assets like real estate or structures (38). On the other hand, the notion of the Metaverse has been given many different definitions by different people. The Metaverse, a 3D virtual environment, aims to replicate and improve the real-world experience online (36). Many leading blockchain and technology businesses have stated their interest in the Metaverse and their intention to use it to support the goals of their various companies. For example, since Facebook has evolved into more than simply a social networking platform and Microsoft has been developing an interactive workspace dubbed the Microsoft Mesh, Facebook chose to alter the name of its parent business to Meta (37).

2.6. Web 3.0

The next stage of the Internet's development, Web 3.0, is thought to deal with many problems mentioned above. In Web 3.0, decentralized technologies are expected to replace centralized social networks and promote more open settings.

Web 3.0 is a new technology that uses a decentralized server for individuals, as shown in figure 9 below. Blockchain helps to organize the decentralization technique (24). Decentralization is essential to ensure the security of the users. A shared data layer will be available to apps developed on the blockchain, which implies that they will no longer be able to own or profit from user data (25). Additionally, it guarantees data accessibility, integrity, and authenticity so that we can always access the information and no one else can alter it. On the other hand, encryption technology makes it possible to own data since it allows data to be sent securely (26). For example, assume A sends B some bitcoin. Since B is the only one with a private key, only B can access the bitcoin. We needed a global ledger system in the past, making it impossible to transfer and receive value through the internet.

Web 3.0 uses the decentralized data server to poetize security and privacy. Users have total control over their data, including the freedom to share and keep their information private. Mainly blockchain is fundamental to web 3.0. Web 3.0 removes centralized web servers and databases for storing application state and backend logic. Instead, a blockchain shown in figure 9 can be used to create apps with a decentralized state system run by anonymous web nodes. Now there might be a question about the decentralized online economy and exchanges. Cryptocurrencies and NFT (Non-fungible tokens) are used in web 3.0 to conduct decentralized online exchanges or transactions. A cryptocurrency wallet with access to NFTs, cryptocurrencies, lending platforms, and decentralized exchanges' borrowing and lending markets (DeXs). Likewise known as a "Web 3.0 wallet." Popular Web3 wallets include MetaMask and Coinbase Wallet (see MetaMask and Coinbase Wallet). See the crypto vocabulary and Web3. On the web,

3.0 clients send an RPC (Remote Procedure Call) request to trigger the blockchain. A user may make a transaction request through the RPC interface and retrieve blockchain-related data (such as block number, blocks, node connection, etc.). All blockchain nodes must reply to an RPC request once it is initiated. Users may access data on the blockchain and submit transactions to various networks via a Remote Procedure Call node or RPC node.

2.7. The RPC layer is accommodating when creating apps, making developers' jobs much more accessible.

For instance, it would not need to create a wallet from scratch for customers to check their crypto holdings within the new DeFi liquidity farming site. Instead, it would only need to create an API that can ask to speak with the wallet to find out what the user has. Additionally, the program that creates the crypto wallet may include API-enabling code to enable compatibility with several different DeFi protocols.

Decentralized applications, accessing blockchain data without owning a user node, streamlining Web 3.0 development, using web sockets to access real-time transaction data, and accessing massive amounts of data are all made possible by

Web 3.0's RPC layer and blockchain. Figure 4 visualizes the decentralized data driven technique using Blockchain in Web3.0.

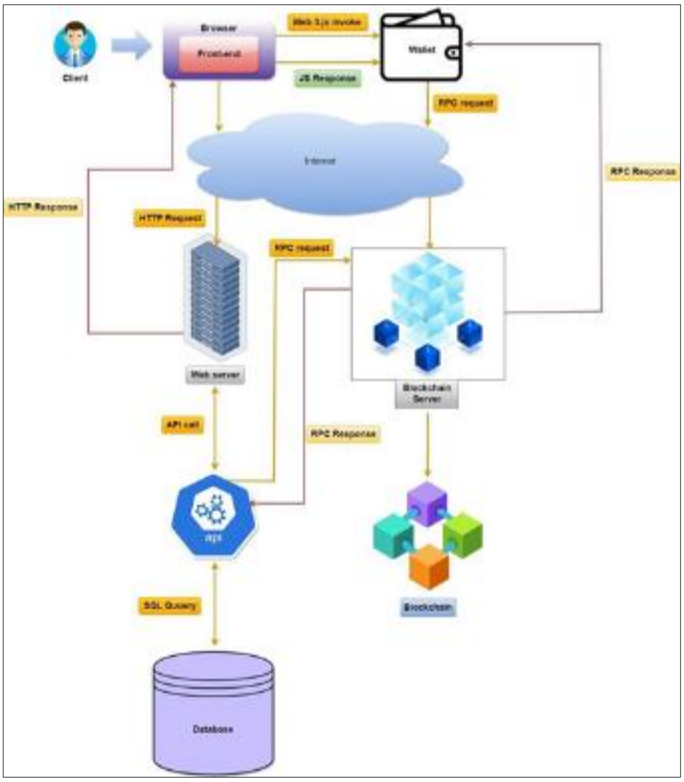

Figure 4 Decentralized Data Driven Technique Using Blockchain in Web3.0

2.8. Metaverse

The world we are living in is now extended to a world that combines the coexistence of our natural world and virtual places (14). At the same time, education, communication, and daily activities are shifting toward a world where everything interacts digitally. Metaverse combines "Meta" and "Verse," where Meta means beyond, and the verse tells the universe. In other words, it is a 3D virtual world of an integrated network where everyone can exist in both the natural world and virtual places through avatars at the same time (15). The current concept of the Metaverse differs from the earlier Metaverse in many ways. For example, deep learning helps improve vision and language recognition accuracy and creates a more mesmeric environment and natural movement where the complexity and processing time are also reduced. At the same time, now it is easier to access Metaverse from anywhere and anytime (16). As a result, Metaverse is now considered the next marvelous thing and the next version of the internet. The concept of the Metaverse is not new, as it was first described by Neil Stevenson in 1992 in his novel Snow Crash (17). However, the film "Ready Player One" brought the concept of Metaverse into the limelight of cutting- edge conversation again, where the film introduces a virtual world called "OASIS" where everyone can use their customized avatar to connect and do whatever they want based on the rules (18). Now, Metaverse is one of the most trending topics among researchers and investors where people invest a lot of money. Metaverse Group, a Metaverse investment-based real estate company, recently bought virtual land for a hilarious price of 2.43 million on a decentralized virtual reality platform familiar as Decentraland. Metaverse's overall revenue opportunity is expected to rise from USD 500 billion to USD 800 billion from 2020 to 2024 (19). On the other hand, in the world of gaming, different examples of Metaverse, like Roblox (www.roblox.com), Fortnight (epicgames.com/fortnight), and Sandbox (www.sandbox.game), are increasing at a tremendous rate (20). At the same time, an enormous number of audiences started to explore Metaverse in detail after the press briefing of Marc Zuckerberg, where he announced the name change of Facebook to Meta (44). As of May 2022, according to google trend reports, in the search engine of google, there has been a considerable increase in searches on Metaverse. Facebook and many leading tech companies like Nvidia Omniverse and Microsoft are also jumping into the world of Metaverse. In addition, famous consumer brands like Coca-Cola and Gucci are selling their non-fungible tokens (NFTs) on the Metaverse platforms (22). Non-fungible tokens are cryptographic tokens where the details of virtual asset ownership are coded to be used to own digital assets (23).

2.9. Industrial Adoption of XR

Major corporations are naturally hopping on the Metaverse bandwagon. For example, the world's most significant social media network, Facebook, announced in October 2021 that it would change its name to Meta. According to the business, the Metaverse is the ”next chapter” for the Internet and, subsequently, for the enterprise. Accordingly, Facebook announced a plan to invest 10 B USD to develop the Metaverse.

Tencent, China's largest social media and gaming company, intends to join the Metaverse. The business has strategic alliances with significant Metaverse participants like Epic Games and the game platform of Roblox. However, the ”nearest and most expansive image” of the Metaverse is probably the gaming platform Roblox, where independent creators make well-liked games by kids and teenagers.

The growth of Roblox has made it easier for us to comprehend how the video game industry is growing and expanding. Over 200 million monthly active users played hundreds of thousands of virtual games on Roblox as of November 2021. Every day in the first three months of 2021, more than 42 million players logged on to Roblox and played the game for roughly 10 billion hours. Additionally, they spent 652 M USD on the website's virtual currency to buy virtual goods like headgear, guns, and hot air balloons. Figure 5 and 6 show the investments of tech giants in Metaverse.

2.10. Case studies of the Adoption of XR: Education and Training

The Covid-19 pandemic brought about significant changes in the education and training landscape, prompting institutions worldwide to explore innovative methods to enhance learning experiences. One such technology that emerged as a powerful tool for immersive learning is Extended Reality (XR), encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). This article discusses three case studies illustrating how XR has been systematically integrated into various educational settings, transforming the way students and professionals acquire knowledge and skills.

2.11. United Nations Industrial Development Organization (UNIDO)

Immersive technologies like VR have proven invaluable in developing practical skills for workers in Morocco's skilled trade sector. UNIDO collaborated with public- private partnerships to design water-specific immersive learning experiences. Aspiring water technicians could navigate virtual water treatment facilities and address real-life scenarios, including system failures and hazardous situations. Exposure to high-risk environments in a safe and controlled capacity equipped students to handle critical situations in their future roles. These virtual offerings complemented theoretical and classroom instruction, with the curriculum being integrated into vocational training centers and universities.

2.12. Harvard's Graduate School of Education

Harvard's Graduate School of Education faced the challenge of providing effective teacher training in virtual settings. To address this, they incorporated XR in simulated field scenarios to recreate the classroom environment. Teachers engaged in professional learning could interact with student avatars controlled by live simulation specialists, allowing them to practice adjusting their teaching practices based on student responses. Mixed Reality (MR) simulations provided standardized settings with personalized feedback, enabling teachers to rehearse and refine specific skills. Emerging research suggests that simulations benefit teachers of all experience levels, with coaching and self- reflection enhancing their growth.

Tech Company	Investments in the Metaverse
Amazon	In an effort to solidify its hegemonic position in the market, Amazon has been working on a "new VR shoppingexperience" since 2018 and is attempting to leverage Metaverse to build a virtual store where customers can interact with digital goods.
Roblox	The only restriction is one's imagination; players can design their own virtual environment or other games. To improve user immersion, Roblox supports VR devices. Roblox has grown to be the biggest user-generated content (UGC) game platform in the world, supporting iOS, Android, PC, Mac, and more platforms.
Facebook	Facebook released the virtual reality social platform Facebook Horizon in September 2019 and opened a public beta in August 2020. Facebook said that it will take over as the Creating a Metaverse firm within five years and investing at least $10 billion in its Reality Labs are the goals of the Metaverse project team. Facebook announced in October 2021 that it would change its name in Meta.
Epic Games	Epic Games made a $1 billion investment announcement in April 2021 to create a metaverse, and bought Skethfab, the biggest 3D model site, to take over Skethfab's user traffic and expand its market share in the metaverse.
Disney	Building a "theme park metaverse," according to Disney's chief technology officer Tilak Mandadi, will be the next development in the company's theme parks.
Snap Chat	In order to saturate the globe with digital content, Snapchat created personalized avatars and filters. The Bitmoji service, which allows users to pose for real-world photos and make their own 3D Bitmoji characters, was just introduced by Snapchat.
Nvidia	Nvidia released the Nvidia Omniverse plan on August 11, 2021, with the goal of developing the first virtual collaboration and simulation platform.
Microsoft	Microsoft is cautious about Metaverse. Wei Qing: The "Metaverse" has practical value only when it returns to the physical world.
Decentraland	The first fully decentralized virtual world owned by users is a VR one built on Ethereum. Decentraland's primary focus is art, and it has a section for the display of digital artwork.
Tencent	Tencent has made a number of investments in the Metaverse ecosystem, such as the "Avakinlife" game, the Spotify music streaming service, etc. In September 2021, Tencent requested for the registration of the "Kings Metaverse" and "TiMi Metaverse" trademarks.
Alibaba	Alibaba submitted applications to register trademarks like "Ali Taobao Metaverse" and "Metaverse" ". The Metaverse is divided by XR Lab's director Tan Ping, holographic construction in layer L1, holographic construction in levels L2, and L3 (virtual and actual fusion), L4 (virtual and real simulation, linkage).
Byte Dance	ByteDance has invested in visual computing and AI computing platform More Thread, owns popular platforms like Douyin, produced the game "Restart the World," and purchased PICO, a Chinese manufacturer of VR equipment.
NetEase	The design of Metaverse by NetEase is centered on the gaming industry and offers simple tools for game creation. The business made investments in both the IMVU virtual character platform and IMPROBABLE's meta-computing technology, which enables third parties to create virtual worlds.
Shenzhen Zqgame Co.Ltd	A leading Chinese game studio is Zqgame. Zqgame published the BrewMaster preview on September 6, 2021. Players can launch enterprises in this game and see how they will affect real-world situations.

Figure 5 Investments of Tech Giants in Metaverse: Part A

Tech Company	Investment in the metaverse
Wondershare Technology Group Co.,Ltd	Realibox has received funding from Wondershare Technology to improve its business model in the AR/VR space and give a strong technical foundation the Metaverse's initial deployment's basis
Sony, Hassilas	The first Japanese Metaverse platform is called Mechaverse. On this platform, businesses may swiftly launch new products and give participants access to 3D model tests and video introductions.
GREE	GREE's subsidiaryREALITY manages the Metaverse business. By 2024, it is projected that 10 billion yen would have been spent on acquiring more than 100 million users worldwide.
Avex Business Development, Digital Motion	The partnership between Avex Business Development and Digital Motion Virtual Avex Group, which intends to offer virtual artist activities, advertise existing animated or video game characters, and virtualize real-artist performances and other events.
SAMSUNG	SAMSUNG has launched the "Samsung Global Metaverse Fund".
SK Telecom	In July 2021, SK Telecom unveiled "ifland," a virtual setting where users can host and take part in meetings using animated characters.
Urbanbase	A 3D spatial data platform for the creation of interior design and real estate is called Urbanbase. In the B+ funding round, the company raised 13 billion won (about 450 million yuan). The cash will be employed to create the 3D and VR/AR technologies Urbanbase must go into the Metaverse.
Metaverse Alliance	25 organizations and businesses have been established by the Korean Information and Communications Industry Promotion Agency to the "Metaverse Alliance" to create the Metaverse ecosystem with the assistance of the public sector creating an open Metaverse platform in various spheres of reality and virtuality, and fostering commercial collaboration.
Sotheby's	53 works from NFTart collections were on display at once as part of the "Natively Digital 1.2: The Collectors" special auction, which was staged by the British auction house Sotheby's.
Maze Theory	A "fanMetaverse" based on well-known IPs and fanuniverses will be developed by the renowned British VR studio Maze Theory.
MetaDubai	In order to create the most comprehensive virtual world picture, economic system, and applications feasible, MetaDubai is developing a Metaverse city in Dubai based on blockchain, NFT, AI, and decentralized data storage.
Ripple	Ripple, a blockchain payment business, has announced plans to open a regional office at the Dubai International Financial Center (DIFC).
Stage11	The European venture capital firm Otium Capital led a €5 million investment round that Stage11, a French Metaverse music platform, closed to produce immersive Metaverse music.
RIMOWA	RIMOWA, a German luxury luggage company, announced in May on Instagram that it would collaborate with design firm NUOVA to release four NFT artworks titled "outlines from the Metaverse."
Gucci	Gucci, an Italian luxury brand, has introduced virtual athletic footwear. Customers can utilize the Gucci bags after purchasing the shoes. Try them out on the gaming site Roblox, the VR social platform VR CHAT, or both.

Figure 6 Investments of Tech Giants in Metaverse: Part B

Figure 7 Architecture of XR in Education and Training

2.13. Stanford University and Masinde Muliro University of Science and Technology (MMUST)

During the pandemic, faculty at Stanford University collaborated with MMUST in Kenya to teach anatomy and emergency preparedness using XR. The immersive medium allowed medical and paramedical students to explore three-dimensional organs with real-time guidance from world-class instructors. The students could manipulate the models, zoom in and out, and examine specific areas, fostering hands-on learning experiences. This application of XR aligns with the constructivist theory of learning, empowering learners with agency and experiential learning. Anecdotal evidence from professors indicated increased student engagement and improved comprehension, application, and knowledge retention.

2.14. Architecture of XR in Education and Training

Extended reality (XR) blends the physical and digital worlds, enabling users to engage with virtual objects and environments while remaining cognizant of their actual surroundings. This technology has the potential to revolutionize education by providing engaging and interactive learning experiences that enhance understanding, retention, and student participation (9). The implementation of extended Reality has brought about the implementation of immersive education, realistic visualization, interactive learning etc as shown if figure 7.

Immersive learning is a central aspect of XR in education, enabling students to explore and interact with virtual objects, simulations, and 3D models. This hands-on approach fosters a deeper understanding of complex concepts, such as scientific experiments, historical events, or architectural designs (10). Students can visualize abstract ideas and interact with them in a more meaningful way, enhancing their grasp of the subject matter.

Visualization and spatial understanding are further enhanced by XR technology, allowing students to visualize and manipulate objects and data in three-dimensional space. This facilitates a better understanding of complex structures, virtual organisms, and astronomical phenomena (11). By immersing themselves in these virtual environments, students develop spatial reasoning skills that are valuable across various disciplines.

Collaborative learning is strengthened by XR, enabling students to collaborate in shared virtual spaces, regardless of their physical locations (12). This fosters teamwork, communication skills, and cooperation as students work together on projects, solve problems, and exchange ideas in real-time.

Personalized learning is a critical advantage of XR in education. Adaptive learning systems can assess students' progress and provide personalized feedback and content tailored to individual strengths and weaknesses (13). This customization enhances engagement and motivation as students receive content and challenges aligned with their abilities and learning styles.

Extended Reality (XR) is poised to revolutionize education in the next decade. XR offers tailored, interactive, and engaging learning experiences, enhancing students' understanding, retention, motivation, and engagement. Subjects like physics and history can be taught through virtual environments and historical settings. XR enables virtual field trips and simulations for hands-on learning and skill practice. However, challenges include high implementation costs, safety concerns, and the need for equitable access. Despite challenges, XR has undeniable potential to transform education by providing a better learning experience in a safe and immersive environment.

2.15. Trustworthiness

Artificial intelligence has significantly altered our lives and will do so going forward. It is being used in increasing industries and situations and has started raising new ways to solve several real-world issues. Nevertheless, it still has several problems that prevent its adoption in applications for enhancing user interactions and system performance. The extensive use of AI and its close ties to business and society have increased productivity and generated advantages. It will also unavoidably influence the current social order and raise ethical questions. Artificial intelligence techniques are commonly used in data analysis to learn from user behaviors, assist choices, track pertinent user characteristics, and notify specific occurrences as needed. However, most existing techniques have not considered the user-specific trust requirement for composite services. Trust is a crucial indicator to determine if a composite service can perform as the user expects. Deploying and integrating complicated autonomous systems into our daily lives will become a substantial undertaking as they become more commonplace. The connection of trust between machines and humans is increasingly recognized as one of the critical characteristics of successful integration. The correct usage of machines and independent systems depends on their human-machine correspondence in settings of human-machine interaction. Trustworthy Artificial Intelligence can resolve these issues. From Trustworthy Computing to Trustworthy Artificial Intelligence till now, is shown in figure 8.

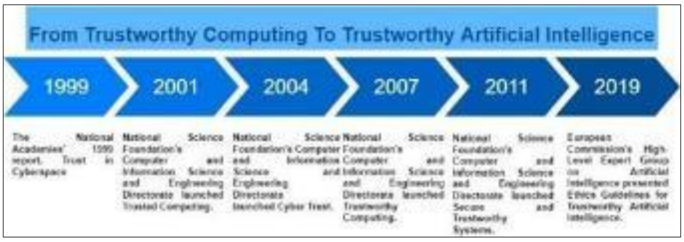

Figure 8 Timelines of the Advancements of Trustworthy Artificial Intelligence

2.16. Way of Trustworthiness: Formal Verification

Several defects have recently been discovered in computer systems, ranging from concurrency faults to security flaws to network failures. While some significant problems are caused by implementations deviating from the design specification, others are attributable to errors in the system design or specification (40). Formal verification, in which qualities are definitively established over a broad area, is one method for increasing end- user trust in computer systems. If, on the other hand, a counterexample is found during the verification process, this information may be used to enhance the system (39). Strong accuracy guarantees based on mathematical proofs are provided by formal method verification, which is also good at finding difficult-to- find defects. Formal verification can be done manually or automatically. The advantage of formal verification is that it eliminates the need to thoroughly verify each unique input value or action, which is impractical for vast state spaces. Today, companies like Intel, IBM, Microsoft, and Amazon employ these methods in the hardware and software industries (41). In recent years, formal verification has experienced a new wave of interest due to the increasing size and complexity of formal modeling languages, algorithms and tools, and hardware and software (42). Formal verification is a means to offer verifiable assurances and boost confidence that the system will function as intended. Figure 9 shows the internal architecture of two types of formal verification model.

2.17. Enhancing Trustworthiness of XR in Education and Training

It is necessary to accurately account for the elements impacting trust and quantify their relative relevance to calibrate trust for successful human-machine interaction.

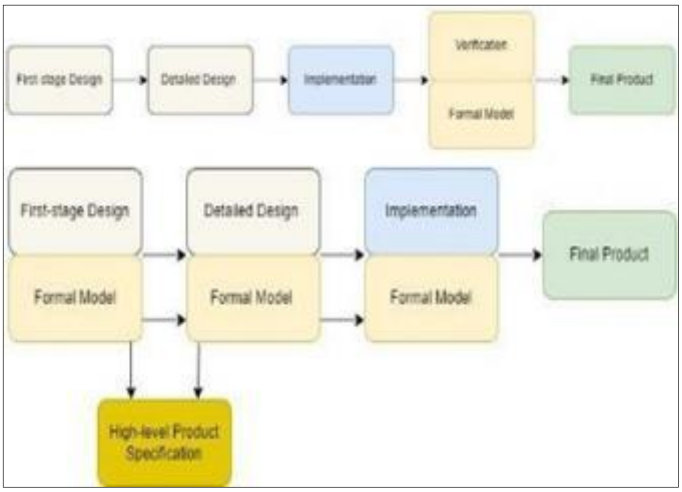

Figure 9 Architecture of Formal Verification Model: Traditional and Machine Learned

This article discusses the human-centric and machine- centric viewpoints on the functional understanding of human-machine trust. The discussion's human side explains the variables, scales, and methods that may be used to gauge and quantify trust in people. The consideration of the machine component includes ethical frameworks for trustworthy machines, built-in machine guarantees, and trustworthy artificial intelligence. Most people take Artificial Intelligence-based technology as a blank space that they do to trust based on their personal experience because most of the approaches are the basis of a mathematical term that is challenging for the public to grasp. However, many security risks, such as unauthorized access and suspicious behavior brought on by a lack of verification architecture, influence the social interaction between objects. Others include trying to portray a harmful item accurately to win the trust of other things. Modern Deep Learning and Big Data analytic-based Artificial Intelligence systems, however, demand substantial computation and communication resources, which results in losing privacy throughout the training and reasoning phases. Fundamentally broken down into the trust, privacy, and cyber resilience domains, as well as the intersections between each. Numerous principles and tools have been made available internationally. However, only a small number have been adopted at the community level, primarily owing to a lack of information, ability, and resources (21).

Extended Reality (XR) is gaining popularity among organizations and educational institutions. However, its widespread adoption has raised ethical concerns. XR can be misused for accessing sensitive information, data manipulation, and behavioral monitoring. This has prompted organizations to develop guidelines and best practices for responsible XR use. Ensuring privacy, security, and safeguarding against misinformation and manipulation are crucial aspects of responsible XR use. By taking appropriate measures, organizations can leverage XR in a safe and secure manner for all users. A comprehensive framework for enhancing trust in XR in education is shown in figure 10.

Figure 10 Assessing Trust of Extended Reality in Education and Training

Transparency and Information: Ensure transparency in the use of XR technology by providing comprehensive information to all stakeholders, including students, parents, teachers, and administrators. This information should cover the purpose of XR implementation, the data collected, the security measures in place, and the potential benefits and risks involved.

Privacy and Data Security: Prioritize privacy and data security to build trust. Establish clear policies and guidelines for data collection, storage, and usage. Adhere to privacy regulations such as the General Data Protection Regulation (GDPR) and implement robust security measures to protect sensitive data.

Ethical Use and Content Standards: Define ethical guidelines for the use of XR in education. Ensure that XR content aligns with educational standards and values, promotes inclusivity and diversity, avoids bias, and encourages responsible and respectful behavior.

User Training and Support: Provide comprehensive training and support to all stakeholders involved in using XR technology. Educators should receive training on integrating XR into the curriculum effectively, while students should be taught about responsible XR use and digital citizenship.

Research and Evaluation: Foster ongoing research and evaluation of XR technology in education. Conduct studies to assess the impact of XR on learning outcomes, engagement, and accessibility. Share research findings transparently to build confidence in the effectiveness and educational benefits of XR.

Collaboration and Community Engagement: Foster collaboration among educational institutions, technology developers, researchers, and policymakers to collectively address challenges and share best practices. Engage the educational community through conferences, workshops, and forums to promote dialogue, gather feedback, and encourage continuous improvement.

Accessibility and Inclusivity: Ensure that XR technology is accessible to all learners, including those with disabilities and diverse learning needs. Develop XR applications and content that accommodate different learning styles, support multiple languages, and provide customization options for individual preferences.

Continuous Improvement and Iteration: Maintain an iterative approach to XR implementation in education. Regularly seek feedback from users and stakeholders, and use that feedback to refine XR applications, content, and policies. Embrace new technological advancements and adapt the framework accordingly to stay up to date.

Risk Mitigation and Contingency Planning: Identify potential risks associated with XR implementation and develop mitigation strategies. Establish contingency plans to address technical issues, disruptions, or emergencies that may arise during XR sessions. Proactive risk management can instill trust and confidence in technology.

Long-term Sustainability: Develop a long-term sustainability plan for XR implementation in education. Consider factors such as infrastructure requirements, device management, software updates, and budgeting. Ensure that the technology remains reliable and supported over time to prevent trust erosion.

2.18. Limitations and Future Research Opportunities

Extended Reality (XR) has the potential to revolutionize education by creating immersive and interactive learning experiences. However, there are several challenges that need to be addressed, along with future research opportunities, to fully realize the benefits of XR in education. Some of the key challenges and research opportunities- Hardware Limitations: One of the primary challenges in implementing XR in education is the need for specialized hardware such as headsets and controllers, which can be expensive and limit accessibility. Future research opportunities lie in developing cost-effective and lightweight XR devices that are comfortable and easy to use for extended periods, making them more accessible to students and educators.

Content Creation and Integration: Creating educational XR content requires specialized skills and resources. Integrating XR seamlessly into existing curricula and learning management systems is also a challenge. Future research can focus on developing intuitive content creation tools and standards that allow educators to easily create and customize XR experiences. Additionally, exploring effective methods of integrating XR into traditional teaching methods and curriculum frameworks is essential.

Pedagogical Approaches: Designing effective pedagogical approaches that leverage the unique capabilities of XR is crucial. Identifying the best ways to use XR for different subjects, learning styles, and age groups requires ongoing research. Investigating how XR can enhance collaboration, critical thinking, and problem-solving skills can provide valuable insights for educators.

Technical Stability and Performance: XR experiences need to be stable and perform well to ensure an immersive and comfortable learning environment. Reducing latency, improving image quality, and optimizing real-time rendering are research areas that can enhance the technical stability and performance of XR systems. Advancements in computer vision, graphics processing, and network infrastructure are crucial in this regard.

User Interface and Interaction: Developing intuitive and user-friendly interfaces for XR applications is essential to ensure smooth interaction between users and the virtual environment. Research opportunities lie in exploring novel input methods, gesture recognition, voice commands, and haptic feedback to improve the user experience in XR educational applications.

Accessibility and Inclusivity: Ensuring XR experiences are accessible and inclusive for all learners, including those with disabilities, is a significant challenge. Future research can focus on developing accessibility guidelines, techniques, and tools that cater to diverse needs, such as providing alternative modes of interaction and accommodating visual impairments.

Ethical Considerations: The use of XR in education raises ethical concerns related to privacy, data security, and content appropriateness. Ongoing research is needed to establish ethical frameworks, guidelines, and policies that address these concerns, ensuring the responsible and ethical use of XR technologies in educational settings.

Assessment and Evaluation: Designing effective methods for assessing and evaluating learning outcomes in XR environments is an ongoing challenge. Future research can explore innovative assessment approaches that capture the unique benefits of XR, such as tracking and analyzing user behavior, performance, and engagement data to provide meaningful feedback to students and educators.

Cost and Scalability: Implementing XR in education can be costly, requiring investments in hardware, software, and infrastructure. Future research can focus on cost-effective solutions, such as cloud based XR platforms, that reduce the financial burden on educational institutions and enable scalability across classrooms and educational settings.

Teacher Training and Professional Development: Equipping educators with the necessary skills and knowledge to effectively incorporate XR into their teaching practices is crucial. Research opportunities exist in developing comprehensive training programs, professional development initiatives, and communities of practice that support educators in harnessing the full potential of XR for improved learning outcomes.

3. Conclusion

Enhancing trust in extended reality (XR) technology is critical for its successful implementation and adoption in education. By implementing the comprehensive framework presented in this paper, educational institutions can establish a solid foundation of trust among students, parents, teachers, and administrators. Transparency, privacy, ethical use, user training, research, collaboration, accessibility, continuous improvement, risk mitigation, and long-term sustainability are key considerations that form the pillars of this framework. By prioritizing these aspects, educational institutions can create a trustworthy XR ecosystem that maximizes the educational benefits of XR technology while mitigating potential risks. With enhanced trust, XR has the potential to revolutionize education by providing immersive and engaging learning experiences that empower learners and prepare them for the future.

Compliance with ethical standards

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