This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

Constructing an Edu-Metaverse Ecosystem: A New and Innovative Framework

Minjuan Wang, *Member IEEE*, Haiyang Yu*, Zerla Bell, Xiaoyan Chu

***Abstract*—The Metaverse is a network of 3D virtual worlds supporting social connections among its users and enabling them to participate in activities mimicking real life. It merges physical and virtual reality and provides channels for multisensory interactions and immersions in a variety of environments [1]. Metaverse is considered the third wave of the Internet revolution, and it is built on new and emerging technologies such as Extended Reality (XR) and Artificial Intelligence (AI). Research on the impact of the Metaverse on education exploded in 2022. Here we explore learning across the Metaverse and propose a new and innovative theoretical framework by reviewing literature and synthesizing best practices in designing metaverse learning environments.**

This Ecosystem consists of four major hubs: A) Instructional design and performance technology hub, B) Knowledge hub, C) Research and technology hub, and D) Talent and training hub. Common to all four hubs are the factors in the three wheels (Fig. 8): a) Infrastructure, business industry, and communication: b) technology access and equity, and c) user rights, data security, and privacy policy. We believe that this framework can help guide emerging research and development on the applications of Metaverse in education. We also hope this paper can serve as a launch pad for the special issue on Metaverse and the Future of Education supported by the IEEE Education Society.

***Index Terms*— Metaverse, Metaverse for Education, Theoretical framework, Ecosystems**

I. INTRODUCTION

THE term Metaverse actually originated in 1992's science fiction novel *Snow Crash* by Neal Stephenson but only became a "buzzword" with Facebook's company name change to Meta in 2021. In December 2021, the first Metaverse Summit was held through live social media broadcast in China, which attracted thousands of participants and marked the official start of the Metaverse era in Asia. Soon after, hundreds of new technology start-ups emerged around the world and are all focused on developing platforms and applications for the Metaverse. A new wave of entrepreneurship spurred the fast development and application of the Metaverse in mostly Entertainment, E-commerce, and Education.

From a technology perspective, the Metaverse is considered the third wave of the Internet revolution, and it is built on new and emerging technologies including XR (extended reality), 5G, AI, data processing, etc. [2], [3]. XR includes Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and 3D photos and videos. Scholars around the world also acted quickly upon this new development and are exploring how the Metaverse can be used in teaching and learning and what impact it will generate on the future of education [1], [2].

In particular, there are crucial ethical issues related to the Metaverse and XR technologies, including privacy, equity, accessibility and intellectual property. Currently, it seems that corporations and capitals are driving the development of the Metaverse and its use in various sectors of society. When an intervention is profit-driven, ethical issues might not be at the core of consideration. The vast digital divide in the past decades is an example of it. When the world is still trying to bridge the digital divide, we might face a new "Metaverse divide". The latter is a term that emerged at IEEE-sponsored iLRN (immersive learning research network) 2022 conference, during a workshop conducted by the IEEE Education Society's Technical committee on immersive learning (TLC). Here we define "Metaverse divide" as the division of users who can and cannot access the metaverse worlds and technologies, which may give rise to the disparities in information and resource acquisition. Therefore, what can policymakers and educators do to prevent the spread of new inequities and divides associated with the educational metaverse environments?

Here, by defining Metaverse for Education (Eduverse) or Educational Metaverse (Edu-Metaverse as we coined in this paper) and constructing a new theoretical framework (an Ecosystem), we aim to provide a clearer vision and understanding of the various metaverse worlds, so as to raise international awareness of the Metaverse' social and educational impact. We believe that this new Edu-Metaverse framework is groundbreaking and can serve as a foundation for the fast-emerging research and development endeavors in this arena.

This paragraph of the first footnote will contain the date on which you submitted your paper for review, which is populated by IEEE. *(Corresponding author: Haiyang Yu).* Haiyang Yu and Zerla Bell are co-second authors.

Minjuan Wang and Zerla Bell are with San Diego State University, San Diego, CA 92182 USA (e-mail: mwang@sdsu.edu, zbell9805@sdsu.edu). Second and corresponding author Haiyang Yu is with Jilin University, Changchun, 130012 China (email: hai_yang@jlu.edu.cn). Third author Xiaoyan Chu is with Zhejiang University, Hangzhou, 310058 China (email: xiaoyan_chu@zju.edu.cn).

This research is mainly a systematic review and analysis of documents, tools and platforms in the public domain and therefore does not involve any human subjects.

Color versions of one or more of the figures in this article are available online at http://ieeexplore.ieee.org

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

II. Literature Review

A. The Metaverse and Its Unique Features

Recent research [2], [3] revealed that Metaverse has the potential to facilitate the digital transformation in every aspect of our physical lives, including social networking, e-commerce, education, games, and digital currency. At the core of the Metaverse stands the vision of an immersive Internet. As a gigantic, unified, persistent, and shared realm catalyzed by emerging technologies such as XR, the Metaverse is considered the digital 'big bang' of cyberspace and the catch-all term for immersive technologies used to access it. When applied to teaching and learning, the Educational Metaverse (Edu-Metaverse) has been used in various settings from K-12 to higher education to corporate training.

Additionally, both research [2], [3] propose an XR-driven ecosystem: the digital twins-native continuum, a virtual environment blending physical and digital worlds facilitated by the convergence between the Internet and web technologies. Microsoft and the social media giant Meta are leading the way in mapping the design for industry standards along with the Metaverse Standards Forum. These efforts would make the companies' nascent digital worlds compatible (real-world interoperability) with each other [4], helping to bridge the digital divide gap and to prevent the potential “Metaverse divide” as defined by the technical committee on immersive learning housed in IEEE’s Education Society.

Min and Cai [5] ascribe three aspects of the Metaverse that make it differ from conventional VR or AR: “shared,” “persistent,” and “decentralized.” While “shared” and “decentralized” are familiar terms to most, “persistent” is somewhat abstract. Some define persistent as the existence of Metaverse regardless of time, space and the user’s presence [5]. In addition, AI is a required technology to enable the world of the Metaverse to work following the rules defined by the creator. Thus, an AR or VR system could be part of the Metaverse for presenting the virtual content. Moreover, “decentralized” technologies (e.g., blockchains) are required to ensure that economic activities can be safely conducted and that personal property and signing in the Metaverse will not be modified by others, except by the creator or administrators.

One aspect of immersion that the Metaverse can provide is through the use of avatars. In addition to multiple applications, to experience Metaverse to its fullest, emergent technologies such as wearable devices are highly recommended [6]. For example, the CEO of Meta Platforms, Mark Zuckerberg, labeled the Helmet Mounted Display (HMD) such as Oculus, as a "social computing platform" [7]. Moreover, some scholars have indicated that, in addition to VR and AR, the advancement of brain-computer interfaces (BCI) will further facilitate the adoption of the Metaverse [1]. A BCI is a device that translates brain signals into commands that a computer or other machine can execute; BCIs are still in development, but they hold great promise for people with cognitive learning impairment [8].

B. The Metaverse: Applications and Educational Platforms

The advent of immersive technologies has further promoted the wider use of metaverse tools and technologies in teaching and learning. Students in a metaverse world supported by XR technologies can interact with teachers and communicate with classmates through their avatars, creating an immersive learning opportunity that enhances the students' learning motivation. For instance, Siyaev and Jo [9] investigated the use of mixed reality (MR) in industry maintenance to provide an engaging learning experience for aircraft maintenance. Crespo *et al*. [10] analyzed educational virtual environment applications and the dissemination of knowledge in free courses in the Metaverse using OpenSim. Saundarajan *et al*. [11] researched Photomath, an AR mobile learning app for teaching mathematics. Their findings showed that applying AR in mathematics can enhance students' learning outcomes. Furthermore, Park and Kim [12] identified the types of world in the Educational Metaverse, including survival, maze, multi-choice, racing/jump, and escape rooms.

Table I below displays exemplary applications of the Metaverse in K-12 and higher education. The Edu-Metaverse framework presented in this paper (Fig. 8) is derived from research, development, and exemplary use cases.

TABLE I
Recent Metaverse Platforms for Education

Metaverse Platform	**Characteristics**
SLOODLE, a dynamic learning environment which links 3D virtual environment to an open source learning management system (LMS) [13]	An interactive and immersive laboratory to teach algorithms and programming
Immersive Journalism [14]	Characterized by the representation of events on a spherical stage generated from real images that the user can control, giving the sensation of being present in the place; collaboration activity designed to develop speaking skills
VoRtex [15]	Primarily designed to support collaborative learning activities with the virtual environment Designed to support educational standards
VR-making and metaverse-linking for instructional content [16]	Represents an open-source accessible solution developed using modern technology stack and metaverse concepts; Designed for pre-service English teachers in instructional VR content design of K–12

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

	English digital textbooks
VRChat, AltSpaceVR, EngageVR, Virbela, Sansar, High Fidelity, Sinespace, Somnium Space, Mozilla Hubs, Decentraland, Spatial and Meta Horizon Worlds, etc. [1]	Third generation social VR environments offering sensory immersion; Offering an embodied user representation, a series of tools for online education and meetings, and access through devices beyond VR HMDs.
Cave Automatic Virtual Environment (CAVE) Immersive VR [17]	A serious game for developing cognitive skills in (a) fire prevention, (b) fire extinguishment, and (c) school evacuation
Virtual worlds types for creating gameful experiences [12]	Access to the Metaverse where they interact with other users and provision of equal educational opportunities.
Agents Virtual Laboratory (AViLab) gamified system [18]	An educational tool dedicated to experimentation and demonstration regarding an agent's features and basic principles.

C. Metaverse and Metaversity: Exemplary Platforms

There are currently many platforms and applications in both VR and AR, with new ones being designed and developed in countries that are leading the Metaverse movement (e.g., China, USA, Latin America and some of the European countries). Here we choose to showcase the ones that are in larger scale and are widely used. In addition, all authors have experienced these platforms through teaching, learning or conferencing. For example, Virbela Open Campus has been running at the forefront of the VR environments. During the peak of the pandemic (2020-2021), Virbela became a major platform for hosting international conferences. The Immersive Learning Research Network (iLRN), a fast growing nonprofit organization led by scholars from North America and Europe, partnered with Virbela to construct a multi-functional campus for research, conferencing, and teaching.

Following are screenshots taken from the IEEE's flagship TALE conferences that were successfully held on the iLRN's campus (see Figs. 1-3). Figure 4 shows a guided field trip of iLRN's campus, which is similar to a teaching session some universities are conducting in this environment.

Fig. 1. A conference committee meeting in Virbela

Fig. 2. Keynote session (stage and audience)

Fig. 3. A virtual exhibition hall in IEEE-TALE conference

Fig. 4. A teaching session in iLRN's Virbela campus

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

With the popularity of the Metaverse worlds, Metaversity (Meta-University) is also on the rise. A Metaversity is defined as a higher education university that has been recreated as a digital twin using XR technologies. One of the major players is again Virbela in an online Micro-MBA collaboration program, Virbela was able to replicate the dynamics and design of the campuses of the University of California, San Diego (UCSD) in California, USA and Waseda University in Tokyo, Japan. The tailored international virtual campus boasts the pillars of spatial togetherness, interactive presentations, and collaborative work in real-time. According to Cynthia Hanson, Director of Strategic Innovation and Educational Technology at UCSD, "Virbela enriched the overall learning experience by promoting collaboration, stimulating discussion, and creating a feeling of spatial togetherness — components that some find lacking in today's online learning modalities" [19, Para 3].

Another major player behind Metaversity is VictoryXR, which aims to create immersive learning experiences by using VR and AR. They also provide educators with training and 3D objects to teach various subjects [20].

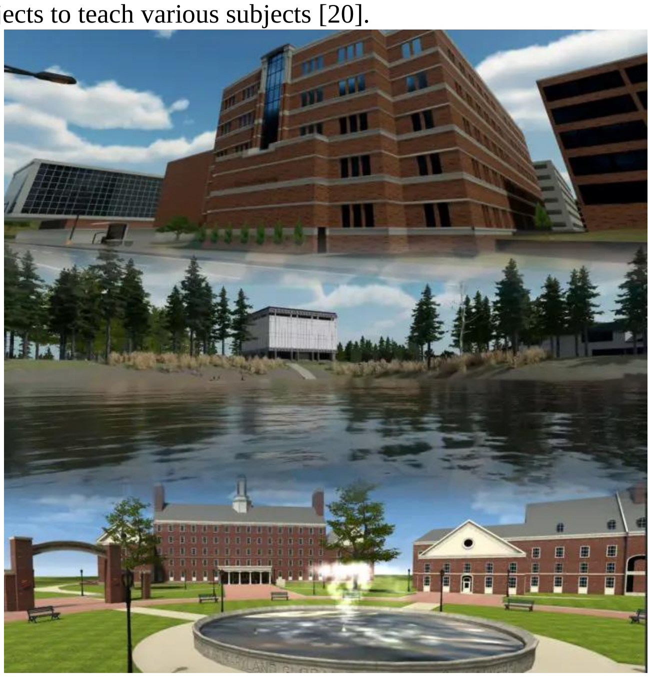

Fig. 5. A virtual campus featured by VictoryXR [20]

According to its website, VictoryXR currently (at the time of publishing) has 14 clients in its Metaversity initiative, including both high schools and higher-educational institutions. These Metaversity campuses can operate in both synchronous and asynchronous mode, and can include many different types of learning classrooms such as starship, dinosaur island, an art history museum, etc.

D. Emergent Teaching and Learning in the Metaverse

Table II displays a sampling of emergent trends that show potential teaching and learning application for framing a sustainable Edu-Metaverse. For example, industrial, manufacturing, healthcare, and like institutions wherein research funding is readily available to use the Metaverse to learn concepts and real-world use cases. Such practice can also bring transformative outcomes to the global education system.

TABLE II
EMERGENT TEACHING AND LEARNING IN THE METAVERSE

Metaverse Platform	Application
Smart Factory [21]	Different combinations of modern technologies to create a hyper-flexible, self-adapting manufacturing capability.
Robotics Metalaboratory [22]	Designed for robotic neuro-ergonomics; a novel “twinning design” concept based on physical replicas of physical twin (PT) components enriched with virtual models and computational features.
Serious Game-based Digitally Enhanced Advanced Services (DEAS) [23]	Designed to educate players about services offered by the manufacturer and the multiple benefits of the service agreement
VR-based simulations on Oculus Quest HMDs [24]	Designed for maritime industry safety training
Aircraft Maintenance enhanced with a speech interaction [9]	Provides guidance and supervision during the maintenance process, delivering trainees step-by-step instructions, MR visualizations, and aircraft operation manuals to complete maintenance, repair, and overhaul (MRO) tasks
Digital pathology system [25]	Designed for use in medicine that requires high-fidelity image; Involving blockchain-based smart contracts using nonfungible token (NFT) standard and Interplanetary File System for data storage
Smart glass-Assisted Interactive Tele-mentoring (SAIT) [26]	Mentors and Mentees of Different Levels; Sharing of First-person and Eye-level View via Smart glass; Extended Use Cases with Bi-directional Interaction.

III. OTHER MODELS THAT ARE RELATED TO EDU-METAVERSE

Previous research has attempted to draw models that can reflect the nature of the Metaverse. There have also been models describing the ecosystem of technology. However, there is a lack of theoretical framework delineating the structure of

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

the Metaverse for education and the associated factors. For example, the Seamlessness, Presence, Interoperability, Concurrence, and Economic flow (SPICE) model (Fig. 6) by Hwang and Lee [27] features the Metaverse as a continuous connection between various experiences on a single platform. In this environment the user spatially or temporally feels they are on the platform (sense of presence) even though physical contact is impossible and where data and information are interconnected in the real world (interoperability). Multiple users can simultaneously acquire different experiences and information (concurrence). As in the real world, in the Metaverse, economic market principles thrive (economic flow).

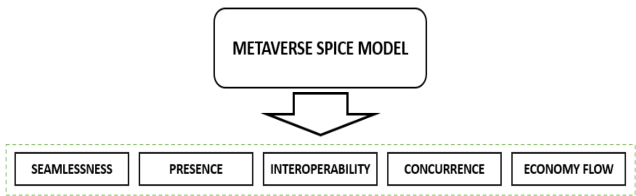

Fig. 6. The Metaverse SPICE model [27]

Darko, currently serving as the head of AR developer relations at Snap Inc., proposed a Tech Ecosystems (Fig. 7) in 2019, which is "an interconnected and interdependent network of diverse entities coming together to spur innovation in the tech environment pertaining to products and services in a sustainable manner" [28, Para #6]. This framework consists of six critical components: Strong developer community, Engagement and connection, Established businesses and companies, Accelerators and tech Hubs, Tech-focused startups, and Universities and schools. Based on this model, Darko discussed convincingly how ecosystems can support growth and innovation sustainability in technology.

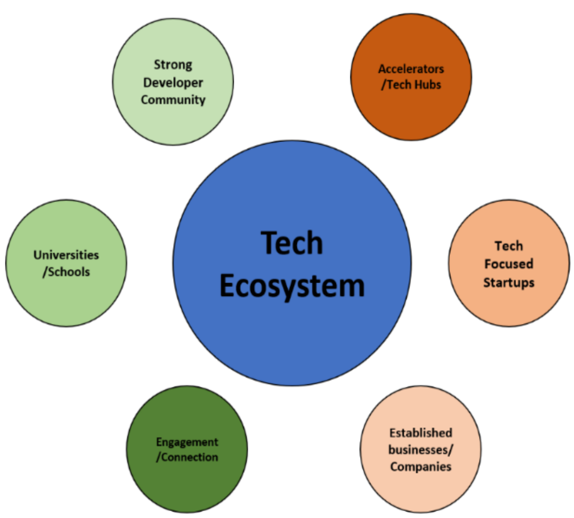

Fig. 7. Darko's tech ecosystems [28]

Darko's conclusion is that "the value tech ecosystems bring far outweighs the complexity and time it takes to cultivate it" [28, Para #16]. He further argues that only sustainable ecosystems can enable technological innovations.

In 2021, Duan *et al*. summarized the 3-layered structure of Edu-Metaverse: basic infrastructure, interactivity, and ecosystems [29]. This might be the very first paper that advocated for building a holistic system. Soon after, in their trail-blazing paper titled *Educational Metaverse: Challenges and Reflections of the New Generation of Online Education*, Zhai, Chu and Wang further analyzed the theoretical basis and characteristics of Edu-Metaverse. Through real application scenarios, they discussed the ecological structure of Edu-Metaverse [30].

Building on Duan's study [29], Zhai and his colleagues argue that the Metaverse is not simply a technology-supported environment. Instead, it is a complete system comprising of various crucial factors [30]. In this holistic system, single-channel user interaction extends to a multi-dimensional, real-time cooperation space. Based on the trusted digitization of assets and identities, Edu-Metaverse can greatly enhance and simulate authentic teaching scenarios. It can also facilitate the building of communities among users such as instructors and their students. This very first paper on Edu-Metaverse [30] in China, which is co-authored by two authors of this paper (Wang & Chu), hypothesizes that the Edu-Metaverse ecosystem should comprise technology support, interaction modality and design principles. Core to the ecosystem is user interaction, which should be supported by existing and emerging technologies and also guided by the principles of cross-cultural communications. In a holistic and positive metaverse environment, instructors and learners will be able to create their virtual identities or digital twins through avatars that can vividly represent their actual physical, cultural, psychological and spiritual existence. Compared with traditional online communication, the Edu-Metaverse provides instructors and students with a more 3D stereoscopic interaction. The interplay in Edu-Metaverse can not only enrich the interaction among its users but can also generate new relationships between real users and avatars as well as between avatars and avatars. Cross-cultural and "cross-identity" communications in the Metaverse are fascinating topics that can use more systematic studies.

Finally, Zhai *et al*. [30] also discuss the various challenges associated with Edu-Metaverse, including data management, digital copyright, influence of venture capital on the value and fairness of education, and the impact of algorithm on learners' attitudes and perceptions. Even though they were unable to provide solutions, they call for continuous attention of developers and researchers on these critical challenges.

IV. THE EDUCATIONAL METAVERSE (EDU-METAVERSE) ECOSYSTEM

In response to the digital transformation and relevant challenges in K-12 and higher education and technology industries, stakeholders will need to effectively communicate and deliver actions, maintain and manage the increasing requirements of the Edu-Metaverse platform to facilitate its sustainable growth. Here we propose the first version of an Edu-Metaverse Ecosystem (as shown in Fig. 8), which synthesizes the aforementioned models (Fig. 6 & Fig. 7) and draws upon theories and beliefs from an extensive and systematic review of relevant literature.

This particular Ecosystem (Fig. 8) consists of four major hubs: A) Instructional design and performance technology hub, B) Knowledge hub, C) Research and technology hub, and D) Talent and training hub. Common to all four hubs are the factors in the three wheels on the left: a) Infrastructure, business, industry, and communication; b) Technology access and equity, and c) User rights, data security, and privacy policy. Below we describe each of these hubs and their components in detail.

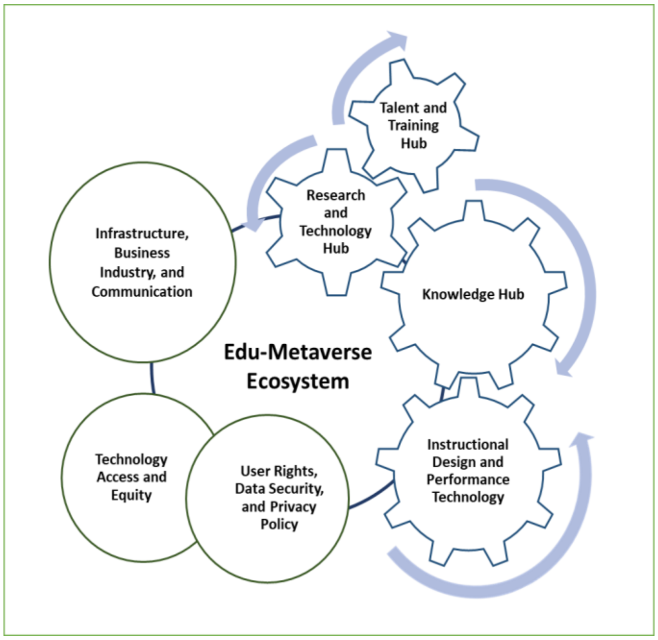

Fig. 8. A new framework for the Edu-Metaverse Ecosystem

A. Instructional Design and Performance Technology

Instructional design (known as ID) and performance technology (known as PT) are two of the major pillars in the discipline of Learning Design and Technology (LDT). Instructional design refers to the systematic design and development of learning activities by using theories primarily from education, psychology and communication. Performance technology (PT) focuses on improving the work outcomes of individuals and organizations by analyzing gaps and identifying solutions. The "technology" in PT mainly refers to systematic approaches, methods, and practices than hardware and software.

Both instructional design and performance technology play an important role when framing this Edu-Metaverse ecosystem. The principles for designing a 3D learning environment existed as early as 2010, which placed great emphasis on being learner-centered and constructive [31]. An effective 3D learning environment should mirror an effective real learning setting, which is instructionally sound, contextual or immersive, action oriented and also promotes discovery learning and collaboration [31].

In addition to embracing the aforementioned principles [31], well-designed curricula, courses, and learning experiences should be able to provide an enjoyable learning experience, and also to improve learners' cognition, knowledge transfer, experiential learning outcomes, and consequently the sustainability of the Edu-Metaverse ecosystem. Therefore, we pinpoint the major factors in the ID and PT Hub as sustainability, accessibility, intellectual property, learning needs and usability.

1) **Sustainability**

In general, sustainability is about the maintenance and preservation of value. Specific definitions of sustainability vary by contexts and by disciplines. The U.S. Partnership for Education for Sustainable Development (USPESD) defines sustainability education as a "combination of content, learning methods, and outcomes that helps students develop a knowledge base about the environment, the economy, and society, in addition to helping them learn skills, perspectives, and values that guide and motivate them to seek sustainable livelihoods, participate in a democratic society, and live in a sustainable manner" [32, p. 2]. The United Nations also advocates Sustainable development goals for quality education, to promote inclusive and equitable education for lifelong learning opportunities for all at a global level [33].

Extensive research [34] has revealed that students' social and emotional engagement can lead to better learning outcomes in both face-to-face and online settings. We believe that this principle also applies to learning in the Metaverse. Therefore, supporting positive interactions and collaboration in a metaverse world would be the core of a balanced ecosystem. The widely promoted and adopted concept of Universal Design for Learning (UDL) [35] is touted as a framework that can promote sustainable education in various settings. UDL is "a framework to improve and optimize teaching and learning for all people based on scientific insights into how humans learn" [35, Para 1]. The UDL guidelines proposed by the Center for Applied Special Technology (CAST) focus on providing multiple means of engagement, representation, and action & expression [36]. We believe that these guidelines are applicable to teaching, learning, and training conducted in a metaverse environment, where learners are motivated and immersed in learning activities and will be able to apply concepts and skills from the Edu-Metaverse to the real world. A sustainable higher-educational Metaverse environment such as a Metaversity would also support shared governance, where administrators, faculty, staff and students actively participate in decision-making and policy development as in the real world. Finally, a sustainable metaverse platform will need to be usable and accessible, which are further discussed below.

2) **Accessibility and Intellectual Property**

Accessibility is a fundamental requirement for websites and web services. Under the accessibility requirement, all users should be able to navigate and interact with the web, regardless of their age, abilities, locations or devices used. How can the Metaverse be accessible to all users is still under debate and the conversation is led by industries. Some companies believe that the Metaverse can transcend the limits of our physical world and reinvent it in the virtual 3D worlds. Some worry that the Metaverse tools, apps, and platforms might not be accessible and inclusive of all users and thus can enlarge the digital divides we have been trying to bridge.

Accessibility in the Metaverse and Edu-Metaverse also need clearer definitions. For example, one interesting accessibility issue might occur in library services. Digital libraries may exist in a metaverse world, even if the challenges of identifying and connecting with users in this context are immense. A specific case in point is that a library cannot give a physical book to a virtual avatar. Instead, the library would need to license the e-book under a contract. However, there is no guarantee that publishers will work with libraries in this regard [36].

Authors of this paper are not accessibility experts, but we believe in the principles of accessibility and would advocate for the development of accessible metaverse technologies and learning environments such as a meta-university (metaversity). We hope that this paper will serve as a starter for this conversation and would spur systematic research on how to create accessible and user-centered metaverse worlds.

Intellectual property would be another concern. Inventors, developers and users alike will want to share but also ensure ownership and credit for their creative work. Intellectual property needs to develop alongside the creation of the Metaverse. The intellectual property in Edu-Metaverse is fundamental to how the Metaverse intersects with other industries, such as content generation, content ownership, and content multiplatform for institutions [36].

3) Need and Usability

Metaverse tools and platforms have actually been in use before the 2021 Metaverse summit, even though this summit marks the official start of the metaverse movement in Asia. Several years before 2021, Metaverse studio (https://studio.gometa.io/) and its App (also named Metavers) by GoMeta Inc. have been popular among K-12 educators around the world, to develop interesting and interactive Augmented Reality (AR) for classroom use. The blogs hosted by GoMeta showcases exemplary use of Metaverse in many schools, to support project-based learning, field trip activities and in-class collaboration among students.

Immersive learning is the main pedagogy underlying XR technologies, which are the current backbones of metaverse platforms such as Virbela and VictoryXR. During the historical COVID pandemic, the demands for more engaging learning environments (in K-12 in particular) were certainly increasing. The emergence of learning across the Metaverse phenomenon is not unexpected. 3D learning environments are also suitable for higher education and the training industry, in disciplines that require hands-on practice, costly prototyping development, or dangerous industrial operation.

As to usability, designers and instructional designers will need to work closely with the developers to assess learning needs or opportunities, so as to create usable and user-friendly tools and learning activities. Current design principles for 3D learning environments [31] will need further development to address the uniqueness of the still-developing metaverse.

Based on previous research on learning in the Metaverse and other 3D settings [37]-[38], the standards below may serve as starting points in the design of the Edu-Metaverse:

- Smart AI-embedded design for effortless navigation;
- Ease and efficiency of use, especially for beginners, the disabled, and technology-challenged users;
- Current and updated research and evidence-based information;
- Instruction mirrors the curriculum, well-constructed instruction delivery, and learning outcomes as expected and desired;
- Learners are satisfied and excited to participate in the next visit to the Edu-Metaverse.

B. Knowledge Hub

Knowledge Hub should be the center of this ecosystem, where student learning occurs through participation, knowledge creation, retention, reflection and sharing. These learners can range from K-12 to higher education and are from all disciplines. We believe that specialized Science, Technology, Engineering, the Arts, and Mathematics (STEAM) organizations (e.g., Women in STEAM, Two Bit Circus Foundation, Project Fibonacci Foundation, Inc., and STEAM Craft Edu) can directly benefit from new and innovative ways of teaching and learning resulting from efforts invested into the research and technology hub. In addition, the design and development of instructional systems and learning rely on frequent user feedback, as described in the widely practiced models--ADDIE (Analysis, Design, Development, Implementation, & Evaluation) and SAM (Successive Approximation Model). Through continuous addressing of user feedback and the improvement of user experiences, learning activities and environments can eventually live up to user expectations and to serve their learning needs.

C. Research and Technology Hub

Research and Technology Hub is where the innovation occurs and it can drive the evolution of the Metaverse. A vibrant research and technology environment is essential to maintain a practical, up-to-date, and valuable Edu-Metaverse ecosystem. A growing number of empirical studies have proved that some innovative teaching and learning approaches, such as using VR/AR learning materials, are conducive to students' cognitive development, academic performances, learning engagement, and learning perceptions [39-41].Currently the driving force in this Hub is the major tech giants such as Microsoft, Google (Alphabet Inc.), Amazon Web Services, Meta Inc. and some of the STEAM-focused higher educational institutions.

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

Digital education platforms profoundly impact how pedagogical intervention is understood and practiced. Learning design based on sound pedagogical theories is reflected on platform algorithms and interfaces. In turn, learning analytics acquired through the platform can shape design and pedagogic choices [42]. The aforementioned tech giants are all actively flexing their technical capacities to influence diverse education systems, by introducing new governing technologies into educational settings in the form of hardware, software, data analytics, and algorithms [43]. In addition, many small start-ups supported by venture capitals are also diving into this new metaverse territory, through collaboration with schools, colleges, and universities. Their products tend to be small-scaled but cost and user-friendly. The emergence of Meta-university (Metaversity) is a direct result the collaboration between technology companies and educational institutions. Section V of this paper provides a more in-depth analysis of Metaversity through the lens of this proposed Ecosystem (Fig. 8). At this time, high schools and universities around the world have built campuses in the Metaverse and are carrying out teaching and research activities in these 3D virtual worlds. The relationship between industry and education is essential for the sustainable development of Edu-Metaverse. On the other hand, new rules and regulations are needed to protect intellectual rights, data security, and privacy in the Metaverse. There also need to be boundaries on this collaboration, as venture capitals and educational entities can carry different goals and missions.

D. Talent and Training Hub

The continuous development of talents and human resources is an important aspect of society and its various organizations. The Ecosystem in this paper (Fig. 8) therefore has a Hub for Talent and Training, which covers the sphere of professional development and training solutions. Large and influential organizations such as ATD (The Association for Talent Development) have been the trend-setter in both methods and the use of technology. The gamut of factors involved in this hub is rich and diverse, ranging from information technology to andragogy to quality assurance and assessment. The talent training field is often fast in adopting new and emerging technologies. As the Edu-Metaverse continues to grow and expand its outreach, its application in industrial training and workforce development is in fact endless. For example, Siyaev and Jo [9] worked with Boeing to develop an aircraft maintenance metaverse. They built a speech interaction module powered by a deep learning-based model that enables trainees "to talk" with Mixed Reality (MR) content and control the workflow of the maintenance process. The speech interaction creates a tremendous possibility to imitate an expert in the field of aircraft maintenance, who can effectively guide trainees during the education process. This speech module can also facilitate trainees' learning by providing timely tutoring and required materials such as technical manuals, instructions, and reference videos.

E. Infrastructure, Business Industry, and Communication Hub

The hub on the left of the Ecosystem is about infrastructure. A successful Edu-Metaverse Ecosystem is dependent upon the formation of state-of-the-art infrastructure and a healthy relationship with the business industries, especially those who manufacture and distribute both physical and virtual parts and services used in the Edu-Metaverse platform (e.g., sound system XR developers/startups/investors). Obviously, a reliable communication system for service providers would be critical.

Businesses that are well-informed of their customers' needs are well positioned to improve their products and to meet these needs. Consumers of the Edu-Metaverse are learners, from K-12 to higher education to the general public. This user diversity poses great challenges for product and service development. Businesses would need to accurately gauge user expectations and to collect their feedback. For example, Khan *et al*. conducted a study to address user experience and communication of digitally enhanced advanced services offered in the manufacturing sector [23]. Their evaluation results revealed that learners preferred to receive information through a game environment versus other more static learning settings. In addition, learners also expressed their wishes for drastic improvements, which entails incorporating Artificial intelligence (AI) for more complex game scenarios, real-time adaptability of the training system, and overall expansion of the user service scenarios for enriched data acquisition and analysis results.

The Edu-Metaverse requires joint efforts among computing communities to develop and sustain robust infrastructure and communication systems. Van Huynh *et al*. [44] proposed a digital twin scheme that guarantees stringent reliability and low latency requirements, which are highly applicable to the future infrastructure of the Metaverse. Digital communication, including shared or collaborative projects and interactions in private spaces in the Edu-Metaverse, will undoubtedly evolve as both communication technology and infrastructure progress.

F. Technology Access and Equity Hub

Equity is a fundamental element of educational research and practice and should be the imperative goal of Edu-Metaverse. In digital learning, accessibility is crucial for achieving educational equity. An equitable and accessible Edu-Metaverse should be able to adapt to all disciplines and various educational settings. Light, minimalist, cost-effective wearable devices should become more affordable for users from different socio-economic and cultural backgrounds. Policies need to be in place to ensure such equity and to prevent the widening of digital divide and the emergence of a new Metaverse divide as we call it.

Nevertheless, equity in the Edu-Metaverse will be an uphill proposal in that business industries want to make and keep profits. It will take all the entities in the ecosystem to find solutions to make the Edu-Metaverse platform available and a standard education tool for all. The Edu-Metaverse is worthwhile only when its design reflects real-world user experiences and can effectively immerse learners in a 3D virtual environment. The outlook for Edu-Metaverse is bright but challenges remain, as further described in the section below.

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

G. User Rights, Data Security, and Privacy Policy Hub

The principal issues to consider in this Hub are the treatment of privacy and security of the users' information, including personal profiles, behaviors, activities, communication, and other usage data. In the U.S. for example, federal and state initiatives and oversight are essential for requiring developers, institutions, and corporations to keep users' privacy data secure and their rights protected. In addition, the policy must include safekeeping of information such as protocols for logins, private conversations or communication, and strict guidelines for assessments to prevent identity theft and fraud. In addition, what do privacy and security mean for one’s digital twin or avatar? How much will privacy and security overlap with and differ from their meanings in the real world? More research needs to be conducted on the critical factors in this Hub, so as to serve as the theoretical basis for policy-making. Since the 1990s, digital literacy and cyber ethics have been driving the healthy development of the Internet. Accordingly, we need to define and promote “meta-literacy” and “meta-ethics” for a promising evolution of the Metaverse. While the Edu-Metaverse can greatly transform teaching and learning, access to users’ digital data is also extensive and thus requires extra effort to protect their "digital dignity" as addressed in Chavez and colleagues’ timely article on how we lost privacy to the big tech [45].

V. Apply the Ecosystem model to Analyze Metaversity

Higher education and non-profit organizations are currently spearheading the transition into Edu-Metaverse by building Metaversity. The virtual campus of iLRN, for example, is known for its ease-of-use, scalability (up to 2,000 concurrent visitors), and the capabilities to support collaboration on a shared virtual geography. The campus’ design and operation align with the theory of situated virtual embodiment, the sense of being in the same space at the same time with colleagues and friends who might be spread out around the globe [46].

East-of-use and accessibility are critical to users. At present, many VR platforms are not designed for mobile devices, which are more commonly used than computers in many countries. Virbela campuses, for example, require Windows 7 SP1+ 64-bit or newer or Mac OS X 10.11 or newer to run. It is currently incompatible with Chromebooks or Linux based computers. “Virbela Intercom App requires iOS 8.0 or newer. It is compatible with iPhone, iPad, and iPod touch” [47]. Still, the Intercom App has limited features and can only support voice communications on its open campus [47]. In addition, metaverse worlds need to accommodate users with learning barriers, physically or mentally.

For scalability, event hosting on iLRN’s virtual campus can range from small one-time group meetings (e.g. student clubs, single class sessions, departmental meetings) to full use of the Campus island for a large multi-day event with simultaneous sessions, social networking sessions, games, poster or sponsor booths in the Expo Hall, keynote speakers, breakout sessions, and dances with live DJ's or social events on the beach [45].

VictoryXR, on the other hand, employs visual immersion technologies to recreate digital twins of high schools and universities. Students can choose to participate in learning on a conventional campus or in the Metaverse. VictoryXR also announced that in 2022 Meta Inc. will fund ten universities across the United States to build Metaversity [48]. Morehouse College in Atlanta, Georgia, USA was one of the first institutions to start this initiative (Fig. 9) [49].

As a pioneering case of Edu-Metaverse, the design, development and conduct of the aforementioned Metaversity align with the Edu-Metaverse Ecosystem proposed in this study. Metaversity relies on its rich 3D learning resources to promote the sustainability, accessibility and usability of the education system, support the activities of multiple educational hubs, ensure system operability, and also have policies in place to protect user rights.

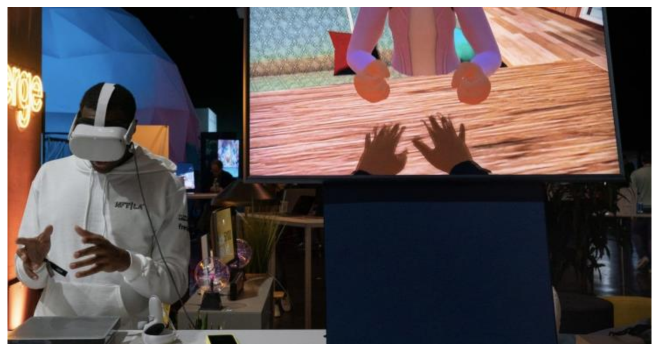

Fig. 9. Students in Morehouse College exploring Metaversity

A. Promoting Sustainability, Accessibility, and Usability

Metaversity seems to meet the requirements of the United Nations’ Sustainable Development Goals (SDG) to ensure inclusive and equitable education and to promote lifelong learning opportunities for all. COVID-19 abruptly interrupted traditional schooling and brought a pause to field-based learning in informal settings, such as museums for science and technology. Although distance learning supported by video calls and resource sharing has been a widely used alternative, it is far from desirable in learner engagement. Zoom fatigue has become another “mini-pandemic” and even became a discussion topic for health professionals and news media. For K-12 students in particular, video conferencing might not be the best way to learn. A new and innovative method is needed to immerse them in the learning process, so as to develop their higher-order and critical thinking skills.

VR learning objects such as human organs, historical artifacts and biological molecules, are obviously much more engaging than PowerPoint slides. At the same time, Metaversity breaks the limits of physical space to support learning activities outside the classroom. Metaversity provides educators with over 60 learning scenarios, including interstellar spaceships, historical art museums, and more [20]. With the emergent of innovative and creative technologies, it is possible to build scenarios that transcend reality in Metaversity and to provide a more immersive and authentic online learning experience.

Immersive learning can not only satisfy the various needs of different learners but can also provide better accessibility

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

without the constraints of the real world. In the context of the pandemic, Metaversity has the great potential to enhance the resilience of teaching and learning, so as to ensure sustainability in the face of unpredictable crises and challenges.

B. Supporting Educational Hubs

Metaversity affords sufficient digital learning resources, research scenarios and training spaces for the knowledge and technology hub and the talent and training hub. In the knowledge hub, Metaversity uses various technologies such as XR to support students' acquisition of various types of knowledge. Compared with ordinary knowledge presented in the form of text and pictures, learning materials in Metaversity are 3D and multidimensional. Numerous empirical studies have demonstrated the effectiveness of VR technologies on learner immersion and learning outcomes.

In addition, Metaversity can create an ideal experimental environment for researchers by excluding various interference factors in the real world. In addition to a single scenario, Metaversity can simulate realistic engineering systems in the virtual world as digital twins. It can simulate and predict system effects, reduce the cost of actual operations, and provide a reference for realistic technology development. For instance, the Swiss University of Applied Sciences has built a "Smart Learning Factory" (SLF) to support coursework in digital manufacturing, helping learners understand manufacturing development in the physical world through digital twins [50].

Regarding talent training, the interactivity of Metaversity enables learners to learn and practice their skills. Rather than merely transmitting multimedia information to learners in a linear fashion, a Metaverse learning environment can immerse learners and also support learner interactions. It can infuse artificial intelligence technologies to provide adaptive learning through recommending learning scenes and activities. Learners collaborate, acquire and apply their skills in virtual scenarios, which can make talent training less costly and also avoid the dangers of training in real scenarios (such as firefighting).

Additionally, educators need to collaborate with Metaversity developers and the technology industry, to improve the design and usability of new and current tools, platforms, and systems.

C. Ensuring Technical Feasibility and User Rights

The design and operation of Metaversity also need to consider the infrastructure, technology access, and user rights issues as mentioned in our Edu-Metaverse Ecosystem. Based on our tests and analysis, the Metaversity constructed by VictoryXR is accessible through several portable devices, such as Meta Quest and Pico Neo. These devices are well adapted to Metaversity, enabling the virtual world to acclimate to the learner's movements. As a result, learners have great freedom to roam, interact and engage in Metaversity. For user rights, VictoryXR states that they not only abide by federal and state regulations regarding data access and user privacy but also make the underlying data platform compliant with the most stringent European General Data Protection Regulation (GDPR) privacy standards [20]. Data repository, privacy and governance are common issues that all Metaverse platforms should proactively address.

VI. CONCLUSIONS

The educational landscape around the globe is constantly changing, especially with the ongoing and never-ending pandemic. Digital learning has been re-inventing itself every seven years since 1994 when Netscape went public [51]. The year of 2001 marked the age of openness through MIT's open courseware. In 2008, the first MOOC was created, and 2015 was the start of personalized learning [51]. Now in 2022, coupled with the pandemic, we entered the age of the Metaverse for education (Edu-Metaverse), which has the potential to greatly transform traditional ways of teaching and learning.

Online and virtual environments lend themselves to soft skills training and development, and reduced risk engagement training in absentia of time and location limitations. Now, the task is to design instruction to best share content and adjust pedagogy to close the digital gaps and bring about equity and inclusion, access, and sustainability. However, with the development of technologies supporting the many metaverse worlds, the world might face a higher level of digital divide and a new type of divide coined as the "Metaverse divide".

The Edu-Metaverse ecosystem as presented in this paper takes potential value, ethical and security issues into consideration and suggested solutions to some of the challenges. By pointing out these issues, we hope more research can be conducted to address the many layers of challenges associated with the metaverse tools and environments for learning. In addition, instructional design is essential for any technological innovation to be successful in education. In driving inclusion, for learners with impairment and the elderly in particular, learning design must involve careful research for every part of the experiential learning (e.g., ease of use) and accessibility (e.g., money matters such as tuition, remote or low-level technology locations). Design also needs to consider learner and teacher support (e.g., academic and psychosocial needs and technology needs such as AI devices), community collaboration, learner support after graduation (e.g., job search, career counseling, student loan repayment or forgiveness agreements), and excelling institution, state, federal, and international standards and policies.

Similar to the Cybergogy model [34], the Ecosystem proposed in this paper will need more testing and fine tuning to align with the practices in the real world. With the Ecosystem framework, we also bring forward several critical terms including the Metaverse, the Edu-Metaverse, metaverse environments, metaverse divide (meta-divide), meta-literacy, and meta-ethics. All of these terms are new and request more systematic research. Therefore, this paper will pave the way for TLT's upcoming special issue on Metaverse and the Future of Education, scheduled to publish before the summer of 2023. It will also serve as a starting point for meaningful and rich conversations surrounding this exciting but unknown Metaverse era.

Acknowledgment

We would like to dedicate this paper to IEEE-TLT for its 15th anniversary. Special thanks to all reviewers for their rigorous reviews and insightful comments. We also want to thank the publishing team for their efficient management of this paper.

References

[1] S. Mystakidis, “Metaverse,” *Encyclopedia*, vol. 2, no. 1, pp. 486–497, Feb. 2022, doi: 10.3390/encyclopedia2010031.

[2] H. Guo and W. Gao, “Metaverse-powered experiential situational English-teaching design: An emotion-based analysis method,” *Front. Psychol.*, vol. 13, Mar. 2022, doi: 10.3389/fpsyg.2022.859159.

[3] L. H. Lee *et al*., “All one needs to know about metaverse: A complete survey on technological singularity, virtual ecosystem, and research agenda,” *J LATEX Class Files*, vol. 14, no. 8, Sept. 2021, doi: 10.48550/arXiv.2110.05352.

[4] K. Paul. (2022, July 25). *Meta and other tech giants form metaverse standards body, without Apple, Reuters*. [Online]. Available: https://www.reuters.com/technology/meta-other-tech-giants-form-metaverse-standards-body-without-apple-2022-06-21.

[5] T. Min and W. Cai, “Portrait of decentralized application users: An overview based on large-scale Ethereum data,” *CCF Trans. Pervasive Comput. Interact.*, vol. 4, pp. 124–141, Feb. 2022, doi: 10.1007/s42486-022-00094-6.

[6] P. Cipresso, I. A. Giglioli, M. A., Raya, and G. Riva, “The past, present, and future of virtual and augmented reality research: A network and cluster analysis of the literature,” *Front. Psychol.*, vol 9, Nov. 2018.

[7] B. Egliston and M. Carter, M. “Critical questions for Facebook’s virtual reality: Data, power and the metaverse,” *Internet Policy Rev.*, vol. 10, no. 4, Dec. 2021, doi: 10.14763/2021.4.1610.

[8] V. Vaidyanathan. (2022, July 25). *What is a brain-computer interface? Science ABC*. [Online]. Available: https://www.scienceabc.com/innovation/what-is-a-brain-computer-interface.html.

[9] A. Siyaev and G-S. Jo, “Towards aircraft maintenance metaverse using speech interactions with virtual objects in mixed reality,” *Sensors*, vol. 21, no. 6, Mar. 2021, doi: 10.3390/s21062066.

[10] R. González Crespo, R. F. Escobar, L. Joyanes Aguilar, S. Velazco, and A. G. Castillo Sanz, “Use of ARIMA mathematical analysis to model the implementation of expert system courses by means of free software OpenSim and Sloodle platforms in virtual university campuses,” *Expert Syst. Appl.*, vol 40, no. 18, pp. 7381-7390, Dec. 2013, doi: 10.1016/j.eswa.2013.06.054.

[11] K. Saundarajan, S. Osman, J. A. Kumar, M. F. Daud, M. S. Abu, and M. R. Pairan, “Learning algebra using augmented reality: A preliminary investigation on the application of photomath for lower secondary education,” *Int. J. Emerg. Technol. Learn.*, vol. 15, no. 16, pp. 123–133, Aug. 2020, doi: 10.3991/ijet.v15i16.10540.

[12] S. Park and S. Kim, “Identifying world types to deliver gameful experiences for sustainable learning in the metaverse,” *Sustainability*, vol. 14, no. 3, Jan. 2022, doi: 10.3390/su14031361.

[13] F. B. Nunes *et al*., “A dynamic approach for teaching algorithms: Integrating immersive environments and virtual learning environments,” *Comput. Appl. Eng. Educ.*, vol. 25, no. 5, pp. 732-751, Sept. 2017, doi: 10.1002/cae.21833.

[14] S. Herrera Damas and M. J. Benítez de Gracia, “Immersive journalism: Advantages, disadvantages and challenges from the perspective of experts,” *Journal. Media.* vol. 3, no. 2, pp. 330–347, May 2022, doi: 10.3390/journalmedia3020024.

[15] A. Jovanović, and A. Milosavljević, “VoRtex metaverse platform for gamified collaborative learning,” *Electronics*, vol. 11, no. 3, Jan. 2022, doi: 10.3390/electronics11030317.

[16] H. Lee and Y. Hwang, “Technology-enhanced education through VR-making and metaverse-linking to foster teacher readiness and sustainable learning,” *Sustainability*, vol. 14, no. 8, Apr. 2022, doi: 10.3390/su14084786.

[17] S. Mystakidis *et al*., “Design, development, and evaluation of a virtual reality serious game for school fire preparedness training,” *Educ. Sci.*, vol. 12, no. 4, Apr. 2022, doi: 10.3390/educsci12040281.

[18] V. M. Petrović and B. D. Kovačević, “AViLab—gamified virtual educational tool for introduction to agent theory fundamentals,” *Electronics*, vol. 11, no. 3, Jan. 2022, doi: 10.3390/electronics11030344.

[19] VirBELA, LLC. “*UCSD Launches Its International Micro-MBA Program.*” https://www.virbela.com/case-studies/ucsd (Accessed August 20, 2022).

[20] VictoryXR, Inc. “*Virtual Reality Metaversity: What You Need to Know about Learning in The Metaverse.*” https://www.victoryxr.com/metaversity (Accessed August 20, 2022).

[21] L. O. Alpala, D. J. Quiroga-Parra, J. C. Torres, and D. H. Peluffo-Ordóñez, “Smart factory using virtual reality and online multi-user: Towards a metaverse for experimental frameworks,” *Appl. Sci.*, vol. 12, no. 12, June 2022, doi: 10.3390/app12126258.

[22] G. Barresi, C. Pacchierotti, M. Laffranchi, and L. De Michieli, “Beyond digital twins: Phygital twins for neuroergonomics in human-robot interaction,” *Front. Neurorobot.*, vol. 16, June, 2022, doi: 10.3389/fnbot.2022.913605.

[23] M. S. Khan *et al.*, “Improving user experience and communication of digitally enhanced advanced services (DEAS) offers in manufacturing sector,” *Multimodal Technol. Interact.*, vol. 6, no. 3, Mar. 2022, doi: 10.3390/mti6030021.

[24] G. Makransky and S.Klingenberg, ‘Virtual reality enhances safety training in the maritime industry: An organizational training experiment with a non-WEIRD sample,” *J. Comput. Assist. Learn*, vol. 38, no. 4, pp. 1127-1140, Mar. 2022, doi: 10.1111/jcal.12670.

[25] H. Subramanian and S. Subramanian, “Improving diagnosis through digital pathology: Proof-of-concept implementation using smart contracts and decentralized file storage,” *J. Med. Internet Res.*, vol. 24, no. 3, Mar. 2022, doi: 10.2196/34207.

[26] H. Yoon, “Opportunities and challenges of smartglass-assisted interactive telementoring,” *Appl. Syst. Innov.*, vol. 4, no. 3, Aug. 2021, doi: 10.3390/asi4030056.

[27] R. Hwang and M. Lee, “The Influence of Music content marketing on user satisfaction and intention to use in the metaverse: A focus on the SPICE model,” *Businesses*, vol. 2, no. 2, pp. 141–155, Apr. 2022, doi: 10.3390/businesses2020010.

[28] J. Darko. (2019, July 1). *Understanding tech ecosystems & how they support growth and innovation, Medium*. https://medium.com/@joe_darko/understanding-tech-ecosystems-how-they-support-growth-and-innovation-d4e345de20da (Accessed August 22, 2022).

[29] H. Duan, J. Li, S. Fan, *et al*., “Metaverse for social good: A university campus prototype,” in *Proceedings of the 29th ACM International Conference on Multimedia*, ACM, 2021, pp. 153-161.

[30] X. S. Zhai, X. Y. Chu, M. J. Wang, *et al*., “Educational Metaverse: The Shape, Challenges and Reflections of the New Generation of Internet Education,” Open Education Research, vol. 28, no. 1, pp. 34-42, Jan. 2022. 教育元宇宙: 新一代互联网教育形态的创新与挑战, 开放教育研究.

[31] K. M. Kapp, “*Principles for designing 3D learning environments*.” https://karlkapp.com/principles-for-designing-3d-learning-environments/ (accessed August 25, 2022).

[32] US Partnership (USPESD). “*US Partnership for Education for Sustainable Development National Education for Sustainability K-12 Student Learning Standards Version 3 – September 2009.”* https://celfeducation.org/wp-content/uploads/2020/04/US-Partnership-for-Education-for-Sustainable-Development-USPESD-K-12-Standards.pdf (accessed August 21, 2022).

[33] United Nation (UN). *“Sustainable Development Goals.”* https://www.un.org/sustainabledevelopment/education.html (accessed August 23, 2022).

[34] M. J. Wang, M. H. Kang, “Cybergogy for engaged learning: A framework for creating learner engagement through information and communication technology,” in *Engaged learning with emerging technologies*, D. Huang and M. S. Khine, Eds. Dordrecht, Netherlands: Springer, 2006, pp.225-253.

[35] Center for Applied Special Technology (CAST), Inc. “*About Universal Design for Learning.*” https://www.cast.org/impact/universal-design-for-learning-udl.html (accessed August 23, 2022).

[36] P. Fernandez, “Facebook, Meta, the metaverse and libraries,” *Libr. Hi Tech News*, vol. 39, no. 4, pp. 1-5, May 2022, doi: 10.1108/LHTN-03-2022-0037.

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

[37] D. Pimentel, G. Fauville, K. Frazier, *et al*. (2022, July 27). *An introduction to learning in the metaverse, Meridian Treehouse*. https://scholar.harvard.edu/files/mcgivney/files/introductionlearningmetaverse-april2022-meridiantreehouse.pdf (Accessed August 25, 2022).

[38] S. G. Johnson, T. Potrebny, L. Larun, D. Ciliska, and N. R. Olsen, "Usability methods and attributes reported in usability studies of mobile apps for health care education: Scoping review," *JMIR Med. Educ.*, vol. 8, no. 2, Mar. 202, doi: 10.2196/38259.

[39] F. Cortés Rodríguez, M. Dal Peraro, and L. A. Abriata, "Online tools to easily build virtual molecular models for display in augmented and virtual reality on the web," *J. Mol. Graph. Model.*, 114, July 2022.

[40] G. Makransky and R. E. Mayer, "Benefits of taking a virtual field trip in immersive virtual reality: Evidence for the immersion principle in multimedia learning," *Educ. Psychol. Rev*., Apr. 2022, doi: 10.1007/s10648-022-09675-4.

[41] B. Wu, X. Yu, and X. Gu, "Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis," *Br. J. Educ. Technol.*, vol. 51, no. 6, pp. 1991–2005, Sept. 2020, doi: 10.1111/bjet.13023.

[42] N. Kerssens, and J. van Dijck, "Governed by edtech? Valuing pedagogical autonomy in a platform society," *Harv. Educ. Rev.*, vol. 92, no. 2, pp. 284–303, July 2022, doi: 10.17763/1943-5045-92.2.284.

[43] B. Williamson, K. N. Gulson, C. Perrotta, and K. Witzenberger, "Amazon and the new global connective architectures of education governance," *Harv. Educ. Rev.*, vol. 92, no. 2, pp. 231–256, July 2022, doi: 10.17763/1943-5045-92.2.231.

[44] D. Van Huynh, S. R. Khosravirad, A. Masaracchia, O. A. Dobre, and T. Q. Duong, "Edge intelligence-based ultra-reliable and low-latency communications for digital twin-enabled metaverse," *IEEE Wireless Commun. Lett.*, June 2022, doi: 10.1109/LWC.2022.3179207.

[45] T. Chavez, M. Johnson, J. Andersen. (2022, July 27). *Toward data dignity: How we lost our privacy to big tech.* https://fortune.com/2022/01/28/big-tech-data-privacy-ethicaltech (Accessed August 22, 2022).

[46] Virbela. (2022, Aug.7). "*Hardware and software requirements*." Virbela User Support Site. https://support.virbela.com/s/article/Hardware-and-Software-Requirements?language=en_US (Accessed August 25, 2022).

[47] iLRN. (2022, Aug.7). *About the iLRN Virtual Campus.* [Online]. Available: https://immersivelrn.org/pages/virtual-campus.

[48] T. H. Tran. (2022, July 27).*The Metaverse Is Going to College. But Will It Suck?* [Online]. Available: https://www.thedailybeast.com/the-metaverse-is-expanding-to-universities-and-colleges-with-metaversities.

[49] R. Edward. (2022, July 27). *Morehouse Breaking Bold New Technology for Metaverse Learning*. https://atlantadailyworld.com/2022/05/21/morehouse-breaking-bold-new-technology-for-metaverse-learning-video-2 (Accessed August 25, 2022).

[50] R. Hänggi, F. Nyffenegger, F. Ehrig, *et al.*, "Smart learning factory – network approach for learning and transfer in a digital & physical set up," in IFIP International Conference on Product Lifecycle Management, Springer, 2020, pp. 15-25.

[51] C. Bonk (2017, June 27), "The fourth industrial revolution meets the fourth E-learning revolution", keynote speaking for the annual conference of the Immersive Learning Research Network (iLRN), Coimbra, Portugal.

Minjuan Wang (Member, IEEE) was born in Lingbao, Henan Province of China and obtained her BA in Chinese literature from the Beijing/Peking University, M.A. in comparative literature from Penn State University, and Ph.D. in information science and learning technologies from University of Missouri-Columbia.

She is a professor and program chair of Learning design and technology at San Diego State University, California, USA. She also serves as the new Editor-in-Chief for *the IEEE Transactions on Learning Technologies (TLT)*. Her research specialties are multidisciplinary, focusing on using new and emerging technologies in teaching and training, extended reality (XR) and immersive learning, Metaverse for K12 and higher education, and the design and implementation of artificial intelligence for teaching and learning (with a focus on research and the standards associated with its educational implementation). She is an internationally recognized scholar and has keynoted about 30 international conferences. She has more than 100 peer-reviewed articles published in indexed journals and books. She is the co-author of the highly influential Cybergogy for Engaged Learning model and is considered a high-impact author in online, mobile and hybrid learning.

Dr. Wang is a member of IEEE and the IEEE Education Society. She co-chairs the Education Society's technical committee for immersive learning. She is also a member of the Association for Talent Development (ATD) and Association for Educational Communications and Technology (AECT).

Haiyang Yu (correspondence author) was born in DaQing, Heilongjiang province of China in 1979. He received his Ph.D. degree in international relations from Jilin University in 2008 and started his assistant professorship in the same year.

Since 2016, he has been a Professor with the School of Administration, Jilin University. He is the author of more than 30 articles. His research interests include strategic decision analysis and the use of innovative technologies in teaching and learning. Dr. Yu was an executive director of China National Association for International Studies and vice chairman of Institution for Northeast Asian Studies, Chinese Association of Asia-Pacific Studies.

This article has been accepted for publication in IEEE Transactions on Learning Technologies. This is the author's version which has not been fully edited and content may change prior to final publication. Citation information: DOI 10.1109/TLT.2022.3210828

Zerla Bell is a Librarian at Palmer Way School, one of ten elementary public schools in the National School District in National City, California, USA. She earned her B.S. degree in Microbiology and is working towards a Master's degree in Learning Design and Technology at San Diego State University. Her research interests include designing instructions for new learning environments, Metaverse for learning, and the use of extended reality in K-12 classrooms focusing on STEM disciplines. In her previous career, she was a Clinical Project Leader, a Chemist, then a Homemaker. She hopes to write a children's book one day.

Xiaoyan Chu received the BSc degree in educational technology from Nanjing Normal University in 2021. She is currently working towards the Master's degree in educational technology, College of Education, Zhejiang University. Her research interests include Edu-Metaverse, XR (extended reality) for immersive learning, and the use of Artificial Intelligence in K12 and higher education.

She was an intern with Ken Blanchard, leading companies specializing in performance improvement and leadership training; and also a publicity chair assistant for several IEEE flagship conferences such as TALE and iLRN.