https://doi.org/10.37420/j.eeer.2023.002

A Study on the Development and Innovation of Traditional Chinese Medicine Education from the Perspective of the Metaverse

Weiyang Ye[1,*]
[1]College of Innovation and Entrepreneurship, Wenzhou University, Zhejiang, China, helaojiu007@163.com
***Corresponding author,E-mail: helaojiu007@163.com**

Abstract
Traditional Chinese medicine (TCM) education plays a crucial role in advancing the construction of a Healthy China and the innovative development of TCM heritage. However, it currently faces challenges such as a lack of immersive experiences in online education, a disconnect between theory and practice, and the neglect of the study of classical TCM texts. The metaverse presents new opportunities for the transformation and growth of TCM education. It embodies three primary features: immersive experiences, novel technological integration, and the convergence of the virtual and the real, providing a fertile ground for empowering TCM education and fostering imaginative possibilities. In this context, we propose an architecture for TCM education in the metaverse and the coexisting application scenarios of the metaverse within TCM education. These scenarios encompass the use of virtual classrooms and virtual libraries. Additionally, we elaborate on the challenges that lie ahead in this transformative journey.

Keywords: Traditional Chinese medicine education; Educational metaverse; Architecture; Symbiotic application scenario; Challenge

1 INTRODUCTION

To achieve ample advances in China's traditional Chinese medicine (TCM) progress, TCM education is a vital hallmark. Since founding of the new China, there have been marked developments in TCM education. In the 1950s, the state opened TCM colleges and universities in cities such as Nanjing, Shanghai, as well as Beijing, and integrated TCM education within the scope of national higher education. Currently, there are 42 TCM colleges and universities in China, which have preliminarily developed a diversified talent training mode (Yi et al., 2016; Cheng, 2017). To improve the quality of TCM education, the state has introduced a series of related measures. For instance, in August 2017, the Ministry of Education and the National Administration of Traditional Chinese Medicine jointly issued the "Guiding Opinions on Deepening the Reform and Development of TCM Education through Hospital-School Coordination", in which deployments are made for reformation and development of TCM education in terms of training TCM talents and upgrading the system of TCM master-apprentice education, among others (The Ministry of Education of the People's Republic of China, 2017). In January 2021, the General Office of the State Council issued the "Notice concerning the Several Policies and Measures for Accelerating the Characteristic Development of TCM". This notice requires that a solid foundation be laid for training of TCM talents and it includes measures such as improving the overall levels of TCM education, adhering to development of TCM master-apprentice education, and strengthening the evaluation as well as incentive of TCM talents (National Administration of Traditional Chinese Medicine, 2021). These measures show the significance of training TCM talents to achieve China's health care objectives. In recent years, there have been many achievements in TCM education, however, the traditional TCM education mode can no longer meet learner needs, therefore, it requires continuous reformation.

Advances in science and technology have led to emergence of new information technologies, such as cloud computing, big data, and AI. Due to these advances, “metaverse” has become a new research frontier. The metaverse is a collection of technologies such as cloud computing, big data, digital twins, and blockchain. It can enrich 3D immersive experience, educational contents, and create unique advantages in education, training, behavioral formation, and other aspects. Thus, it offers a new opportunity for reformation of TCM education. By proposing the integration of metaverse and TCM education, we aim at creating a new learning environment, reform teachers' teaching modes, optimize the educational resource systems, and improve the quality of TCM education (Luo et al., 2021). The contributions of this paper in this field can be summarized as: i. It proposes a detailed architecture of TCM education metaverse, which is majorly composed of infrastructure, data, data processing, technological, application, and interaction layers; ii. It puts forward a symbiotic application scenario of metaverse embedding in TCM education, which is composed of two application scenarios, i.e., virtual classrooms and virtual libraries and iii. It elucidates on possible challenges that will likely limit the applications of metaverse TCM education.

The remaining parts of this paper are arranged as follows: Section 2 describes the existing problems with TCM education; Section 3 introduces the concepts of “metaverse” and “educational metaverse”, the theoretical basis of empowerment of TCM education by the metaverse, and application advantages of metaverse in TCM education; Section 4 proposes an architecture of TCM education metaverse; Section 5 describes some application scenarios of the metaverse in TCM education while Section 6 presents the challenges that will likely be faced by metaverse TCM education in future. This paper provides a novel approach for reformation and development of TCM education.

2 CHALLENGES ASSOCIATED WITH TCM EDUCATION

In Chinese civilization, TCM is a treasure that is a crystallization of more than 5,000 years of civilization. It has played an essential role in the fight against COVID-19, which broke out in China at the end of 2019. Chinese herbal medicines can be administered to confirmed patients, suspected patients, and close contacts to effectively curb the spread of COVID-19. The "three medicines and three prescriptions" selected through clinical screening are modifications of famous prescriptions in TCM classics(Sun, G.; Dong, L.2022). Effectiveness of TCM in treatment and curbing the spread of infections enhances the cultural confidence in TCM, and shows the significance of TCM education. In this context, cultivating inter-disciplinary medical professionals with strong practical abilities and of high quality to support high-quality development of China’s TCM cause is vital. Currently, in China, TCM talents are trained via two channels; training by TCM colleges and universities as well as via TCM master-apprentice education. Training by TCM colleges and universities has been very fruitful for a period of over 40 years since the reforms. By enriching specialty contents, expanding school sizes, and attracting international students, TCM colleges and universities have been vital in expanding the pool of TCM talents and in training TCM professionals in subject fields of clinical medicine and TCM theory among others. Advances in development of TCM education have been faced with various challenges, which are discussed in detail from the following three aspects.

2.1 Lack of a sense of immersion in online education

Due to COVID-19, most colleges and universities resorted to online teaching, which, in some institutions, occupies most of the teaching time in a semester. Compared to offline teaching, online teaching relies on electronic communication devices and the internet, as well as PPTs, videos, audios, and other relevant material. It is cost-effective, flexible, and free of geographical as well as spatio-temporal constraints, however, it has its limitations(Su, B.2022). Sometimes online teaching is misconstrued as an online delivery of resources and is solely concentrated on forms instead of contents, resulting in a lack of realistic interaction scenarios. Due to a shortage of interactive situational teaching, a lack of the offline teaching atmosphere and a sense of immersion, as well as the absence of teacher-student interactions, students often show a weakened sense of participation, low interest and enthusiasm in learning. Moreover, some online teaching platforms, such as Tencent Classroom and Tencent Meeting, can only show the actual number of participants in a classroom based on backstage data, but cannot reveal or evaluate the real learning state of learners, including their psychological and physiological data. This means that it is impossible to guarantee teaching quality or effects by relying on these platforms.

2.2 Separation of theory and practice

In applications, TCM is a highly practical discipline. Many basic courses of the discipline, such as naprapathy, acupuncture, pulse-taking, and identification of Chinese herbal medicine, rely on professional devices and lots of practice. For instance, in pulse-taking, theoretical teaching alone is insufficient in helping students distinguish between different pulse conditions or to master the correct operating steps of pulse-taking within a short period of time. Therefore, one-to-one practical guidance as well as operational descriptions and explanations should be provided to students. Traditionally, the teaching mode of TCM begins with theoretical knowledge, followed by practice. Under the new normal of regular COVID-19 prevention and control, online teaching of theoretical knowledge has become the main teaching mode. Online teaching does not offer any opportunities for students to practice their clinical skills or consolidate the learned theoretical knowledge. In clinical practice, students lacking the support of relevant theoretical knowledge often easily forget what they have learned, resulting in separation of theory and practice(Zhang, A.Y.et al., 2022).

2.3 Neglect of TCM classics learning

In learning, TCM education covers various subjects, including Chinese herbal medicine, prescriptions, diagnostics, as well as TCM fundamentals and is also closely associated with TCM classics such as The Yellow Emperor's Classic of Medicine, Treatise on Febrile Diseases, and Synopsis of Prescriptions of the Golden Chamber. Learning TCM classics is an important approach through which TCM practitioners can improve their clinical competence. The significance of learning TCM classics has been emphasized by many famous traditional Chinese physicians. But, specialty settings of TCM colleges and universities in China are based on division of modern medicine, which stresses the importance of Chinese herbal medicines, TCM fundamentals, and diagnostics but neglects TCM classics. The TCM classics should be included among the specialty courses so that learners can understand relevant contents through practical operations. When lacking both TCM thinking and clinical practice, learners often mechanically recite classic words and sentences, without gaining any in-depth understanding (Liang et al.,2022).

3 EMPOWERMENT OF TCM EDUCATION BY THE METAVERSE

3.1 Concepts of “metaverse” and “educational metaverse”

Metaverse has become a hot topic in the information technologies field. Globally, high-tech enterprises have set foot in metaverse-related fields. In March 2021, Roblox went public on the New York Stock Exchange, emerging as "the first share of the metaverse" (Li & Ma, 2022). In October, Facebook announced that it had renamed the company as Meta, saying that it would transform itself into a metaverse company (Kraus et al., 2022). Locally, domestic internet enterprises, such as Huawei, Baidu, Tencent and Alibaba have also entered metaverse-related fields through investment, acquisition, and development.

The "metaverse" concept was first coined by the American novelist, Neil Stephenson, in his science fiction Snow Crash. According to this work, everyone in the real world has a network avatar, and people from the real world can live together in virtual spaces by relying on technical devices and network avatars (Bale et al., 2022; Ahn et al., 2022; Jää-Aro & Snowdon, 2001). Scholars have expressed different views on what a metaverse is. Matthew Ball, one of the earliest researchers of the metaverse, believes that the metaverse requires the support of eight elements; hardware (such as augmented reality (AR) and virtual reality (VR)), computing power, networking, interchange tools and standards, virtual platforms, means of payment, services and assets, contents, and user behaviors (including consumption, investment, and decision-making). Roblox explained the eight key metaverse characteristics: diversity, immersive, low friction, identity, anywhere, friends, low economy, and civility. Wu et al. reported that the metaverse is a digital society that is based on digital technologies, in which people participate in the ternary world with digital identities, and that it is characterized by virtual-real fusion. In 2021, Tsinghua University released the Metaverse Development Research Report of 2020–2021 (Center for Journalism Studies of Tsinghua University, 2021), suggesting that the metaverse is a new type of internet application and a social form that fuses virtuality and reality by integrating multiple new technologies, which provides users with immersive experience based on technologies such as extended reality (XR), digital twins, and blockchain (Lan et al., 2022; Gu, 2022). In summary, the metaverse is an ultimate digital medium that integrates all digital technologies, including blockchain, interactive technology, virtual reality, immersive experience, internet, and cloud computing (Wang et al., 2022; Yang et al., 2022).

The metaverse was first applied in the education field in 2003. A typical example is “Second Life”, an online virtual platform created by Linden Lab in the US. In the "Second Life" metaverse, users can offer virtual schools, virtual classrooms, virtual libraries, virtual lectures, and other teaching scenarios. Other examples include the world's first virtual-reality high school and the immersive virtual laboratory that was created by Morehouse College, both of which are in the US. When it comes to “educational metaverse”, domestic scholars have their own understanding. Zhong et al. are of the opinion that educational metaverse provides learners with more intelligent teaching services and experiences under the support of intelligent technologies. Hua posits that educational metaverse is the application of the metaverse in education. Teachers, students, and managers can open virtual classrooms in the metaverse, where they can interact. The metaverse is an immersive field for teacher-student interactions (Hutson, 2022; Guo & Gao, 2022; Chen, 2022; Han, 2022; Lee & Kim, 2021). Liu et al. defined educational metaverse as an educational environment of virtual-real fusion that is shaped by new-generation information technologies (Liu et al., 2022). Analysis of the above concepts revealed three important characteristics of educational metaverse; immersive experience, new technology integration, and virtual-real fusion. These core characteristics can empower TCM education, extend the educational metaverse field beyond the limitations of the physical world, and make up for the deficiency of TCM education in the real physical world.

3.2 Theoretical basis of empowerment of TCM education by the metaverse

3.2.1 Learning theory of situated cognition

Learning theory of situated cognition, established and developed by Maslow and Rogers, emphasizes that individual psychology arises in the context that constitutes, guides, and supports cognitive processes, the nature of which is determined by situations. Situations form the basis of all cognitive activities. In theory of situated cognition-based learning, students actively process and construct learning information and knowledge, emerging as subjects of learning. Therefore, teachers impart knowledge, guide and promote their learning (Huang, 2016; Kim & Hannafin, 2008; Kim, 2012). Theory of situated cognition-based computer technologies can effectively organize teachers, students, teaching media, and other elements. In this organization, students can exercise initiatives under the guidance and help of teachers, participate in real situations, understand and master knowledge through autonomous learning and group collaborations. The educational metaverse can break through spatio-temporal constraints, set up "on-site" virtual situations according to learning requirements, and provide students with certain learning support so that they can form teams and collaborative communities in the same task situations. These effects promote effective implementation of situational teaching (Zallio & Clarkson,2022).

3.2.2 Flow theory

The flow theory, which was first proposed by the American psychologist, Mihaly Csikszentmihalyi, refers to a state in which people are highly concentrated on an activity and get pleasure from it without being affected by external factors. This theory holds that the primary factor affecting immersion is the relationship between "challenges" and "skills" (Qu, 2022; Csikszentmihalyi, 1990). That is, in the face of a huge challenge, learners often feel a loss of control over the environment and can easily fall into a negative psychological state. However, when learners' skills are equivalent to the challenges, they tend to have a positive attitude (i.e., immersion), which improves their learning efficiency (Lee et al., 2007). The educational metaverse is highly realistic and immersive, which enhances learners' senses of existence, presence and fully arouses their enthusiasm in learning.

3.3 Application advantages of metaverse in TCM education

3.3.1 Enhancement of teaching experience

The metaverse is a collection of various technologies, including blockchain, AI, XR, and digital twins. It can be used to construct an interactive, embodied, and permanent learning system that is characterized by virtual-real fusion for online learners. The system is of significance in breaking through virtual and real boundaries of learning spaces and bridging the geographical separation between teachers and students, thereby creating a seamlessly connected, deeply integrated immersive learning field (Onggirawan et al.,2023). In a metaverse ecology, teachers can self-define scenario characteristics of virtual classrooms based on course or subject features. The virtual classroom environment can change freely with subjects, so that each learner can experience the charm of different subjects from visual, auditory, tactile, and other perspectives. This characteristic of virtual classrooms stimulates the curiosity of students in courses and their desire for exploration, thereby improving their attention and learning efficiency.

3.3.2 Maintenance of synchronous interactions

The 5G technology has endowed the metaverse with a core attribute of synchronous simulation, which is important in realizing highly synchronous interactions between virtual spaces and real learning resources. This guarantees an increasingly realistic interaction effect between teachers and learners in virtual spaces. The low latency of 5G makes it possible for behaviors in real teaching scenarios to receive real-time mapping and feedback in virtual spaces (Accenture, 2022). Moreover, it ensures real-time interactions between teachers and students, and provides network guarantee for deep interactions in immersive learning (Lee et al., 2013). For instance, by relying on metaverse technologies, teachers can upload learning resources to the mobile devices carrying the virtual world, or store them in blockchain, so as to guarantee the security of intellectual properties, copyrights, and data while making them easily accessible to students at any time. With the aid of the AR technology, real world learners can synchronously access learning resources through contactless human interactions. This synchronous transfer offers real feedback to learners, thereby improving the learning quality (Han & Kang, 2022; An et al., 2022)..

3.3.3 Provision of diversified learning resources

The learning resources provided by traditional online teaching modes include texts, videos and PPTs among others, which denote a relatively abstract learning situation. Learners have to convert these static data into 3D dynamic psychological representations in the brain before they can accurately understand relevant learning contents. This conversion process increases the cognitive burden on learners, and may end up weakening their desire for exploration (Dengel & Mägdefrau, 2019). The combination of TCM education and the metaverse can integrate digital teaching resources into real learning scenarios, and present such resources in multi-modal forms, including image-text annotations, simulated animations, and interactive experiments. The vivid and illustrated learning scenarios that are created in this manner can produce multiple sensory stimuli, so that learners can fully mobilize their visual, auditory, tactile, and olfactory sensations in learning. This will speed up the formation, acquisition as well as development of concepts and formation of higher-order thinking in continuous cognitive practice (Efstathiou et al., 2018; Witmer & Singer, 1998; Zhang et al., 2020).

4. Architecture of TCM Education Metaverse

Taking into account the basic characteristics and technical basis of the educational metaverse, we designed an architecture of the TCM education metaverse, which is composed of six layers (i.e., infrastructure, data, data processing, technology, application and interaction layers), as shown in Figure 1.

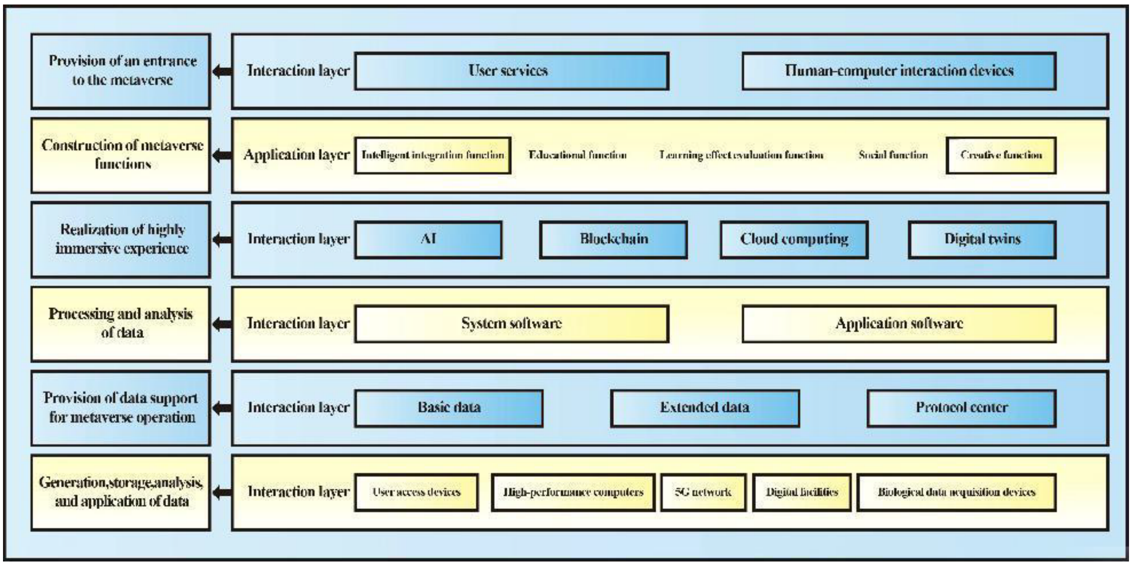

Figure 1. Architecture of the TCM education metaverse.

This picture mainly shows the structure of the metaverse, which consists of six layers, named infrastructure layer, data layer, data processing layer, technology layer, application layer, and interaction layer. The infrastructure layer is the carrier for data generation, storage, analysis, and application. It includes user access devices, high-performance computers, 5G network, digital facilities, and biological data acquisition devices. The data layer provides data support for operation of the TCM education metaverse, including basic data, extended data, and protocol center. The main function of data processing layer is processing and analyzing data, including system software and application software. The technology layer includes AI, blockchain, cloud computing, and digital twins, which help the metaverse achieve a highly immersive experience. The application layer is used to construct the role and operation functions of the educational metaverse, including intelligent integration function, educational function, learning effect evaluation function, social function, and creative function. The interaction layer divided into two parts: user services and human-computer interaction devices, providing users with an entrance path to the TCM education metaverse. Design is done by author.

4.1 Infrastructure layer

The infrastructure layer is the carrier for data generation, storage, analysis, and application. It consists of user access devices, high-performance computers, 5G network, digital facilities, and biological data acquisition devices. User access devices include mobile terminals, GPS positioners and cameras, which can be used to acquire user information (Duan et al., 2021; Dahan et al., 2022). The metaverse is a large-scale multimedia system whose operation requires huge computational costs, which shows the need for a high computing power of computers. The authenticity of 3D rendering in teaching scenarios and enhancing users' sense of immersion can only be guaranteed by continuously improving the computing power of computers (Lee et al., 2021). Since the expected metaverse should be accessible at any time and place, communication technologies are essential for providing basic support. Therefore, 5G technology is of significance in this regard. The 5G network, which is characterized by low latency and high speeds, can provide a suitable communication pipeline support for the TCM education metaverse and realize real-time transmission of massive data resources. Digital facilities include all kinds of electronic devices, including edge computing centers, cloud computing centers, and AI Internet of Things. Edge computing centers and cloud computing centers provide computing power support for processing of massive data. The AI Internet of Things stores the massive data collected by the Internet of Things in cloud and edge devices (Kottursamy et al., 2022). During learning, biological data acquisition devices are majorly used to detect changes in learners' sense of immersion, concentration, and flow experience, so that teachers can directly acquire information about their learning behaviors and follow up their learning attitudes as well as learning states (Kottursamy et al., 2022).

4.2 Data layer

The data layer, used to provide data support for operation of the TCM education metaverse, consists of basic data, extended data, and protocol centers. Basic data includes data on hardware and software of the educational metaverse. Extended data refers to learners' VR characteristic data, perceptual data, and psychological as well as physiological data during immersion. The data layer also has the attribute of assets, which makes it necessary to separate it as an asset and place it under the supervision of protocol centers. Protocol centers establish a series of rules for data applications and ultimately forms a sound educational metaverse supervision system, guaranteeing orderly operation of the TCM education metaverse (Leibe et al., 2016; Li, 2022).

4.3 Data processing layer

The data processing layer is used for data processing and analysis. It consists of two sublayers; system and application softwares. System software includes cloud computing system software, AI control software, and special software for metaverse systems. It is used to control and coordinate the development as well as operation of hardware devices and application software of the educational metaverse. As a software developed to realize specific functions of the educational metaverse, the application software is used for conversion of the physical layer and real application scenarios.

4.4 Technology layer

The technology layer, which consists of AI, blockchain, cloud computing, and digital twins, assists the metaverse in realizing a highly immersive experience. Among them, AI is involved in data analysis, information review, intelligent information recommendation and massive database content generation among others (Collobert & Weston, 2008; Kendall & Gal, 2017; Alhaija et al., 2017; Lu et al., 2015). Blockchain is among the most basic and critical technologies in the metaverse. Having integrated various information technologies, including distributed data storage, encryption algorithm, point-to-point transmission, and consensus mechanism, blockchain can be understood as a decentralized, tamper-proof distributed ledger database (Xu et al., 2018; Berg et al., 2019). It uses encryption technologies to generate data blocks, each of which contains the database-generated information change data. These data blocks can be used to test data correctness and to generate the next data block (Cai et al., 2018). Since blockchain exhibits an anti-counterfeiting, tamper-proof and traceable block-chaining data architecture, its selection to store metaverse data ensures the integrity and security of teaching process-generated data information (Zyskind et al., 2015; Li et al., 2019; Liang et al., 2020; Ren et al., 2019). Cloud computing, a form of distributed computing, can integrate various computing resources for automatic management with application softwares. It can process thousands and thousands of data pieces within a short time so that resources can be efficiently provided (Wang et al., 2015). As a collection of a series of technologies, digital twins can enable things in the physical world to create a digital "clone" in a digital space, and duplicate the real-time state of ontology as well as external environmental conditions onto the "clone" (Agnusdei et al., 2021; Farhat et al., 2021; Fuller et al., 2020; Kostenko et al., 2018; Moi et al., 2020; Piltan & Kim, 2021; Tuegel et al., 2011). In initial construction stages of TCM education metaverse, the digital twins technology can be used to generate and construct virtual classrooms as well as libraries with extremely rich details, thereby creating an immersive sense of presence.

4.5 Application layer

The application layer is used to construct the role and operation functions of the educational metaverse. Based on educational metaverse characteristics, the application layer realizes five functions; intelligent integration function, educational function, learning effect evaluation function, social function and creative function. With regards to intelligent integration function, the metaverse uses big data technology for data analysis and to associate virtual classroom as well as library resources and services. In terms of educational function, 5G, AR, VR, mixed reality (MR), and other technologies create "on-site" learning experience and immersive classroom environments for learners (Kors et al., 2016; Lassagne et al., 2018; Lee et al., 2013; Lee et al., 2022; Liu et al., 2012; Milgram et al., 1995; Pierce et al., 1999; Reilly et al., 2015; Roo et al., 2017; Sakaguchi et al., 2017; Speicher et al., 2019). This smoothens the exchanges and interactions between teachers and students. Regarding the learning effect evaluation function, the metaverse analyzes and evaluates the learning effects of learners by combining blockchain-stored data on users' learning state (including psychological and physiological data and perceptual data) with AI. In terms of social function, the metaverse has a strong social attribute so that when searching information or reading books in public libraries of the metaverse, it is easier for learners to meet other readers with common learning needs and topics. In terms of creative function, the educational metaverse allows users to create freely anywhere. Therefore, provision of educational resources is not limited to individual teachers as schools can invite the government and other colleges and universities to jointly create rich and comprehensive educational resources in the metaverse.

4.6 Interaction layer

The interaction layer provides users with an entrance path to the TCM education metaverse. It is divided into two parts: user services and human-computer interaction devices. User services include mobile visual search (MVS), virtual learning companion (VLC), mobile augmented reality (MAR), educational metaverse navigation, and 3D display of learning resources among others. The MVS helps users to quickly access the necessary learning resources, while MAR provides full-sensory immersive experience to users. Human-computer interaction devices include brain-computer interfaces (BCIs), MR machines, AR devices, VR devices, and wearable devices among others. These devices connect learners to the metaverse. When used in combination with infrastructure layer, human-computer interaction devices can realize multi-sensory information interactions between the educational metaverse and users by integrating various sensing technologies, such as visual perception, phonetic perception, and tactile perception (Alce et al., 2017; Fernandez et al., 2021; Cao et al., 2019; Park et al., 2019).

5 SYMBIOTIC APPLICATION SCENARIO OF METAVERSE EMBEDDING IN TCM EDUCATION

As an integrated form of technological applications, the metaverse provides technical support for reformation of TCM education. Digital twins, 5G, AR, VR, MR, and other visualization technologies provide possibilities for creation of immersive learning experience and 3D display of learning resources. Technologies such as AI, blockchain, and big data provide support for precise evaluation of learning effects, storage and protection of digital learning resources, and establishment of association systems between virtual classrooms as well as library resources and services in the metaverse. Based on this background, this paper proposes some application scenarios of TCM education metaverse in different virtual spaces (Figure 2).

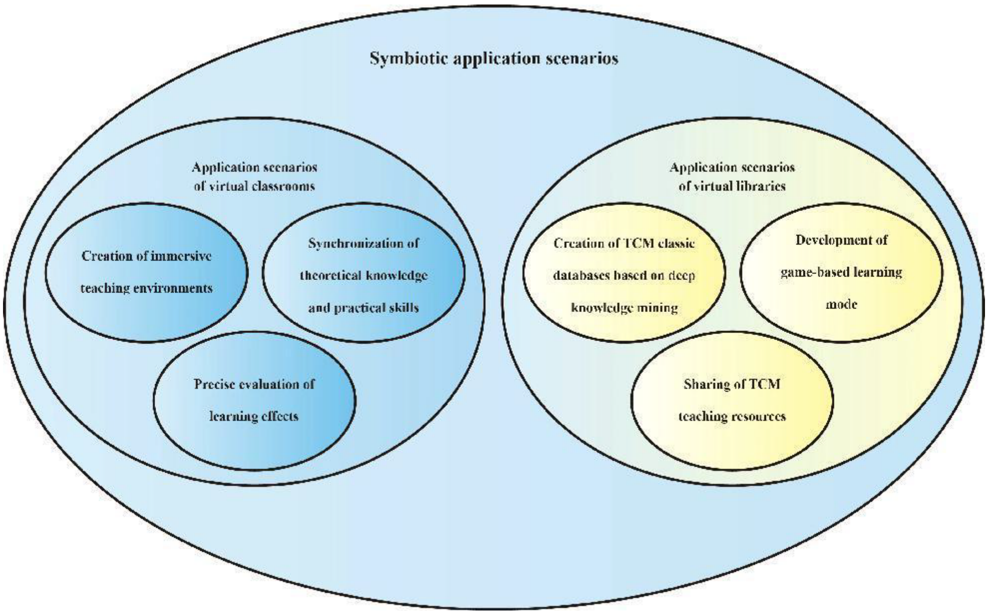

Figure 2. Symbiotic application scenarios of metaverse embedding in TCM education.

This picture depicts some application scenarios of TCM education metaverse in different virtual spaces, including virtual classroom application scenarios and virtual library application scenarios. Design is made by author.

5.1 Application scenarios of virtual classrooms

5.1.1 Creation of immersive teaching environments

The term "immersive" refers to a state in which learners can throw themselves into learning without any interference from external factors. The uncertainties posed by COVID-19 have affected teaching quality and outcomes. Reliance on monotonous PPTs, audios, and videos alone in online teaching have reduced the abilities of teachers to mobilize students and improve their concentrations. Mazuryk et al.(1996) reported that during information acquisition by the human brain, three sensory factors (visual, auditory, and tactile) jointly account for the highest proportion. Virtual reality technologies in the metaverse can stimulate an increase in total proportion of visual, auditory, and tactile factors to as high as 94%, thereby improving students' concentration and knowledge acquisition efficiency. In the metaverse ecology, based on digital twins technology, teachers can reconstruct the same campus classroom scenarios as those in the real world and generate a 3D map of the real world using navigation, positioning, mapping, and other technologies. They can also use ultra-precision indoor positioning technologies to pinpoint virtual teaching environments of teachers and students in the real world (Sun et al., 2022; Zhong et al., 2022).By relying on VR/AR, MR, and other digital devices as well as virtual digital avatars acquired through digital mapping, teachers and students who are geographically separated from each other can locate campus classrooms in the 3D map, that is, switch to virtual classrooms. Virtual classroom scenarios can constantly change with different courses or contents. For instance, classroom scenario of traditional Chinese pharmacology is an antique TCM clinic that is divided into an exhibition area and a digital resources area. The exhibition area shows all kinds of pharmaceutical tools and a Chinese herbal medicine cabinet. The digital resources area stores digital textbooks and digital learning resources that are uploaded by teachers. Everything is displayed in 3D form. In the exhibition area, learners can touch a pharmaceutical tool for a detailed explanation of its name and use. The outside of each drawer in the Chinese herbal medicine cabinet is marked with the name of a TCM processed product, and filled with the processed product inside. In the digital resources area, if a digital textbook in the digital resource box is touched, the textbook, with the aid of AR, XR, and other technologies, will convert 2D static texts into diversified learning resources, such as annotated 3D images, animations, videos, and audios of Chinese herbs. If the 3D image of a Chinese herb is clicked, the classroom scenario will immediately switch to growth environment of the Chinese herb. Therefore, students can understand the natural conditions for growth of the Chinese herb, observe its complete morphology, and check its structure in an all-round manner. Moreover, there is an audio explanation of its efficacy, nature, flavor, meridian tropism, pharmacological actions, applications, use, dose, precautions, and identification among others. This situational experience stimulates learners' interest in learning and promotes their independent inquiry as well as cognitive engagement, thereby improving learning efficiency.

5.1.2 Theoretical knowledge and practical skill synchronization

Online or offline, the existing teaching mode of TCM begins with theoretical knowledge, followed by practice. Even offline practical courses are basically offered in form of teacher demonstrations, with students watching. Hands-on operations opportunities are very rare. The metaverse teaching environment can acquire 3D panorama of the real physical environment so as to present the real scenario and to transcend the virtual, especially for courses with high operational requirements, such as naprapathy, acupuncture, and pulse-taking. Moreover, it can ensure smooth transition from theoretical learning to practical learning and promote the integration of theory and practice (Locurcio, 2022; Skalidis et al., 2022). For instance, in an acupuncture class, the teacher can build a bronze acupuncture figure model in the metaverse to clearly show the position of each acupoint and the structure of each meridian. If an acupoint on the model is gently pressed, a video will be played to explain the functions and acupuncture methods of the acupoint. Teachers can also assign corresponding tasks in various links of a practical class. For instance, in a class about the function, acupoint selection method, and acupuncture method of the acupoint "Liangqiu", teachers can ask students to demonstrate how to find the acupoint and perform the acupuncture. Students can also use virtual acupuncture tools, which are created in advance, to perform practical exercises on the bronze acupuncture figure model. In the PC era, learners rely on devices such as mouses, keyboards, and touch screens to interact with virtual contents. Sharp traces in interaction technologies can result in a sense of unreality for learners. In educational metaverse, learners can use wearable devices (including VR, AR, tactile gloves, force feedback vests, and mechanical arms), somatic senses, and gestures to perform various body movements in the virtual world as in the real world. By performing natural operations on virtual objects, they can experience approximate real sensory feedbacks. During acupuncture operations, students can get a tactile impression that is comparable to that in the real world, thereby gaining a perception about needle insertion depth and acupuncture angle. Practical exercises can also be partnered with an AI robot to provide students with services like knowledge quizzes, pair exercises and learning guidance among others. When a student succeeds, the robot gives encouraging cheers and dances to provide real-time feedback. When a student fails, the robot changes the color of its eyes, gives a hint to the student, and helps him or her correct errors. Such practical operations, which are based on virtual simulation, strengthen the organic integration of theory and practice, and reverses the separation of theory and practice in the traditional TCM education mode.

5.1.3 Precise evaluation of learning effects

Due to COVID-19, online teaching has become a common teaching mode in colleges and universities. However, online teaching platforms only show the actual number of participants in a classroom, but cannot reveal the real learning dynamics of students. Even though most colleges and universities have established a teaching quality evaluation system, evaluation results, for various reasons, are neither accurate nor objective. The learning state of students cannot be accurately established. In this context, the educational metaverse, using biological data acquisition devices and guaranteed by 5G and high speeds, can collect learning process data and learners' physiological data (such as EEG, heart rate, and skin conductance). By identifying data on learners' classroom behaviors, such as facial expressions, language actions, and gestures, it can realize whole-process monitoring and dynamic analysis of learners' learning states. Learning process data, classroom behavior data, and physiological data are eventually stored in blockchain. At the end of a semester, the metaverse combines the data stored in blockchain with teacher evaluation data to evaluate the final learning effects and to develop a personalized learning scheme for each learner. The complete evaluation system of the educational metaverse is conducive for precise evaluation of learning effects and improvement of teaching quality.

5.2 Application scenarios of virtual libraries

5.2.1 Creation of TCM classics databases based on deep knowledge mining

Since learning TCM classics offers an effective way for TCM practitioners to improve their clinical competence, TCM colleges and universities should create TCM classics databases in the educational metaverse, so as to cultivate students' independent learning abilities and form a dense atmosphere for TCM classics learning. In recent years, digital resources of TCM classics have stayed in the scanning digitalization stage and have not been developed or mined in depth. Simple reading and inquiry cannot meet the specialty needs of medical students. To enhance academic reading, TCM colleges and universities should develop and process the massive hidden information in TCM classics (Ye&Zhou, 2021). The digital resources in libraries of some TCM colleges and universities are majorly from three sources: self-owned digital resources, externally procured resources, and network resources. These resources are differentiated in organizational and content forms. In the metaverse, the libraries of TCM colleges and universities should integrate these resources. To achieve semantic linking and interoperability between different resource types, there is a need to establish mapping, integration, protocol, and other standards at the semantic level. Moreover, digital resources from different sources should be clustered in the same scenario for unified narration, realizing scenario interconnection. Second, different resource types should be indexed at the metadata and ontology levels" and associations between entities refined based on semantic ontology. Twining scenarios should be established and various virtual elements constructed based on entities and their association graphs. Finally, virtual-real interactions should be realized. In the entire process, entries in massive TCM classics are clustered to construct a huge knowledge system, which can analyze, track, and filter readers' confusions as well as doubts and form a knowledge chain(Ma&Zhang, 2022). The entry "Bulbus lillii syndrome (lily disease)" in Part 3 of Synopsis of Prescriptions of the Golden Chamber in TCM classics databases can be cited for illustration. If a user touches the entry, the collation and annotation of the entry will appear. Moreover, based on technologies such as digital twins, 3D modeling, and XR, the metaverse shows learners the main symptoms of Bulbus lillii syndrome patients in daily life, and based on syndrome differentiation and related TCM prescriptions, provides a text and a video to explain disease treatment. There are also interactions between learners and the digital virtual human (a substitute for venue staff). Where a user wants to check the composition of each TCM prescription for Bulbus lillii syndrome, the digital virtual human will immediately show users the form and dosage of each Chinese herb. By touching the 3D image of a Chinese herb, the user can understand the nature, flavor, meridian tropism, efficacy, and pharmacological actions of the Chinese herb. The user can also learn related derivative knowledge via the links that are automatically generated from TCM classic databases, including processing methods, health preservation knowledge, prescription groups, and clinical cases among others. The huge knowledge system constructed by the metaverse can deepen medical students' understanding of TCM classics and improve their clinical competence.

5.2.2 Game-based learning mode

Online game is a metaverse prototype. They are similar in many aspects, such as strong socialization, free creation, and immersive experience. Game-based learning is a pertinent application scenario for the educational metaverse (Getchel et al., 2010). Relying on VR, AR, MR, AI, and other technologies, the TCM education metaverse integrates game experience with knowledge learning to improve interestingness and excitement of learning, so that learners can fully devote themselves to learning, enhance their "immersive experience", and realize "learning through play" in real sense. Therefore, a level-based game can be introduced into reading of TCM classics. Before starting the game, students can choose their favorite cartoon characters, garment decorations, historical background, learning props, and derivative products, which all add to entertainment of reading. Each classic TCM book chapter can be treated as a level, and each level can be designed with a challenge in the form of knowledge quizzes or online simulation training. A student who passes the first level can proceed to the next while those who fail are not allowed to proceed. The level-based game progresses from easy to difficult to complicated. Learners reading the same classic TCM book can also participate in the same level of a game, and engage in one-on-one hit (PK). Each time a learner passes a level, they are awarded with a badge. The reader who is the first to pass all levels of a game will be given the title "Champion of Reading". Compared to the dull and tiresome traditional reading mode, this reading mode arouses readers' interests in learning and curiosity for knowledge.

5.2.3 Sharing of TCM teaching resources

Teaching resource quality has a large bearing on teaching quality, which can only be guaranteed when educators and learners have high-quality teaching resources. Due to advances in information technologies, libraries of many TCM colleges and universities have devoted themselves to creating TCM classic databases with their own collection of characteristic resources. To protect their intellectual property rights, some TCM colleges and universities have set up access rights, and limited their service objects to their own teachers and students, while denying access to readers from other TCM colleges and universities. Thus, library teaching resources of these TCM colleges and universities have a low transfer rate, as well as low openness and sharing degrees. Realization of sharing of TCM resources and protection of copyrights at the same time is a major challenge. In the metaverse, the blockchain technology can build an anti-counterfeiting, tamper-proof, and traceable block-chain data architecture(Xie & Li, 2022). This architecture can be leveraged to prevent published digital resources from being tampered with, trace their transactions and flows, and facilitate the right confirmation, storage, as well as circulation. For instance, if a TCM college has created a TCM classics database in the metaverse, then, the library of the TCM college will be entitled to generate a non-fungible token (NFT) to represent the database ownership, and to grant the right of browsing to readers from other TCM colleges as well as universities in the metaverse. All data transfer, authorization, and transaction processes are performed on blockchain, with clear and tamper-proof property rights, so that every creator can become the master of his or her own data.

6 CHALLENGES FACED BY METAVERSE TCM EDUCATION

The AI, blockchain, cloud computing, digital twins, and other metaverse technologies provide new imaginative spaces for TCM education. However, we should also be aware of the challenges faced by TCM education.

6.1 Risk of infringement of intellectual property rights

From an intellectual property rights perspective, the databases created by colleges and universities have copyright infringement risks. The blockchain technology in the metaverse can generate an NFT for uniqueness authentication (the code is replicable, but the timestamp and the encrypted signature are not), which makes colleges and universities unique owners of their knowledge assets. The technology can trace and ensure transaction circulation but cannot identify the founder of user-generated content (UGC), resulting in separation of copyrights and the transaction system. For example, once the resources of a college's self-built database are illegally replicated or reproduced before the transaction, even if the entire transaction process is not replicable, its interests will still be damaged (Xiang et al., 2022; Park, 2022). Moreover, the works in the metaverse may be taken to the real world by other users for secondary development and utilization. This knowledge resources development approach and reconstruction across virtual and real boundaries is likely to cause disputes over intellectual property rights and aggravate the complexity of intellectual property rights management in the metaverse. Protection of intellectual property rights in the metaverse is different from the real world, therefore, it is necessary to predict its complexity and offer a corresponding solution.

6.2 Imperfections of underlying technologies and infrastructural construction

Exploration of TCM education metaverse in China is still in the primary stage. Regarding the involved technologies, there are challenges with immersiveness of virtual reality, 5G network popularity, network transmission speed, intelligence level of AI, AR affinity, and naturalness of human-computer interactions among others. The existing educational infrastructure is imperfect, and there is a need to accelerate infrastructural construction in the fields of 5G, Internet of Things, satellite internet, AI, cloud computing, blockchain, data center, and intelligent computing center among others. In addition, there is a lack of educational metaverse products that are customized for the education field. These technologies and infrastructure need development and perfection to meet the requirement of the educational metaverse, and there is a long way to go to achieve their popularization.

6.3 Absence of sound laws, regulations and standards on educational metaverse

At this stage, the metaverse presents typical characteristics of incomplete contracts, and there is an absence of basic rules on technical standards, contents, and property rights among others. In terms of property rights, the right confirmation of digital assets, ownership and use right of data are poorly defined and they currently form the gray areas of law (Lee, 2022; Nie & Li, 2022). In terms of attribution of tort liability, from the perspective of the virtual world, there is an absence of clear laws and regulations, such as attribution of tort liability in the real world. In terms of content, there are no clear moral or legal standards in the metaverse. Each user is a creator of works, and can create their own works, therefore, creation rules are determined by creators themselves. The relevant state departments should establish a unified industrial standard system of technologies, software, hardware, services, and contents in the metaverse, so as to guide related activities of the educational metaverse to legally and orderly proceed.

6.4 Risk of digital identity leakage

To provide services for teachers and students, the TCM education metaverse must first collect users' social relations, interpersonal interactions, identity attributes, emotional state, brain wave patterns, and other information. Then, it must automatically classify users according to their digital identities, and finally determine their use authorities (Park & Kim, 2022; Wang et al., 2022). However, if a user's personal information is leaked, the users' normal life in the real world will be seriously affected. Therefore, users need a more private identity in the metaverse, which can be created by either of the following two methods: i. Users' digital identities can be managed using Metamask, a browser plug-in wallet. Metamask is a blockchain-based digital identity manager that can help users manage a blockchain-based digital identity (consisting of an address and a private key). A digital identity consisting of an address and a private key can be created as follows. First, there is no need to bind a personal email or mobile phone number for registration, as the computer system can randomly generate a private key. The user must protect the private key from leakage. The private key is only saved on the local computer and will not be uploaded to the Internet. Next, based on calculation, the system will generate a public key corresponding to the private key and generate an address, which is the disclosed digital identity tag of the user on blockchain. In this way, the user has control over the right of identity management. The user can choose which applications to authorize for login, decide which applications can invoke personal data, and even modify or cancel the authorization at any time. Only users with a private key can invoke their own identities. Second, the practice of applying for a Macau Health Code with a Guangdong Health Code can be used for reference. In 2020, after stabilization of the COVID-19 pandemic, Macao was opened to the outside world. Tourists producing a negative nucleic acid test result could apply for a Macau Health Code with a Guangdong Health Code and pass the customs with a green health code. This process involved mutual recognition of Macau Health Code and Guangdong Health Code, which posed some technical difficulties: i. The generation and use of health codes must comply with relevant laws and regulations of the two regions on personal privacy protection and data security. The direction transmission of personal data between the mainland (Guangdong) and Macao was not allowed. ii. Due to prohibition of personal data transmission, it was very difficult to validate the authenticity as well as validity of relevant information without relying on a third-party platform. By relying on blockchain and base figures for privacy computing, institutions of the two regions solved the problem of "application cross-region without data cross-region". That is, Macau Health Code and Guangdong Health Code can be generated in the absence of any backstage data transmission. This practice complies with relevant laws as well as regulations of the two regions and guarantees information security and privacy of users. Operations of TCM education metaverse can refer to this practice by applying privacy computing to the metaverse on a large scale, so as to realize the "authentication but not acquisition" of digital identities and fully protect personal privacy (Yu et al., 2021). Efforts should aim at perfecting the existing laws and regulations on digital publishing and establishing corresponding supervision, complaint, and handling mechanisms, so as to guarantee information and data security of state and individuals.

7 CONCLUSIONS

Currently, the metaverse is at a very primary stage in terms of content supply, technological level and user experience among others. However, due to capital investment, metaverse development has become an irreversible trend. With advances in science and technology, the metaverse will become a digital society that is characterized by data integration, field synergy, as well as virtual-real fusion, and gradually integrate into people's work and life. Despite its achievements, China's TCM education is associated with various challenges, including the lack of a sense of immersion in online education, separation of theory and practice, and neglect of TCM classics in learning among others. As a collection of video game, interactive technologies, AI, blockchain, network, and other digital technologies, the metaverse can provide decentralized UGC creation spaces, an immersive sense of presence, and multiple distributed functional applications for TCM education, providing a new path for reformation and development of TCM education.

ACKNOWLEDGMENTS

This work was financially supported by Soft Science Research Project of Zhejiang Association for Science and Technology in China (grant number: 2022KXCX-KT011).

REFERENCES

Ahn, S. J. (Grace), Kim, J., & Kim, J. (2022). The Bifold Triadic Relationships Framework: A Theoretical Primer for Advertising Research in the Metaverse. J Advert, 51(5), 592 - 607.

Accenture. (2008). Tactile Internet Enabled by Pervasive Networks. Retrieved December 17, 2022, from https://www.accenture.com/_acnmedia/pdf - 68/accenture - tactile - internet - enabled - pervasive - networks

Alce, G., Roszko, M., Edlund, H., Olsson, S., Svedberg, J., & Wallergard, M. (2017). AR as a User Interface for The Internet of Things—Comparing Three Interaction Models. In 2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR - Adjunct) (pp. 81 - 86). Nantes, France: IEEE.

Alhaija, H. A., Dresden, T., & Tübingen, M. I. (2017). Augmented Reality Meets Deep Learning for Car Instance Segmentation in Urban Scenes. Proceedings of the British Machine Vision Conference 2017, Durham, BMVA Press, 1 - 12.

An, J., Yun, H., & Shim, S. (2022). Metaverse Augmented Reality Research Trends Using Topic Modeling Methodology. Knowl Manag Rev, 23(2), 123 - 142.

Agnusdei, G. P., Elia, V., & Gnoni, M. G. (2021). Is Digital Twin Technology Supporting Safety Management? A Bibliometric and Systematic Review. Appl Sci, 11(6), 2767.

Bale, A. S., Ghorpade, N., Hashim, M. F., Vaishnav, J., & Almaspoor, Z. (2022). A Comprehensive Study on Metaverse and Its Impacts on Humans. Adv Hum Comput Interact, 2022, 3247060.

Berg, C., Davidson, S., & Potts, J. (2019). Blockchain Technology as Economic Infrastructure: Revisiting the Electronic Markets Hypothesis. Front Blockchain, 2, 22.

Cai, W., Wang, Z., Ernst, J. B., Hong, Z., Feng, C., & Leung, V. C. M. (2018). Decentralized Applications: The Blockchain - Empowered Software System. IEEE Access, 6, 53019 - 53033.
Cao, Y., Xu, Z., Li, F., Zhong, W., Huo, K., & Ramani, K. V. (2019). Ra: An In - Situ Visual Authoring System for Robot - IoT Task Planning with Augmented Reality. Proceedings of the 2019 on Designing Interactive Systems Conference, San Diego CA USA, ACM, 1059 - 1070.
Center for Journalism Studies of Tsinghua University. (2021). Report on Development Research of the Metaverse (2020 - 2021). Retrieved December 28, 2022, from https://sjc.bnu.edu.cn/sywdlm/zkfb/xwdt2/121319.html
Chen, Z. (2022). Exploring the application scenarios and issues facing Metaverse technology in education. Interact Learn Environ, 1 - 13.
Collobert, R., & Weston, J. (2008). A Unified Architecture for Natural Language Processing: Deep Neural Networks with Multitask Learning. Proceedings of the 25th international conference on Machine learning, Helsinki, Finland, ACM, 160 - 167.
Csikszentmihalyi, M. (1990). FLOW: The Psychology of Optimal Experience. New York: Harper and Row.
Dahan, N. A., Al - Razgan, M., Al - Laith, A., Alsoufi, M. A., Al - Asaly, M. S., & Alfakih, T. (2022). Metaverse Framework: A Case Study on E - Learning Environment (ELEM). Electronics, 11(12), 1616.
Dengel, A., & Mägdefrau, J. (2019). Presence Is the Key to Understanding Immersive Learning. In Immersive Learning Research Network (pp. 185 - 198). London, UK: Springer, Cham.
Duan, H., Li, J., Fan, S., Lin, Z., Wu, X., & Cai, W. (2021). Metaverse for Social Good: A University Campus Prototype. Proceedings of the 29th ACM International Conference on Multimedia, 153 - 161.
Efstathiou, I., Kyza, E. A., & Georgiou, Y. (2018). An inquiry - based augmented reality mobile learning approach to fostering primary school students' historical reasoning in non - formal settings. Interact Learn Environ, 26(1), 22 - 41.
Farhat, M. H., Chiementin, X., Chaari, F., Bolaers, F., & Haddar, M. (2021). Digital twin - driven machine learning: ball bearings fault severity classification. Meas Sci Technol, 32(4), 044006.
Fernandez, C. B., Lee, L. H., Nurmi, P., & Hui, P. (2021). PARA: Privacy Management and Control in Emerging IoT Ecosystems using Augmented Reality. Proceedings of the 2021 International Conference on Multimodal Interaction, Montréal QC Canada, ACM, 478 - 486.
Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital Twin: Enabling Technologies, Challenges and Open Research. IEEE Access, 8, 108952 - 108971.
Getchell, K., Oliver, I., Miller, A., & Allison, C. (2010). Metaverses as a Platform for Game Based Learning. In 2010 24th IEEE International Conference on Advanced Information Networking and Applications (pp. 1195 - 1202). Perth, Australia: IEEE.
Gu, Y. S. (2022). Defining Metaverse in Korean. Stud Philos East - West, 103, 403 - 426.
Guo, H., & Gao, W. (2022). Metaverse - Powered Experiential Situational English - Teaching Design: An Emotion - Based Analysis Method. Front Psychol, 13, 859159.
Han, D. (2022). Exploration for Educational Application of Metaverse: Focusing on Implication for Use in English Education. J - Inst, 7, 10 - 21.
Han, K., & Kang, S. (2022). The Effect of VR and AR - based Education on Creative Problem - Solving Skills in Elementary School. J Creat Inf Cult, 8, 177 - 186.
Huang, C. F. (2016). The application of Situational teaching method in PS Teaching and Learning of secondary vocational schools. Kao Shi Zhou Kan, 92, 120.
Hutson, J. (2022). Social Virtual Reality: Neurodivergence and Inclusivity in the Metaverse. Societies, 12(2), 102.
Jää - Aro, K. M., & Snowdon, D. (2001). How Not To Be Objective. In Churchill, E. F., Snowdon, D. N., & Munro, A. J. (Eds.), Collaborative Virtual Environments (pp. 1 - 15). London: Springer.
Kendall, A., & Gal, Y. (2017). What Uncertainties Do We Need in Bayesian Deep Learning for Computer Vision? ArXiv Preprint ArXiv:1703.04977

Kim, H., & Hannafin, M. J. (2008). Situated case - based knowledge: An emerging framework for prospective teacher learning. Teach Teach Educ, 24(7), 1837 - 1845.
Kim, S. (2012). A Study on the Application of Situated Cognition Theory in the Mathematics Education. Educ Prim Sch Math, 15(1), 1 - 11.
Kors, M. J. L., Ferri, G., van der Spek, E. D., Ketel, C., & Schouten, B. A. M. (2016). A Breathtaking Journey. On the Design of an Empathy - Arousing Mixed - Reality Game. Proceedings of the 2016 Annual Symposium on Computer - Human Interaction in Play, Austin Texas USA, ACM, 91 - 104.
Kottursamy, K., Khan, A. ur R., Sadayappillai, B., & Raja, G. (2022). Optimized D - RAN Aware Data Retrieval for 5G Information Centric Networks. Wirel Pers Commun, 124, 1011 - 1032.
Kostenko, D., Kudryashov, N., Maystrishin, M., Onufriev, V., Potekhin, V., & Vasiliev, A. (2018). Digital Twin Applications: Diagnostics, Optimisation and Prediction. Proceedings of the 29th DAAAM International Symposium, DAAAM International, Vienna, Austria, 574 - 581.
Kraus, S., Kanbach, D. K., Krysta, P. M., Steinhoff, M. M., & Tomini, N. (2022). Facebook and the creation of the metaverse: radical business model innovation or incremental transformation? Int J Entrep Behav Res, 28(1), 52 - 77.
Lan, G. S., Wei, J. C., & Huang, C. Y. (2022). Metaverse for Learning Empowering Education: Constructing a New Pattern of Internet + Education Application. J Distance Educ, 40(1), 35 - 44.
Lassagne, A., Kemeny, A., Posselt, J., & Merienne, F. (2018). Performance Evaluation of Passive Haptic Feedback for Tactile HMI Design in CAVEs. IEEE Trans Haptics, 11(2), 119 - 127.
Leibe, B., Matas, J., Sebe, N., & Welling, M. (2016). A deep learning - based approach to progressive vehicle re - identification for urban surveillance. In Lecture Notes in Computer Science. Cham: Springer International Publishing.
Lee, C., Rincon, G. A., Meyer, G., Hollerer, T., & Bowman, D. A. (2013). The Effects of Visual Realism on Search Tasks in Mixed Reality Simulation. IEEE Trans Vis Comput Graph, 19(4), 547 - 556.
Lee, E., Kim, S., Lee, Y., & Han, K. (2007). A Study on Teaching - Learning Strategies for Flow Experience in e - Learning Environment. J Korean Assoc Comput Educ, 10(1), 21 - 30.
Lee, H. G., Chung, S., & Lee, W. H. (2013). Presence in virtual golf simulators: The effects of presence on perceived enjoyment, perceived value, and behavioral intention. New Media Soc, 15(6), 930 - 946.
Lee, J., & Kim, Y. (2021). A study on the immersive metaverse system to improve the concentration of education. TeBS, 22, 3 - 14.
Lee, L. H., Braud, T., Hosio, S., & Hui, P. (2022). Towards Augmented Reality Driven Human - City Interaction: Current Research on Mobile Headsets and Future Challenges. ACM Comput Surv, 54(1), 1 - 38.
Lee, L. H., Braud, T., Zhou, P., Wang, L., Xu, D., Lin, Z., Kumar, A., Bermejo, C., & Hui, P. (2021). All One Needs to Know about Metaverse: A Complete Survey on Technological Singularity, Virtual Ecosystem, and Research Agenda. ArXiv Preprint ArXiv:2110.05352
Li, H. C., & Ma, J. (2022). Reconstruction of "Human, Field, and Object" in Metaverse Library from the Perspective of Immersive Theory. Inf Sci, 40(1), 10 - 15.
Li, M. (2022). Research on Service Mode and Technical Framework of Smart Library from the Perspective of Metaverse. Inf Stud Theory Appl, 45(3), 89 - 93. https://doi.org/10.16353/j.cnki.1000 - 7490.2022.03.013
Li, R., Song, T., Mei, B., Li, H., Cheng, X., & Sun, L. (2019). Blockchain for Large - Scale Internet of Things Data Storage and Protection. IEEE Trans Serv Comput, 12(6), 762 - 771.
Liang, B. X., Huang, S. Q., & Fang, W. B. (2022). Discussion on the Application of Traditional Chinese Medicine Classics and Traditional Chinese Medicine Thinking in Teaching. Chin Med Mod Distance Educ Chin, 20(2), 34 - 36.
Liang, W., Fan, Y., Li, K. C., Zhang, D., & Gaudiot, J. L. (2020). Secure Data Storage and Recovery in Industrial Blockchain Network Environments. IEEE Trans Industr Inform, 16(10), 6543 - 6552.
Liu, G. P., Gao, N., Hu, H. L., & Qín, Y. C. (2022). Edu - Metaverse: Characteristic, Mechanism and

Application Scenarios. Open Educ Res, 28(1), 24 - 33.
Liu, H., Bowman, M., & Chang, F. (2012). Survey of state melding in virtual worlds. ACM Comput Surv, 44(4), 1 - 25.
Locurcio, L. L. (2022). Dental education in the metaverse. Br Dent J, 232(3), 191.
Lu, J., Wu, D., Mao, M., Wang, W., & Zhang, G. (2015). Recommender System Application Developments: A Survey. Decis Support Syst, 74, 12 - 32.
Ma, Y. H., & Zhang, C. (2022). Research on the construction of application scenarios of book publishing under the background of metauniverse. Sci Technol Chin Mass Media, 2(1), 10 - 14.
Mazuryk, T., & Gervautz, M. (1996). History, applications, technology and future. Virtual Reality. Retrieved from https://www.cg.tuwien.ac.at/research/publications/1996/mazuryk - 1996 - VRH/TR - 186 - 2 - 96 - 06Paper.pdf
Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1995). Augmented reality: a class of displays on the reality - virtuality continuum. In Telemanipulator and Telepresence Technologies (pp. 282 - 292). Boston, MA: SPIE.
Moi, T., Cibicik, A., & Rølvåg, T. (2020). Digital twin based condition monitoring of a knuckle boom crane: An experimental study. Eng Fail Anal, 112, 104517.
National Administration of Traditional Chinese Medicine. (2021). Some policies and measures to speed up the development of traditional Chinese medicine characteristics. Retrieved February 9, 2021, from http://www.satcm.gov.cn/xinxifabu/guowuyuanxinxi/2021 - 02 - 09/20093.html
Nie, H. H., & Li, J. (2022). The Order of the Metaverse: A Perspective of Incomplete Contract Theory. Rev Ind Econ, 2(2), 186 - 198.
Onggirawan, C. A., Kho, J. M., Kartiwa, A. P., Anderies., & Gunawan, A. A. S. (2023). Systematic literature review: The adaptation of distance learning process during the COVID - 19 pandemic using virtual educational spaces in metaverse. Procedia Comput Sci, 216, 274 - 283.
Park, K. S. (2022). The Study on IPR Issues Surrounding Uses of NFTs in Metaverse. Law Res Inst Chungbuk Natl Univ, 13, 83 - 121.
Park, Y., Yun, S., & Kim, K. H. (2019). When IoT met Augmented Reality: Visualizing the Source of the Wireless Signal in AR View. Proceedings of the 17th Annual International Conference on Mobile Systems, Applications, and Services, Seoul Republic of Korea, ACM, 117 - 129.
Park, S. M., & Kim, Y. G. (2022). A Metaverse: Taxonomy, Components, Applications, and Open Challenges. IEEE Access, 10, 4209 - 4251.
Piltan, F., & Kim, J. M. (2021). Bearing Anomaly Recognition Using an Intelligent Digital Twin Integrated with Machine Learning. Appl Sci, 11(10), 4602.
Qu, X. X. (2022). Research on the development of online education based on educational metaverse. Sci Technol Ecnony Mark, 4, 149 - 151.
Reilly, D., Echenique, A., Wu, A., Tang, A., & Edwards, W. K. (2015). Mapping out Work in a Mixed Reality Project Room. Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, Seoul Republic of Korea, ACM, 887 - 896.
Ren, Y., Leng, Y., Cheng, Y., & Wang, J. (2019). Secure data storage based on blockchain and coding in edge computing. Math Biosci Eng, 16(4), 1874 - 1892.
Roo, J. S., Gervais, R., Frey, J., & Hachet, M. (2017). Inner Garden: Connecting Inner States to a Mixed Reality Sandbox for Mindfulness. In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, Denver Colorado USA, ACM, 1459 - 1470.
Sakaguchi, K., Haustein, T., Barbarossa, S., Strinati, E. C., Clemente, A., Destino, G., Pärssinen, A., Kim, I., Chung, H., Kim, J., Keusgen, W., Weiler, R. J., Takinami, K., Ceci, E., Sadri, A., Xain, L., Maltsev, A., Tran, G. K., Ogawa, H., Mahler, K., & Heath Jr, R. W. (2017). Where, When, and How mmWave is Used in 5G and Beyond. IEICE Trans Electron, E100.C, 790 - 808.
Skalidis, I., Muller, O., & Fournier, S. (2022). CardioVerse: The cardiovascular medicine in the era of Metaverse. Trends Cardiovasc Med. https://doi.org/10.1016/j.tcm.2022.05.004

Speicher, M., Hall, B. D., & Nebeling, M. (2019). What is Mixed Reality? Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow Scotland Uk, ACM, 1 - 15.

Sun, G., & Dong, L. (2022). Thinking and practicing of traditional Chinese medicine teaching model in the post - epidemic era. J Tradit Chin Med, 30(1), 19 - 21.

Sun, J., Gan, W., Chao, H. C., & Yu, P. S. (2022). Metaverse: Survey, Applications, Security, and Opportunities. ACM Comput Surv, 1, 1 - 35.

Su, B. (2022). Enhancement of Online Education to the Teaching Paradigm: Taking Academic Medical Postgraduate Cultivation as an Example. Front Med, 9, 807469.

Tuegel, E. J., Ingraffea, A. R., Eason, T. G., & Spottswood, S. M. (2011). Reengineering Aircraft Structural Life Prediction Using a Digital Twin. Int J Aerosp Eng, 2011, 154798.

Wang, G., Badal, A., Jia, X., Maltz, J. S., Mueller, K. M., Myers, K. J., Niu, C., Vannier, M., Yan, P., Yu, Z., & Zeng, R. (2022). Development of metaverse for intelligent healthcare. Nat Mach Intell, 4(11), 922 - 929.

Wang, Y., Chen, I. R., & Wang, D. C. (2015). A Survey of Mobile Cloud Computing Applications: Perspectives and Challenges. Wirel Pers Commun, 80(3), 1607 - 1623.

Wang, Y., Su, Z., Zhang, N., Xing, R., Liu, D., Luan, T. H., & Shen, X. (2022). A Survey on Metaverse: Fundamentals, Security, and Privacy. IEEE Commun Surveys Tuts, 25(1), 319 - 352.

Witmer, B. G., & Singer, M. J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. Presence, 7(3), 225 - 240.

Xie, H. P., & Li, Y. N. (2022). The new landscape and regulatory challenges of digital publishing in the metaverse era. Media, 6(2), 74 - 77.

Xiang, A. L., Gao, S., Peng, Y. T., & Shen, Y. (2022). Knowledge Reorganization and Scene Reconstruction: A Metaverse for Digital Resources Management. Doc Inf Knowl, 39(1), 30 - 38.

Xu, D., Li, Y., Chen, X., Li, J., Hui, P., Chen, S., & Crowcroft, J. (2018). A Survey of Opportunistic Offloading. IEEE Commun Surveys Tuts, 20(3), 2198 - 2236.

Yang, K. R., Sung - Chul, Y., Park, S. K., & Gyou, L. B. (2022). Establishing the Framework of Industry Metaverse based on Digital Twin through Case Studies. J Korea Multimed Soc, 25(9), 1122 - 1135.

Ye, W. Y., & Zhou, S. H. (2021). Digital publishing of ancient Chinese medicine books based on the principle of FAIR. Pub Res, 2(1), 49 - 54.

Yu, J. N., & He, C. (2021). Metaverse. Bei Jing: Zhong Xing Press.

Zallio, M., & Clarkson, P. J. (2022). Designing the metaverse: A study on inclusion, diversity, equity, accessibility and safety for digital immersive environments. Telemat Inform, 75, 101909.

Zhang, A. Y., Wang, B., Xie, M., & Liu, H. (2022). Application of metaverse in Clinical Teaching of Surgery. Chin Med Educ Technol, 36(3), 390 - 395.

Zhang, S., Yao, L., Sun, A., & Tay, Y. (2020). Deep Learning based Recommender System: A Survey and New Perspectives. ACM Comput Surv, 52(1), 1 - 38.

Zhong, Z., Wang, J., Wu, D., Zhu, S., & Jin, S. (2022). Analysis of the Application Potential and Typical Scenarios of Educational Metaverse. Open Educ Res, 28(1), 17 - 23.

Zyskind, G., Nathan, O., & Pentland, A. (2015). Decentralizing Privacy: Using Blockchain to Protect Personal Data. In 2015 IEEE Security and Privacy Workshops, San Jose, CA, USA, 180 - 184.