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USER EXPERIENCE FACTORS IN IMMERSIVE EDUCATION

THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
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GÜLŞAH ATAŞ

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IN
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USER EXPERIENCE FACTORS IN IMMERSIVE EDUCATION

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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

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Prof. Dr. Ender KESKİNKILIÇ
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of **Master of Science in Computer Engineering, Atılım University**.

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Prof. Dr. Gökhan ŞENGÜL
Head of Department

This is to certify that we have read the thesis USER EXPERIENCE FACTORS IN IMMERSIVE EDUCATION submitted by GÜLŞAH ATAŞ and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

____

Asst. Prof. Dr. Damla TOPALLI
Supervisor

Examining Committee Members:

Assoc. Prof. Dr. Sacip TOKER
Information Systems Eng. Department, Atılım University __________________________

Asst. Prof. Dr. Damla TOPALLI
Computer Engineering Department, Atılım University __________________________

Prof. Dr. Nergiz Erçil ÇAĞILTAY
Software Engineering Department, Çankaya University __________________________

Date: *16.01.2024*

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : Gülşah ATAŞ

Signature :

ABSTRACT

USER EXPERIENCE FACTORS IN IMMERSIVE EDUCATION

Ataş, Gülşah
Department of Computer Engineering
Supervisor: Asst. Prof. Damla Topallı
January 2024, 80 pages

In this thesis, we aim to conduct an in-depth analysis of User Experience within educational dentistry systems that use immersive technologies. The first goal of the thesis was to define User Experience factors that play a crucial role in the user's encounters with immersive systems, such as Virtual Reality or Augmented Reality. A systematic review study was conducted, which revealed nine underlying factors that affect User Experience in various Virtual Reality applications, namely engagement, usability, immersion, technology adoption, emotion, presence, experience consequence, judgment, and competence. Furthermore, a questionnaire was conducted with dentistry students to assess their opinions and perceptions about using Augmented Reality in their education. Principal Axis Factoring was conducted on the questionnaire, which revealed three underlying factors: knowledge and outcome, emotive submersion, and ease of use. Experience consequence, judgment, and competence cluster under the knowledge and outcome factor; emotion, engagement, immersion, and presence cluster under the emotive submersion factor; while ease of use is comprised of technology adoption and usability. Moreover, a Pearson correlation coefficient was performed to evaluate the relationship between the three factors that were obtained from Principal Axis Factoring.

Keywords: Virtual Reality, Augmented Reality, User Experience, Dentistry Education.

ÖZ

SANAL EĞİTİMDE KULLANICI DENEYİMİ FAKTÖRLERİ

Ataş, Gülşah
Bilgisayar Mühendisliği Bölümü
Tez Yöneticisi : Asst. Prof. Dr. Damla Topallı

Ocak 2024, 80 sayfa

Bu tezde, Sanal Gerçeklik ve Artırılmış Gerçeklik teknolojilerini kullanan diş hekimliği eğitimi programlarının kullanıcı deneyimi üzerindeki etkisinin derinlemesine bir analizi yapılmıştır. Tezin ilk amacı, kullanıcının Sanal Gerçeklik veya Artırılmış Gerçeklik gibi sistemlerle etkileşimlerinde en önemli rol oynayan kullanıcı deneyimi faktörlerini tanımlamaktı. Çeşitli Sanal Gerçeklik uygulamalarında kullanıcı deneyimini etkileyen dokuz temel faktörü ortaya çıkaran sistematik bir inceleme çalışası yapıldı. Bu çalışmanın sonucunda etkileşim, kullanılabilirlik, sürükleyicilik, teknolojinin benimsenmesi, duygu, mevcudiyet, deneyimin sonucu, muhakeme ve yeterlilik faktörleri elde edildi. Ayrıca, diş hekimliği öğrencilerine eğitimlerinde Artırılmış Gerçeklik kullanımına ilişkin görüş ve algılarını değerlendirmek amacıyla bir anket uygulandı. Anket üzerine temel eksen faktör analizi yapıldı ve üç temel faktör ortaya çıkarıldı: bilgi ve sonuç, duygusal derinlik ve kullanım kolaylığı. Bilgi ve sonuç faktörü altında deneyim sonucu, muhakeme ve yetelilik faktörleri gruplandı. Duygusal derinlik faktörü altında duygu, etkileşim, mevcudiyet ve sürükleyicilik faktörleri gruplandı. Kullanım kolaylığı faktörü, teknolojinin benimsenmesi ve kullanılabilirlik faktörlerinden oluştu. Son olarak, temel eksen faktör analizinden elde edilen üç faktör arasındaki ilişkiyi değerlendirmek için Pearson korelasyon katsayısı hesaplandı.

Anahtar Kelimeler: Sanal Gerçeklik, Artırılmış Gerçeklik, Kullanıcı Deneyimi, Diş Hekimliği Eğitimi.

To my family

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LIST OF SYMBOLS/ABBREVIATIONS

VR	Virtual Reality
UX	User Experience
AR	Augmented Reality
MR	Mixed Reality
XR	Extended Reality
HMD	Head-Mounted Display
CAD	Computer-Aided Design
CS	Cybersickness
IVR	Immersive Virtual Reality
IVE	Immersive Virtual Environment
QoE	Quality of Experience
VLE	Virtual Learning Environment
UP	User Performance

CHAPTER 1

INTRODUCTION

The term "immersive technology" describes innovative methods for creating, displaying, and interacting with experience, material, and applications. With the use of immersive technologies, users can interact naturally with blended reality by fusing virtual and real-world content. The line separating the real world from the virtual becomes hazy when a user looks, feels, or even hears another environment. Immersive technologies have altered how people interact with technology by fusing the virtual with users' senses of sight, sound, and even touch. Because of how organic the interaction is, the user may cease to perceive some aspects of the virtual content and come to believe that the physical world and the virtual world are the same. As a result, users get a sense of belonging to the simulated environment. Technologies that assist immersive experiences include haptics, drones, cameras, omnidirectional treadmills, gesture recognition, spatial sensing, voice recognition, 3D displays, 3D audio, Augmented Reality (AR), Mixed Reality (MR), and Virtual Reality (VR) headsets. Following are some definitions of these technologies based on the contents of the research.

- A simulation is a temporal representation of how a system or process might operate in the real world. A model is necessary for a simulation; the model represents the fundamental characteristics of the system or process in real life, while the simulation itself shows how the model changes over time.
- Head-mounted displays (HMDs) are a type of projection technology that creates small displays that can be incorporated into eyeglasses or on a helmet or hat. HMDs for VR are headsets with helmets or adjustable straps. The user is fully enclosed in the virtual world via VR headgear. The screen is completely black when turned off. When the VR HMD is turned on, the user enters an

immersive virtual environment. AR and MR HMDs are see-through, allowing the user to manipulate the virtual aspects that are embedded into real-world objects. While MR HMDs enable interaction with the virtual elements, AR HMDs allow the user to witness these adjustments.

- Haptic technology, also referred to as kinesthetic interaction or 3D touch, enhances human connection with virtual environments by providing tactile input in the form of pressure, vibrations, and motions. With every interaction, haptics provides the user with feedback. One such way to provide feedback would be for the user to attempt to push an object in the virtual environment and experience its weight. Another example would be creating vibrations to enhance immersion in a virtual game environment. Users can engage with haptics more realistically and naturally by dragging, pushing, and easily zooming in and out instead of tapping or hitting buttons on a screen.
- Virtual Reality (VR) utilizes an HMD with two near-eye monitors, which provide a 360-degree view of the virtual world, to completely replace the user's physical surroundings with a digital environment. Users of VR can fully immerse themselves in the experience and become disconnected from reality.
- Augmented Reality (AR) blends the virtual and the real world to give users an immersive experience. Virtual objects and data are layered on top of the real world while creating an AR environment. Users can perceive what is going on around them, thus they are not entirely cut off from reality. Therefore, virtual components such as animations and images are added to the real world. AR devices use computer vision and machine learning techniques to understand the real environment both conceptually and physically. The filter functionality seen on the majority of social media platforms for photo sharing is a demonstration of AR. Such filters apply various effects to the camera view that are meant to depict the real world, including changing the user's hair color or putting a hat on the user.
- Mixed Reality (MR), sometimes referred to as hybrid reality, enables real-time synchronization between the virtual and physical worlds. As the most recent immersive technology, MR demands substantially more computing and processing power than VR or AR and the usage of an MR headset is essential.

For instance, in an MR environment, users may place and interact with a computer-generated object in the real world.

- Extended Reality (XR) includes both virtual and real-world integrated environments as well as human-machine interactions. It includes VR, AR, MR, and the transitional realms that exist between AR and VR technologies. These are brought about by wearables and computer technologies. Through computer technologies and wearables, XR offers a sensory experience.

Nowadays, several advancements and advantages are realized through the application of these technologies across various fields. These technologies, for instance, are offering highly beneficial improvements in various educational contexts [1], [2], [3]. One of these areas where trial-and-error learning is crucial and significant is dental education programs. However, these kinds of learning environments can't always be offered in dentistry faculties sufficiently for the large numbers of students. The implementation of VR and AR for hands-on tasks in dentistry offers a useful alternative to traditional methods of training in dentistry. The primary goal of this thesis is to gain a deeper understanding of the views of dental education students regarding the integration of AR into educational programs. In order to achieve this, a thorough review of the literature is performed to examine relationships between VR technologies and user experience. The application of AR in dentistry education programs was then examined. Finally, in order to gain further insight into the perspectives of dentistry education students concerning AR technology in their curricula, a questionnaire is implemented. The study's literature review is presented from the two main perspectives in the next section.

CHAPTER 2

BACKGROUND OF THE STUDY

The background of the study is twofold. First, a systematic review is conducted to analyze associations between VR Technologies and UX, through reviewing related literature. Second, the usage of AR technology in dental education programs is reviewed. As a result of these review studies, a questionnaire conducted to dental education students about their intentions on AR implementations was analyzed to provide some insights about the implementations of AR in dental education programs.

2.1 AR in Dentistry

Dentistry is a profession that demands both learned information and coordinated motor abilities to execute any patient treatment plan as effectively as possible. Dental students have historically been practicing on phantom heads and teeth to improve their clinical skills before treating real patients. When teaching dentistry, instructors can help students achieve precision in their clinical abilities by using 3D real-time computer simulations. An essential component of dental education involves retaining the anatomy of the head and neck. Traditionally, students have been instructed in anatomy using lectures and textbooks with 2D graphics. Students are frequently taught using cadaveric skulls in this conventional teaching method. Nonetheless, it is challenging and inefficient for students to accurately visualize all vascular, neural, and muscular connections. During the COVID-19 pandemic, students suffered from a lack of study chances and the inability to train under their teachers' close supervision at their universities which hindered the development of pre-clinical skills.

A recent study blended digital tools and a 3D augmented curriculum – an interactive 3D experience that combines computer-generated features with real-world perspective – with conventional teaching methods, such as using cadavers. The study found that students’ comprehension of anatomy was superior to that of the control group (which received instruction from textbooks and 2D illustrations) and that the 3D experience improved students’ understanding and memory of anatomy [4].

VR can be divided into three categories based on the degree of immersion: semi-immersive, immersive, and non-immersive. The basis of semi-immersive VR is a CAVE (Cave Automatic Virtual Environment). Using a wearable headgear and a pen-shaped controller that can detect both hand leaps and eye movements, an immersive VR system records 3D visuals and allows the user to interact with them while fully engaged in a virtual environment. In non-immersive VR, the user interacts with virtual graphics using mouse-based 3D simulations on a 2D desktop computer monitor, rather than wearing a wearable device and being a part of a virtual scene. By identifying anatomical components and superimposing them in the user’s field of vision, AR scenarios can gather visual data to enhance dental procedure guidance. Certain AR systems superimpose 2D visuals, which deprive students of a sense of depth and consequently compromise accuracy and operational safety. The Microsoft HoloLens AR system works with various optical systems and significantly enhances the optical architecture of current AR display systems.

Through VR, dental students can see oral procedures as active participants, which broadens their scope of knowledge. Additionally, with the assistance of professionals, students might attempt to replicate the oral therapy scenario. With the use of VR, it is possible to produce remarkably realistic images in a small area, such as a computer screen. Recently, many virtual dentistry trainers have been developed, some of which are available to purchase. One such application is SIMODONT, a preeminent worldwide supplier of VR dental education. Consequently, many reviews have been published of these applications. Some of them expressed skepticism and suggested that VR trainers should only be utilized as supplemental tools for the time being, while others concluded that VR trainers are successful at improving technical abilities [5]. AR and VR are two very different methodologies because AR overlays digital content on real-world objects. Consequently, dental trainers that employ AR have a different organizational structure than those that use VR. There are other digital technologies used in dentistry education, computerized dentistry simulations or the implant real-time imaging system [5].

VR and AR are helpful resources for pre-clinical training programs that involve clinical practice and learning. Dentists can utilize VR to show patients what to expect from a procedure before they go through with it. Additionally, VR can help reduce dental fear. VR uses laser scans to build a 3D model of the patient's teeth and any other required oral and extraoral structures. The computerized model is then loaded into a simulator. This simulator can be used by dental professionals and students to practice and complete assessments before doing the procedure on an actual patient. Dental specialties that use VR include orthodontics, implantology, restorative dentistry, oral and maxillofacial surgery, dental public health, and dentistry education [6]. AR primarily attempts to improve clinical practice in the dentistry domain by merging the real and digital worlds, as it allows clinical information to be visualized on patients directly. The main use of AR in dentistry is to augment reality with digital information, allowing for more effective patient-dentist communication through pictures, videos, and three-dimensional models. Unlike VR, AR is an interactive technology that lets the user work on a patient's teeth or anatomical features in a 3D environment that has been registered using simple imaging methods. VR uses specially designed and advanced software to construct a virtual three-dimensional environment that stimulates the user's senses with input and experiences provided by a computer.

There are several ways that AR and VR differ from each other. For instance, while VR is managed by a system, AR enables users to alter their presence in the real world. Second, a headgear device is needed to access VR, while a smartphone can access AR. Moreover, VR can only enhance the virtual world; AR can enrich both the actual and virtual worlds. Until recently, the primary applications of AR and VR in dentistry have been in the subspecialties of orthognathic surgery and dental implantology. Computer-aided learning, AR, and VR, all of which are employed in simulation, are gradually replacing pre-clinical education. Before working with patients, students can improve their psychomotor abilities for operations by practicing pre-clinical, standardized learning competencies through these kinds of simulations [7].

VR is utilized in dentistry for teaching dental students and for pre-treatment implant planning, while AR is often used to teach patients about tooth morphology, maxillofacial surgery, and the administration of local anesthesia. AR simulators use multisensorial computer-generated content to improve the user's vision of the real environment [8]. Haptic technology is also used because it facilitates two-way communication between the user and the environment and enhances the simulation of a healthcare setting for teaching purposes.

VR simulations are built on the principles of engagement and immersion. In dental training simulations, students are immersed in an authentic virtual clinical setting, such as an operating room, and they engage virtually with the environment in real-time.

Objective performance evaluation and a flexible, adaptable environment are two advantages of employing VR simulations in dental education. A disadvantage of VR simulations in dentistry is their high cost, which prevents many institutions from employing the technology.

VR has been shown to increase student understanding and can standardize clinical instruction to help with dentistry training while drastically cutting down on staff time. It is feasible to create a learning environment that will help students become more confident and knowledgeable about maxillofacial procedures. Pre-clinical dentistry education has long made use of simulations. The use of VR in clinical instruction raises certain ethical questions, such as the use of fewer natural teeth in restorative training. Before interacting with patients, VR allows students to rehearse pre-established and standardized learning abilities, which aids in the development of psychomotor skills necessary for procedures. Phantom heads with artificial or removed teeth were used in dental teaching in the past to assist students in learning the appropriate techniques.

As technology advances, VR and AR may replace conventional teaching techniques due to their advantages in user integration. Through the application of pre-programmed integrated scenarios into an operative environment, VR has been employed throughout time to practice procedure-related skills in pre-clinical dentistry setup. Mannequin-based or haptic-based computerized VR simulators are available. While haptic simulators use devices for feedback in virtual models and are used for operator training, mannequin-based simulators allow users to practice dental procedures using actual dental instruments. In order to more accurately replicate the therapeutic context, haptics enable two-way communication between the user and the surroundings. In dentistry, simulation enables the practitioner to operate on both soft and hard tissues while receiving tactile feedback through the sensation of touch. The user can then react by providing force, vibration, and motion to the user. Several procedures have administered AR in biomedical sciences and continual efforts are being made for their advancement which has led to mobile devices with AR. Integrating realistic experiences in a pre-existing setup is required to achieve optimum skills.

Various researchers concur that there is a great deal of educational and motivating potential in using AR in teaching and learning to support interactive, group, and individual experiences. Learning institutions have also begun to embrace intelligent tutoring. AR improves educational opportunities by enabling a range of learning processes and activities that can be carried out unsupervised. By exposing students to interactive learning in a VR environment, dentistry students can enhance their knowledge and skills while also lowering their anxiety levels when treating patients. Additionally, access to high-quality interaction, educational materials, and reduced training costs are all made possible with VR integration. Advances in simulation and haptic feedback technologies enable preclinical dentistry students to become practicing clinicians through a variety of training programs being created globally [6].

CHAPTER 3

METHODOLOGY

The main aim of this study is to discover the main UX factors impacting immersive technologies. For this aim, this thesis study has two main research questions.

RQ1. What are the studied UX factors of immersive technologies in the literature?
RQ2. What are the UX Factors through the eyes of dentistry students?
RQ2.1. Is there any correlation between the three discovered factors?

3.1 Methodology of the first part of the study (RQ1)

A systematic review study is undertaken to explore the literature to determine the primary UX characteristics for immersive technology for the first research question.

3.1.1 Search Strategy

Using the Web of Science database, the following search query was run, since the goal of this study is to examine UX in VR technology.

("VR" OR "VIRTUAL REALITY") AND ("UX" OR "USER EXPERIENCE")

A total of 1634 results were obtained from the database at this point.

3.1.2 Inclusion and Exclusion Criteria

Review papers are the only type of articles included in this study. There were several types of review articles included, including systematic reviews, scoping reviews, literature reviews, integrative reviews, technical reviews, and systematic literature reviews. After excluding all article types other than reviews, 52 articles remained for analysis.

This review included studies published within the last ten years. There were no exclusion criteria to apply because the resulting 52 publications were all published between 2013 and 2023. Similarly, including only open-access studies yielded the same result because all 52 publications were freely available.

The next set of requirements was limited to studies conducted in English. After removing articles that were not in English, 51 articles were left. One piece was written in French.

3.1.3 Study Selection and Data Extraction

Analyzing the articles that were gathered from the earlier steps was the final step in the methodology. Chapter 3 delves into the analysis of 51 articles, all of which were determined to be pertinent to the subject matter of this review.

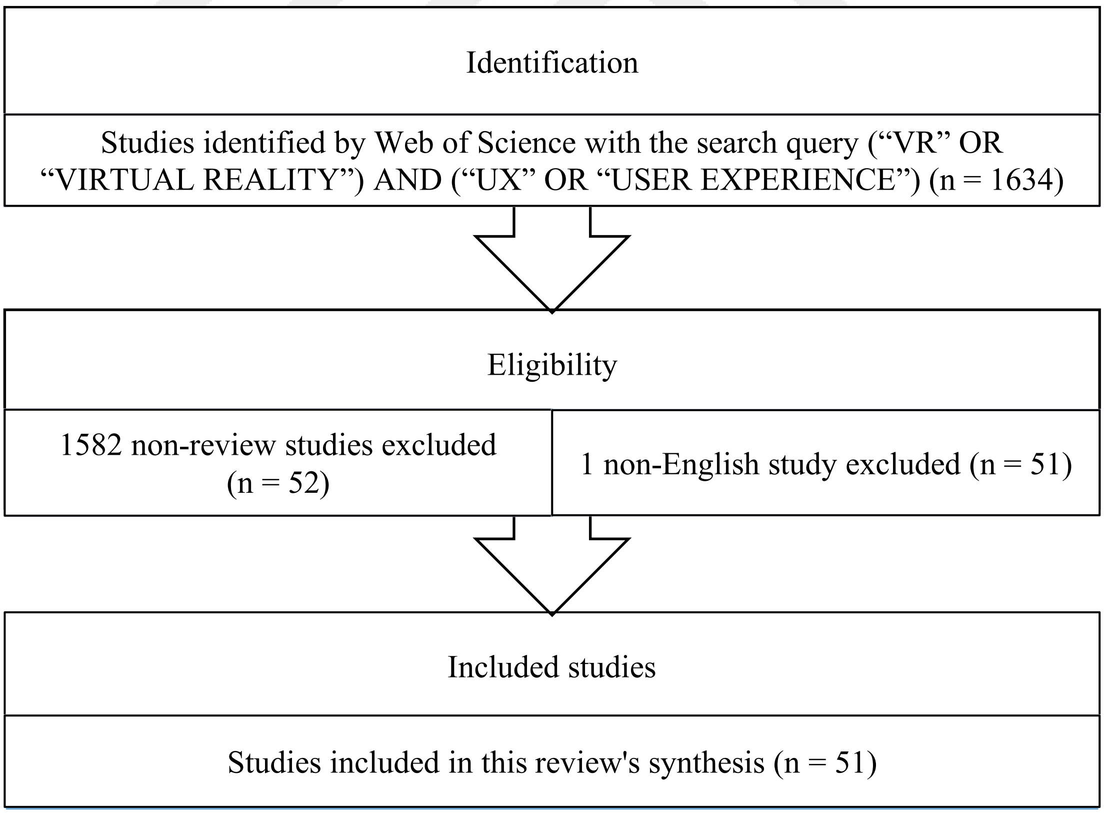

Figure 3.1 Flowchart of the Study Selection Process

3.1.4 Discovered UX Factors

Upon analyzing all 51 articles, recurring patterns in VR system UX were identified. These factors were organized in 9 terms: engagement, usability, immersion, technology adoption, emotion, presence, experience consequence, judgment, and competence. Each factor is covered in detail in this section.

3.1.4.1 Engagement

The term "engagement" refers to how a user interacts with VR tools. This can involve the user moving around in the virtual environment, recognizing and altering virtual objects, and performing physical gestures or movements that are reflected on the screen [9]. As the user interacts with VR tools more naturally and intuitively, the user's VR experience is improved overall [10]. Users report a better overall experience when engagement is improved, and they take an active role in the system instead of simply being observers [2]. Furthermore, users assert that they are more inclined to use a VR system for an extended amount of time when it provides them with more interactive content within the environment [11]. Together with the concepts provided by the literature, this thesis also discusses the interaction between multiple users in multi-user virtual environments under the engagement factor. Additionally, the degree to which a user interacts with the system and the extent to which they can alter virtual material are both considered aspects of engagement.

3.1.4.1.1 Flow

Flow is a key component of engagement and the overall realism of the system; it is the extent to which the user is fully submerged in the virtual world as a result of a continually captivating and interesting system [12]. System flow is improved when users are kept interested in the system and are constantly challenged and motivated to showcase their talents within the system [13]. When engaging in naturally fulfilling activities and facing obstacles appropriate to their ability level, the user enters a state of flow [14].

Of the 51 research articles included in the corpus, flow was referenced in 23 articles. The notion of flow encompasses the possible actions that the user may take; hence, the coherence of the entire system is what is meant to be understood as the flow of the system. The user's activities should be portrayed in immersive technology as closely as feasible to reality. In order to provide natural mobility within the system, the hardware being utilized must be able to replicate the user's natural movements within the virtual world. The flow of the system needs to be well thought out, accounting for every scenario, and ensuring seamless transitions between each scene [15]. Thus, flow is described as a subfactor of engagement, because it is controlled directly by the level of engagement in the VR system.

3.1.4.2 Usability

According to ISO (2010), usability is the extent to which a system helps users accomplish a particular objective in an effective, efficient, and satisfactory manner [16]. The system has to act in a precise and thorough way in order to achieve the goals. The system's efficiency is determined by the ratio of resources used to system efficacy. Last but not least, high levels of acceptance are shown by a system being easy for users to use [16]. Usability problems arise when VR apps fail to consider the user's needs while offering a secure environment.

The efficacy of the system can differ based on its objectives. VR training systems, for example, aim to teach users a skill; hence, to demonstrate high usability, the system must correctly teach the necessary skill with a reasonable resource consumption while providing the user with a comfortable experience [17]. One consequence of poor usability is cybersickness, which arises from users' discomfort with the headsets used in immersive technology [18]. The usability element includes the system's functionality, complexity, efficacy, efficiency, and degree of user pleasure. VR systems need to try to balance resource optimization with user needs and requirements in order to reach their optimal usefulness. Despite the rapid growth of VR technology, the analyzed articles indicate that the most prevalent issues in VR systems with the usability factor are still technical challenges, the system's high complexity, and cybersickness.

3.1.4.2.1 Cybersickness

Cybersickness is listed as a side effect in over half of the reviewed publications due to poor usability (n = 28). Cybersickness is the result of a user's perception of the system being different from their tactile and auditory senses. If the graphics lag or flicker, cybersickness could get worse [19]. Cybersickness issues are being rectified as technology develops, however, sensitivity to cybersickness is also greatly influenced by individual markers. Given that older users have been demonstrated to feel cybersickness more severely than younger and healthier users, users' age and physical state may predispose them to the disease [20], [21].

Physical discomfort is a problem that needs to be resolved in order to provide a positive UX overall. Given that it is the most common side effect, it could make the user's experience unpleasant. Cybersickness is a negative effect that users of VR and AR systems may encounter when using related headsets. Users report that their cybersickness worsens with rapid motions. Most research has used the short-term solution of limiting the duration of headset wear. Another recommendation was to play relaxing music and inhale peaceful scents [18].

Cybersickness is a significant obstacle to the mainstream usage of VR. It can produce varied degrees of discomfort and even destroy the immersive experience. Tian et al. reviewed cybersickness in HMDs using individual susceptibility and concluded that user susceptibility and gender balance have not been included in studies of various groups [18]. Cybersickness is influenced by several elements, including content, interaction, hardware, humans, and experiments. Hardware is used by participants to engage with VR content, further facilitating this connection. Anything that has to do with how users experience the virtual world is referred to as content. Interaction-related aspects are those that are associated with how users interact with VR apps. Task-related properties like navigating, velocity or acceleration, movement controls, and game-related features like narration or sound are all interaction-related factors. Hardware-related factors refer to the technological components of the HMD, such as the field of view (FOV), and hardware quality characteristics such as resolution or latency. Human-related factors are those that are directly related to humans who consume VR content. The other two basic kinds of human variables are intrinsic and extrinsic human factors. The primary intrinsic elements include innate demographic traits such as age and gender. Other intrinsic human factors include the propensity of users to experience motion sickness and cybersickness, as well as characteristics related to health, such as illnesses or bad vision. Accumulated experience, such as prior VR and other simulation experiences, is an example of extrinsic attributes. Finally, the experimental design may have an impact on the severity of cybersickness. Experimental factors include the related variables, such as the duration and frequency of the VR exposure, the use of supplementary interventions like medicine, and posture, the trials carried out before the VR exposure, and the intervals between trials, which are all associated with the experience. Content and interaction have been explored the most, with navigation having been the most extensively investigated element [18]. Hardware-induced discomfort, on the other hand, is currently regarded to be modest as a result of technological developments, but latency has yet to be addressed. However, the impact of content elements may be influenced by hardware considerations, particularly larger hardware. FOV exposes users to more supplementary visual content. The most effective technique for combating cybersickness is to profile human susceptibility based on the previously described factors. As a result, it is recommended that a consistent protocol for experimental setups be developed to allow for comparison and literature synthesis. It is also strongly encouraged to incorporate both subjective and objective evaluations. The authors of the 2022 review also recommend a pre-screening session to identify individual vulnerability before the official experiment [18]. This could be useful for comprehensive cybersickness profiling. Participants could be split into groups according to their susceptibilities—low, medium, and high—for further investigation. A larger sample size and better control are required when considering a factorial design. Furthermore, thorough technique descriptions that address interactivity, VR content qualities, technology requirements, and demographics are needed. It is also crucial that high-susceptibility researchers report on their personal experiences with cybersickness [18].

The primary guideline for avoiding cybersickness is to avoid artificial effects such as animation lag, executing user motion while the user is still, or disrupting the user's natural perspective. Furthermore, mobility in a virtual environment should include the user, which is not always possible given the required activity, such as flying, swimming, or climbing, as well as the environment in which the game is played since the virtual world can be larger than real space. Developers can use teleportation, walk-in-place, or redirected walking to assist with movement in the virtual world under such conditions, but keep in mind that cutting the scene and translations should be avoided to minimize cybersickness. Additionally, each person experiences cybersickness differently based on age, genre, psychological situation, and other factors. However, it can be minimized with practice and by taking frequent breaks when using VR equipment [22].

3.1.4.3 Immersion

Immersion reflects the system's capacity to carry out technical tasks [9]. Immersion may be objectively measured by counting the number of senses engaged, evaluating how much the program isolates the user from the actual world, assessing the visual quality, and determining how well the simulation mimics reality [9], [10]. For a user to feel involved in a digitally created environment, the visualizations need to correctly evoke touch, sight, and hearing while adhering to reality [10]. Even though greater levels of immersion usually result in better user experiences, some users report getting cybersickness as the system gets more immersive.

Although the definition of immersion in a system is determined by its technological features and capabilities, users may interpret it differently depending on personal features like expectations or goals they have for the system [23]. Some users may experience nausea from highly immersive systems due to their physical condition and health [19].

The definition of immersion is consistent and straightforward in all of the reviewed articles and includes factors like the number of senses stimulated, the degree of isolation from the outside world, and how closely the simulation resembles real life.

3.1.4.4 Technology Adoption

As computational power and scientific understanding have risen, the process of creating and implementing immersive technologies has advanced compared to previous years [10]. The high expense of VR systems, which contributes to their low accessibility, is another reason for the present low levels of technology adoption, which affects UX as a whole [24]. The availability of more affordable tools is enhancing technology adoption, but financial and resource limitations keep it from realizing its full potential [10]. Even though certain VR apps offer high usability by achieving efficiency and effectiveness objectives, successful installation and deployment is a criterion that has not yet been reached [25].

Therefore, one aspect of the technological adoption factor is the process of developing, deploying, and utilizing immersive technology. Table 3.1 highlights the significance of this feature in immersive technologies by demonstrating that, as a UX component, technology adoption was noted in the analyzed articles just as frequently as immersion.

3.1.4.5 Emotion

All immersive systems are impacted by emotion, which is a UX feature that VR games particularly value. It relates to how the user feels while using the VR system [12]. To increase the realism of the simulation, a VR system's user's emotional state must be taken into consideration [26], [27]. By providing users with an application that is more engaging to use than routine or repetitive tasks they would normally complete, UX is improved [9], [28]. All user feelings evoked before, during, and after using the VR system are represented by the emotion factor. The emotion that is elicited varies based on the objective of the system. While certain video games may be designed to evoke unpleasant feelings, such as fear, VR training systems seek to be so lifelike that the player feels successful and satisfied after completing a job.

3.1.4.6 Presence

Presence is a subjective factor that represents the illusion of actually being inside the digitally manufactured system [13]. An essential aspect of a VR system's user experience is the sensation of presence, which is a psychological reaction contingent on the user's reaction to being within the virtual environment. Depending on how conscious the user is of using a virtual environment, this response may be intuitively evaluated [9]. The sense of presence is enhanced if the user can alter and contribute to the virtual environment, where the artificially created elements appear too real for users to distinguish between real and fake [29]. The user feels present when interacting with the virtual environment because the system resembles reality, the user's natural gestures, and an overall experience that captures the user [30]. Users behave in ways that are similar to those in real life when they feel present in a virtual environment [10]. The symptoms of cybersickness decrease with improved presence, even though both are dependent on and controllable by the user's particular circumstances, such as age, health, or gender [31]. Users report little interest in using the VR equipment again if their initial experience left them feeling absentminded [24]. The subjective reaction a user has when they are in a virtual environment and can no longer tell the difference between reality and simulation is defined as presence in this thesis. VR systems need to fully engross users while closely mimicking reality and fostering a sense of presence to improve UX.

3.1.4.7 Experience Consequence

The concept of "experience consequence" refers to the difference between the user's pre- and post-VR system knowledge and skill sets. The outcome might include mastering a recently acquired skill or using VR technology to achieve career objectives. When there are negative or nonexistent consequences, users of the VR system report negative user experiences [32]. The users of the VR system must experience the consequences of their choices following what would have happened in a real-life scenario [33].

For instance, to help students experience and learn from mistakes, every option in a VR system used for surgical training needs to be presented in a way that can give feedback based on their actions [34]. In this thesis, the experience consequence factor considers the consequences of actions taken while using the system as well as the consequences encountered after using it. The way the system reacts to user input is one of the UX aspects related to experience consequences.

3.1.4.8 Judgment

Makinen et al. [12] define judgment as the user's ideas and opinions on the VR system. Positive or negative user evaluations can influence how users engage with the system. To avoid negative assessments spoiling the overall experience, researchers provide users with demo sessions to explain the VR system and how to utilize it, which decreases the effect of negative judgments [35]. Any preexisting notions about VR systems, the user's reasons for using the system, or the user's expectations of the system make up the judgment component of this thesis.

3.1.4.9 Competence

The user's level of proficiency with VR tools and systems is referred to as competence [36]. The way a user perceives the system and their overall UX is influenced by their level of competence. To utilize the VR system, users need to have certain fundamental skills. Otherwise, they might criticize the VR system for being difficult to use, even though that may not be the problem [37]. Thus, while assessing UX, the user's level of skill must be considered. Inexperienced users may be able to overcome their lack of competency by receiving training on the essential features and operations of the VR system and tools. In order to understand how to use VR tools or how to run the specific system they will be using, users might need training.

3.1.4.10 Dispersion of UX Factors

Any reference to using VR tools or interacting with other users in a VR system was considered when calculating the factor of engagement during the analytical procedure. The usability element is represented by any discussion of the VR system's efficacy, efficiency, or convenience as well as any mention of cybersickness, which is a side consequence of poor usability. The component of technological adoption encompassed all aspects of user experience that were associated with the use, cost, degree of adaptability, and diffusion of VR systems. Any references to the observable outcomes of utilizing VR, such as learning a new skill, were considered for the experience consequence factor, whether they were observed during or after using the system. The component of judgment was applied to all references to the user’s prior conceptions and views regarding VR systems, as well as to their opinions both before and after utilizing the system. The aspect of competence is correlated with the user's prior knowledge and proficiency with VR tools and systems. In the evaluated articles, immersion, presence, and emotion aspects were all explicitly defined in the same way as described in the previous subsections. Table 3.1 lists all of the relevant papers in the study’s corpus that address each of these factors.

Table 3.1 Corpus of the Study

ID	Reference	Engagement	Usability	Immersion	Technology Adoption	Emotion	Presence	Experience Consequence	Judgment	Competence
S01	Makinen et al., 2022	x	x	x	x	x	x	x	x	x
S02	Kim et al., 2020	x	x	x		x	x	x	x	x
S03	Ijaz et al., 2022	x	x	x	x	x	x		x	x
S04	Tuena et al., 2020	x	x	x	x	x		x		x
S05	Freeman et al., 2017	x	x	x			x	x		
S06	Colombo et al., 2022	x	x	x	x	x	x		x	
S07	Bosman et al., n.d.	x	x	x	x	x	x			
S08	Mohammad & Pedersen, 2022	x	x	x		x	x			
S09	Pellas et al., 2020	x	x	x	x		x	x		
S10	Luddecke & Felnhofer, 2022	x	x	x	x	x		x	x	
S11	Cattan et al., 2020	x	x	x	x	x	x			
S12	Chong et al., 2022	x	x		x	x		x		
S13	Kourtesis et al., 2019	x	x	x						x
S14	Wolfartsberger , 2019	x	x		x		x	x		
S15	Ruan & Xie, 2021b	x	x		x					
S16	Elphinston et al., n.d.	x	x	x		x	x	x		
S17	Pellas et al., 2021	x	x	x		x	x	x	x	
S18	Saha et al., 2022	x	x		x					
S19	Ruan & Xie, 2021a		x	x	x	x			x	

Table 3.1 (continued)

S20	Zou et al., 2021	x	x	x	x	x			x	
S21	Kosmadoudi et al., 2013	x	x	x		x	x	x		
S22	Sudha et al., 2017	x	x	x			x			
S23	Vlahovic et al., 2022	x	x	x		x	x	x	x	x
S24	Li et al., 2020	x	x	x	x	x		x		
S25	Lanyi & Withers, 2020	x	x	x	x	x	x			
S26	Rubio Tamayo et al., 2018	x	x	x						
S27	Diaz-Oreiro et al., 2021		x			x			x	x
S28	Wong et al., 2022	x	x	x	x		x	x	x	
S29	Azofeifa et al., 2022	x	x	x	x		x			
S30	Gong et al., 2021	x		x		x		x		
S31	Grassini & Laumann, 2020	x	x	x	x	x	x	x	x	
S32	Tian et al., 2022	x	x	x		x				x
S33	Lee et al., 2020	x	x	x	x		x	x		
S34	Jang & Park, 2022	x	x		x	x			x	
S35	Iop et al., 2022	x	x	x	x		x	x	x	x
S36	Valencia et al., 2019	x	x			x		x		
S37	Bai et al., 2021	x	x	x	x		x	x		
S38	Goncalves et al., 2023	x	x	x	x	x	x	x	x	
S39	Alamirah et al., 2022	x	x	x	x		x			
S40	Sikder et al., 2014	x			x			x		x
S41	Franke & Haehn, 2020		x		x					
S42	Ozioko & Dahiya, 2022	x	x	x	x	x				
S43	Parekh et al., 2020	x	x	x	x	x	x	x	x	

Table 3.1 (continued)

S44	Calvo-Morata et al., 2022	x			x	x				
S45	Martin-Sacristan et al., 2018	x	x	x	x		x			
S46	Sun, 2021	x	x	x	x					
S47	Koutsiana et al., 2020	x	x		x					
S48	Niu et al., 2022	x	x		x			x	x	x
S49	Beck et al., 2019	x	x			x		x	x	
S50	Lattie et al., 2019	x	x		x	x		x		x
S51	Lu et al., 2022	x	x		x				x	
Total		48	48	36	36	30	26	26	19	12

The UX elements that are discussed in each article are shown in Table 3.1. Although they were referenced frequently in the evaluated literature, flow and cybersickness are not considered distinct UX factors. If the article discussed how natural movement and scene transitions in VR allow the user to be challenged and immersed by the system, the corresponding subfactor flow was counted towards engagement. Cybersickness is a term used to describe symptoms including headaches, nausea, and dizziness brought on by low usability.

3.2 Methodology of the second part of the study (RQ2)

To answer the second research question, a questionnaire was implemented where the participants were 755 students from three different dentistry faculties. The participants of the study were reached through a convenience sampling strategy. The responses of the students to the questionnaire were collected from their respective universities. Table 3.2 demonstrates the number and percentage of the different universities, genders, and grade levels of the students.

Table 3.2 Participants

		n	%
University	Ankara University	350	46.36
	Eskisehir Osmangazi University	229	30.33
	Ankara Yildirim Beyazit University	176	23.31
Gender	Female	466	61.60
	Male	289	38.20
Grade Level	First Grade	227	30.10
	Second Grade	204	27.00
	Third Grade	130	17.20
	Fourth Grade	193	25.60
	Fifth Grade	1	0.10

The majority of the participants were female, with a percentage of almost 62%. First and second-grade students make up the majority of the participants, comprising 57.10% of the participants. Almost half of the students were from Ankara University. The data was collected within a month-long period through Google Forms. Students were provided with a link to the Google Forms questionnaire via their professors at their respective universities after an explanation of the survey was provided. Ethical Committee Approval was obtained from Eskisehir Osmangazi University (April 5, 2022, 313294). The data collection process was completed after one month. The items in the questionnaire that were used in the analysis are shown in Table 3.3. Students had 5 options to respond to these questions in the questionnaire: 1 (Strongly Disagree), 2 (Disagree), 3 (Neutral), 4 (Agree), 5 (Strongly Agree).

Table 3.3 Questionnaire Items

Item1	I have knowledge regarding Augmented Reality (AR)
Item2	I am capable of using AR in learning
Item3	I can understand better when learning using AR
Item4	Using AR in Learning improves the courses
Item5	I can embody better while learning using AR
Item6	AR can help students to better improve their hand skills
Item7	Learning using AR helps me for using the special devices better
Item8	The complexity of the AR technology makes me uncomfortable
Item9	Three-dimensional objects provide a sense of realism in AR activities.
Item10	I am more eager to come to class when AR activities are used.
Item11	I enjoy studying at home using AR activities.
Item12	AR activities make it more difficult for me to learn because AR confuses me.
Item13	It is difficult to use AR activities.
Item14	AR replaces face to face education.

CHAPTER 4

RESULTS

4.1 Results of the Systematic Review on Associations between VR Technologies and UX (RQ1)

This study aims to combine earlier research and offer a thorough overview of each selected article. Each article was analyzed in full text and the analysis is provided in this section, where applications of VR are categorized according to industries and the purpose of the VR application.

4.1.1 VR in Education

With the help of VR technology, students can perform better in the classroom and achieve better learning outcomes. Examples of these opportunities include virtual laboratories and hands-on training. Comparing VR practical instruction to traditional training techniques, users' experience is improved since students can see the results of their activities in real time. With VR applications, students can study more freely since they can see what they want to see and can select how to explore the material.

4.1.1.1 VR in Primary, Secondary and Higher Education

Immersive VR applications are being used to support a variety of instructional design approaches and objectives in both K–12 (Primary and Secondary) and higher education contexts. Pellas et al. [2] investigated how employing a variety of VR applications can potentially increase students' learning performance using instructional design ideas and approaches. Another study conducted in 2020 by Pellas et al. examined the efficiency of VR teaching strategies to guide instructors on the usage of VR technology in STEM education [3]. Science, Technology, Engineering, and

Mathematics education, or STEM education, is a fast-expanding field. The findings of both reviews [2], [3] attest to the fact that using VR in the classroom enhanced learning outcomes in addition to usability and UX. While it is not reasonable to believe that VR is the only factor contributing to better learning outcomes, it can be said that VR can enhance many aspects of education. They also note that while numerous factors, including presence and emotion, have been demonstrated to be influenced by VR technologies, few articles have examined the learning outcomes [2], [3].

According to these two articles, VR technologies provide numerous benefits, which are summarized below [2], [3]

- **Engagement:** Immersive technologies can help to improve engagement, which is considered to be a critical aspect throughout the learning process and is especially significant for STEM courses. Collaborative learning exercises that foster increased participation result in problem-solving and discovery. Because students can access top-notch instructional resources with realistic simulated representational fidelity created by computer devices, VR offers several learning benefits. It enhances students' capacity to collaborate in groups and engage in self-directed learning. One of the simple, low-cost technical solutions that provide experiences that are not limited by time or geography is mobile VR. This technology improves learning, as seen by students' positive attitudes, engagement, learning outcomes, successes, and performance in a variety of STEM topics. Additionally, HMD tools helped students work with their peers more effectively.
- **Cognitive Thinking Abilities:** The majority of research undertaken in K-12 settings discovered that students were able to develop cognitive thinking abilities related to creativity, problem-solving, critical thinking, and metacognition as well as a thorough understanding of complex content. The implementation of an immersive work interface that enables rapid 3-D conceptual design and presenting experience improves student learning outcomes as well as learning performance. VR boosts the motivation and engagement for learning in students. When students achieve more immersion and presence, VR helps them learn more and get better grades. Even though

there are still challenges with technology and complexity that need to be overcome in the future, users had positive impressions when using VR applications.

- **Hands-on Experience:** VR focuses students' attention on experimental activities that encourage learning by doing. Through hands-on learning, students were able to direct the learning materials and received immediate feedback as they were working on the assignments. Specifically, VR and instructional design environments enhanced students' conceptual understanding by facilitating the transfer of their experiences and existing knowledge. VR may also assist students in thinking through and visualizing their ideas and self-learning experiences more clearly. For topics that necessitate learning by doing tasks, game-based learning (GBL) approaches are more appropriate when students may locate essential learning resources within 3-D interactive animations.
- **Interactive Learning:** Students have actively engaged in a range of tasks to select the appropriate points of view using 3-D virtual models or elements for knowledge acquisition. This has been made possible by active instructional methods that allow participants to both observe and explore interactive elements, which may affect the learning outcomes and performance of the students. VR assists students in identifying their mistakes more accurately than traditional settings. Furthermore, if students can elaborate on their content while using HMD devices to interact with 3D visual interactive models, they will be able to deliver more thorough responses with more ease.

Utilizing VR applications could benefit students' education, perhaps because immersive technologies encourage practice-based assignments in particular settings, such as simulations in virtual laboratories. Nevertheless, using VR in the classroom presents some difficulties for both teachers and students. Comprehending the challenges that students encounter when utilizing VR equipment can help instructional designers suggest practical solutions and reduce the effect of these challenges. Thus, the difficulties associated with implementing VR in education might be summed up as follows:

- **Technical equipment:** Although VR is a cutting-edge technology that is available to everyone, instructors and students may not always be able to exploit it to its full potential in various training settings without considering any unique perspectives that this technology may bring. Since most students don't have the in-depth information necessary to fully comprehend how to use VR technology, there may be higher degrees of cognitive overload present. The high cost of some computing devices, along with the novelty of using such immersive technologies in specific learning disciplines makes it difficult for students to meet the technical equipment requirements. Due to the cost of technological equipment and the preparation required for the design, development, and optimization of educational VR programs, the deployment of such solutions is less feasible, especially in large-scale situations.
- **Motivation:** VR is ineffective if students are unmotivated or do not have the opportunity to opt out of using VR technologies. In contrast with an in-person conversation, virtual communication may seem impersonal or undesirable. VR applications must include a variety of communication techniques to maintain interpersonal and group communication. To have a smooth learning experience, VR users must use a variety of hardware and software tools.
- **Instructor Feedback:** Another disadvantage of most immersive VR systems in K-12 education is the possible number of students for whom the instructor must provide feedback at one time. This process may be automated in the future with the help of AI techniques.
- **Cost:** The cost of the software and hardware will decide how broadly VR is used in primary, secondary, and higher education. Low-cost VR headsets, such as Google Cardboard, provide economical, dynamic, and transportable learning experiences that are simple to set up for in-class learning. However, it has been stated that such low-end systems are to blame for students' physical challenges while using VR apps on their phones, as well as worsened simulator sickness complaints.
- **Time:** Most studies indicate that developing VR apps and utilizing them for learner tasks in time-constrained classroom settings require a substantial amount of time, typically less than 50 minutes. Another restriction to consider

is the amount of time required to implement VR-supported educational programs, from the development of technology tools to the end user. This goes beyond the amount of time required to design an application prototype.

- **Development of the Course Materials:** It has been shown in earlier studies that developing and implementing 3D VR apps requires highly skilled researchers and programmers, with Unity being the most reliable platform for incorporating educational content. Therefore, a free, open-source, and/or user-friendly tool for creating VR apps is still required. Teachers also have the responsibility to contribute to the development of course materials, since programmers cannot do so.

4.1.1.2 VR in Healthcare Education

VR has the potential to provide healthcare students and professionals with an engaging and effective learning environment. Real-world patient experiences are seen to be the most motivating components of VR healthcare simulations. VR simulations provide a safe and comfortable environment in which healthcare professionals can practice new abilities and learn from mistakes without compromising patient safety. Serious games (SGs) can be implemented with VR technologies. An SG is made for many purposes other than only amusement. SGs can be used to accomplish professional training; for instance, they can be used to teach technical and non-technical skills in the healthcare industry. Prior studies have revealed largely favorable sentiments regarding VR and SG training in the medical industry.

After performing an integrated literature analysis, Mäkinen et al. identified three main types of VR technology as being used for healthcare learning in 2022 [12]. Haptic simulators were the most preferred technology for healthcare learning. Computer simulations were the second most popular technology. HMD systems were identified in a small number of articles. Most of the time, haptic simulators were used in medical or surgical training. Typically, computer-based simulations were used to train healthcare personnel or in nursing education. HMD simulators were used to train faculty in the healthcare profession. Only five articles using HMDs were found in the review. This may be because HMD technology is still relatively new in the healthcare industry, meaning there isn't enough research done in this field at the moment. Another reason for the underwhelming amount of studies in healthcare education with HMDs could be because they are the most immersive systems that enable users to completely immerse themselves in the virtual world. With the use of this technology, the user can experience something as realistic and immersive as possible. However, such high levels of immersion may hinder educational outcomes in healthcare because students need to have a connection to the real world in this field. Still, every one of the nine UX factors was looked at in connection with HMDs.

The most effective VR-supported teaching method was the discovery technique, which encourages students to expand their knowledge through self-directed learning [12]. Furthermore, team-based education appears to be a potential area for additional research. Because of the complexity of implementing this educational method, few efforts are being devoted toward it at the time; nevertheless, future developments in VR hardware and software development may pave the way for this creative learning area. Problem-solving exercises in-game appeared to improve the quality of students' solutions.

There are a few significant issues that should be addressed, despite the well-documented opportunities that VR offers. Concerns such as time management, instructional design contexts, and course organization, for example, require additional attention. The instructor is responsible for preparing or providing all teaching materials. Students need to master the use of VR technologies properly because of their limited exposure to them, as previous research has often proven. The rapid advancement of VR technology may eventually remove its existing constraints in terms of realism and usefulness. Thus, VR technologies hold great potential for application in medical practice and education. As HMD technology proliferates, users will get more comfortable and knowledgeable with it. The most recent HMD technology is used very differently from previous technologies, and user-centric designs are essential to the quality of the many interactive technologies.

4.1.1.2.1 VR in Healthcare Practice Simulations

VR technologies have been discovered to be used in surgical operation training simulations in healthcare. Surgical simulators allow clinical practice to be integrated with simulator practice. Less experienced doctors or students are instructed by more experienced doctors using real patients in the present surgical education system. However, errors committed during a real surgery may be very hard, if not impossible, to correct. It is imperative that the patient's safety during surgery not be jeopardized for the sake of education. Surgical simulators are safer to employ in surgical training because of these features. According to Moore's law, surgical simulation systems have become increasingly popular as a practical resident training approach in recent years. Complex anatomical relationships are better illustrated on interactive platforms. Acquiring practical skills, theoretical understanding, and procedural knowledge over several years is necessary for training in neurosurgery. These abilities still need to be honed through more study and real-world application after completing residency. Like the aviation sector, neurosurgery now has a "trial-and-error"-based learning approach thanks to simulation, all without putting patients in danger [1].

Several simulation components have been employed in a variety of surgical simulators, including those used for laparoscopic, endoscopic, and microsurgical training. Stereoscopy produces a more realistic 3D perspective, and more complex systems may even simulate dynamic perspective utilizing user head and eye movements. Haptic feedback can be used to simulate tactile qualities. These technologies allow students to hone their skills by allowing them to engage with virtual 3D items that are put in either real-world imagery or virtual settings.

Using XR is one novel way to implement simulations. XR technology offers the ability to improve neurosurgery education by providing a wide range of objective and subjective measurements. In addition to teaching, XR has been applied in medicine for many other objectives, such as informed consent, intraoperative navigation, preoperative surgical planning, and patient education. XR research has also focused on the performance of surgeons in stressful conditions, such as sleep deprivation.

In neurosurgical education, virtual practice provides significant value above the traditional observation-based approach to gaining procedural knowledge. Training in an XR environment may also expose students to a complex library of scenarios, which would help them better prepare for the wide diversity of actual circumstances. These techniques also make it possible for students and instructors who are dispersed over different places to participate in remote learning, where knowledge is shared at different times. This means that unlike in previous research using 360° cameras, more individuals would be able to virtually witness neurosurgical procedures from anywhere in the world, from the comfort of their own homes, without having to compete for a position in the operating room. In areas where access to relevant knowledge is limited, adopting an asynchronous and distributed teaching technology that records surgical procedures and allows viewers to have control over video playback can help progress surgical education. Comprehending neuroanatomy thoroughly is crucial since neurosurgery is complicated due in part to the complex anatomy involved. Students may remember topographic and operative anatomy better if they study it in a virtual setting. Virtual volume rendering technologies are sometimes utilized in conjunction with XR when paired with accurate 3D models or haptic feedback devices. The goal is to authentically replicate surgical processes through the use of illusions of tissue deformation giving customers tactile feedback or demonstrating how it behaves when sufficient force is applied using a real or virtual tool resulting in a more comprehensive experience. When haptic devices are used in an XR application, an entirely new aspect of performance evaluation is revealed, largely through the tracking of force, motion, tremor, and hand ergonomics. Users' performance and dexterity with haptic devices were assessed to choose future neurosurgical residents, as well as to identify skills and monitor current residents' training. Iop et al.'s 2022 article discovered three outcomes for VR in neurosurgery training [1]. Firstly, younger residents self-assessed their performance in the tumor excision simulation as much better than senior residents. Second, past simulation and familiarity with other medical procedures had no discernible influence on participants' perceptions of the simulators. Lastly, throughout the simulation, residents needed less time to become proficient with the haptic device. According to assessments of learning curves among trainees such as neurosurgical residents and medical students, as well as comparisons with that of experienced surgeons, the performance improvement over time tends to be greater in surgeries with less variability in their operative conditions than that in other surgeries such as tumor resection [1].

Surgical training simulators are now widely used in many medical professions to monitor progress, give training in a controlled environment, and objectively assess students' skills. Virtual simulators exhibit construct validity across several modules, as seen by the distinct differentiation of UX levels during simulated phacoemulsification surgery. Lab simulator performance has also improved. The use of simulators in residency training has been linked to a lower frequency of complications from cataract surgery. VR simulators are a helpful tool for evaluating performance and determining trainee competency. They may also aid in improving surgical skills and patient outcomes during cataract surgery [34]. Future opportunities will be determined by the ability to use technical developments in simulators for training and research.

4.1.1.3 VR in Teaching and UX

Even though VR technologies are increasingly being used in practice and education, there are currently relatively few studies on UX in this field. Prior research indicates that UX has a major impact on motivation and learning. However, each VR experience is unique and different since every VR event occurs in the participants' minds. Each individual brings their unique set of abilities, experiences, and backgrounds to the virtual world. Understanding UX is critical when utilizing VR in the classroom. The majority of articles about VR and healthcare have focused on the benefits and applications of VR in various areas of healthcare practice and education.

In immersive virtual environments, 10 UX components have been identified by a systematic review [17]. These components include presence, engagement, immersion, flow, usability, skill, emotion, experience consequence, judgment, and technology adoption. Positive feedback was reported about most of the UX components that were observed. Negative encounters were primarily caused by the usability of the technology. This could be because the most researched aspect of the UX was usability, which could also be partially explained by the fact that some of these systems weren't very user-friendly. Usability and technology adoption were the two most commonly observed UX characteristics of every technology, while factors related to computer-based technologies received the least attention. This could be because computer-based technologies are the most basic kinds of VR applications, allowing for a lower level of immersion. These lower-level applications only stimulate one or a few senses at a time. These technologies are usually of poor quality, with information that is out of sync. Because of usability and technological issues, participants were impatient. This could have led to the participants discontinuing use of the product. The extent to which the UXs are considered will determine how much better learning experiences the technology can offer users, benefitting both students and professionals. Better education from improved UXs can lead to better patient care and safer behavior adoption. Better education is going to lead to better patient outcomes. As VR technology advances, users will be able to enjoy the most immersive experiences conceivable, which will enhance skill development, provide remote training access, inspire the creation of innovative training methods, and enhance patient safety. Since it might be challenging to determine which metrics to utilize, machine learning can be used to evaluate skills more correctly. In the future, evaluating overall performance instead of specific indicators may be a useful method [17].

According to another study by Iop et al. in 2022, the most favored UX categories tend to be usefulness and realism [1]. UX, which takes into consideration how test subjects react to the events, interactions, and feedback related to the simulation environment and tools, is a crucial component of evaluating an XR application or simulation device. In the study by Iop et al. [1] UX metrics of a XR system on neurosurgical education were categorized into several groups. These groups are usefulness, the user's assessment of the impact and efficacy of the application; self-assessment, the user's evaluation and appraisal of their performance; haptic interaction, which pertains to the manipulation of the system's tactile input and output, usability, system feedback, the environment's reaction to user interaction, comfort, or ergonomics, time requirements to carry out actions and receive feedback, engagement, immersiveness, presence, and realism, the application's visual and tactile when appropriate fidelity to actual surgical procedures. The degree of realism that users experience during surgical simulations in an XR environment is a critical factor in evaluating the effectiveness of the learning process. This definition of realism assesses how closely the visual and tactile cues in an XR application mimic a real-life scene in the users' thoughts. It also refers to the correctness of the graphics, interactivity, and context of the program. The more realistic the simulation is, the higher the quality of instruction. Realism is valued more by most experienced users than by their more seasoned counterparts; just one study found no difference in realism across subject groups.

Users may not find every VR technology to their satisfaction in a few instances. Every negative experience had to do with competence or usability. VR systems have been demonstrated to enhance student performance. Several game elements, such as visual appearance, interactivity, immersion, feedback, and competitiveness, may boost learning. When compared to computer-based simulations, haptic devices can create virtual learning environments that are more engaging and captivating. Because they feel more present and motivated, users appear to favor haptic devices over computer-based simulations while learning new skills, which may be because haptic devices provide force feedback on the motions and physical attributes of virtual objects. Therefore, because haptic devices are more immersive than computer-based simulations, they offer a better opportunity to research UXs in immersive environments.

User performance (UP) is another subject that is common among most of the reviewed articles. UP encompasses critical aspects of executed surgical simulations, such as hand-eye coordination, manual dexterity, success metrics, and kinematic coordination, to name a few. The parameters of UP are typically evaluated by skilled neurosurgeons or the test subjects themselves following the surgical simulation. Despite efforts to remove bias, human factors can nonetheless impact judgment and lead to incorrect results. Furthermore, the employment of human actors in the assessment and judgment of surgical performance may skew comparisons across many studies, lowering the overall quality of the presented conclusions.

4.1.2 VR in Healthcare Treatment

Within VR systems, the user is immersed in a computer-generated image and should have unhindered movement and interaction with the virtual items. Patients should be ensured to have good experiences using digital solutions such as VR since consumers will only use VR if they believe the technology fulfills their needs and fully immerses them in the experience. VR technology has been shown to benefit both patients and doctors; patients can use it to learn about their conditions and receive treatment, while doctors can use it to practice and become experts at performing complex procedures [26].

4.1.2.1 VR in Neurofeedback Training

It has been demonstrated that VR technology is helpful and efficient for studying neuropsychology and neuroscience. Traditional methods of studying human neurology depend on simple, static stimuli that may not be ecologically valid in all situations. VR allows for the use of highly controllable interaction and dynamic stimuli in an ecologically relevant environment to gather state-of-the-art cognitive and behavioral data. VR has demonstrated efficacy in evaluating cognitive and affective functions, as well as clinical disorders requiring ecological validity for evaluation, therapy, and rehabilitation [37]. In terms of age demographics and clinical situations, the usage of VR HMDs in neuroscience is gaining in popularity, both for clinical and research purposes. A wide range of demographics have embraced VR technology and approaches. It has been discovered that using new generation HMDs, which give a high-resolution display, quick visual refresh velocity, an ergonomic layout, and controls that allow authentic navigation and activity within the VR scene, improves VR experiences. Kourtesis P. et al.'s findings demonstrate the feasibility of adopting new-generation VR HMDs in cognitive neuroscience and neuropsychology [37].

The notion of biofeedback was initially proposed in 1961, and it contends that people can use physiological tools to regulate physiological changes and avoid harmful stimuli. Neurofeedback training (NFT), the most well-known biofeedback technique, describes how to sense and interpret brain signals. NFT is a vital approach in the intelligent merger of the brain and computer. According to Gong et al.'s evaluation of NFT in 2021, an NFT training simulation may be used to represent the dynamic fluctuations in brain activity that occur when the brain is exposed to varied stimuli [38]. Athletes have been the subjects of earlier techniques in which they were made to regulate this feedback feature during NFT and recollect their workout scenarios. This approach resembles traditional motor imagery training, which teaches athletes to remember the actual sport through their imagination, but with the help of visual visuals or music that relates them to the outside world. Then, by recalling their bodily sensations at that exact moment and visualizing every movement, athletes can improve their performance. When NFT and VR are combined, an immersive training environment is created, improving the overall experience. In earlier studies, individuals with neurological disorders like Alzheimer's disease and stroke were treated with a combination of VR and NFT procedures, which showed improved treatment outcomes compared to traditional NFT approaches. In other studies, the electrical activity in the human brain during VR immersion has been monitored, and the results have shown that emotions and fatigue levels can be identified. NFT should be used in conjunction with VR, AR, or MR technologies to enhance users' sensory experiences [38]. Virtual interaction has not yet been included in NFT technology, but if VR and NFT are ever integrated, brain regulation may be much more successful.

VR technology integration into NFT is difficult because of brain signal acquisition techniques. Participants' large body movements during the feedback phase generate motion distortions in the recorded signal, interfering with the feedback effect. Gong et al. published a study in 2021 that combined VR with NFT, discovering that participants were more involved in the VR experience and gradually improved their performance while utilizing NFT techniques [38]. Additionally, the study demonstrated that VR simulations can sustain the NFT training effect and slow down participants' decline in interest in training [38].

4.1.2.2 VR in Treatment of Mental Health Disorders

VR is considered the most advanced way of human-computer interaction in the domains of psychology and neuroscience because it enables users to interact, communicate, and immerse themselves completely in a computer-generated environment. VR-based interventions, encompassing simulations, have been employed and evaluated in multiple clinical trials addressing issues such as anxiety disorders, eating and obesity disorders, stress-related disorders, pain management, phobias, and post-traumatic stress disorder. VR simulations can be utilized during dental procedures to divert patients and reduce their sense of pain and anxiety [39].

Due to VR's therapeutic value for conditions like anxiety disorders, stress-related disorders, eating disorders and obesity, pain management, addiction, and schizophrenia, researchers from a wide range of professions support its use in mental health. However, the application of VR in therapeutic settings has historically been limited due to the expensive cost of virtual tools and their poor usability. By therapeutic techniques, patients' requirements and expectations, and therapy approaches, VR is commonly used as a simulative tool to recreate exact and realistic situations that imitate essential or dreaded moments while accurately managing the flow of all stimuli. Patients can participate in simulations of situations that would be extremely dangerous in real life, such as being afraid of heights, and they can also broaden the scope of traditional therapy. Additionally, VR makes it possible to customize and grade the level of difficulty for each patient individually while repeating the same simulation several times to help lower anxiety. VR is a cognitive and simulative technology that can be used to treat mental health issues [21].

Lattie EG et al. conducted a review of the literature to assess the effectiveness, usability, acceptability, uptake, and adoption of digital treatments for mental health that addressed anxiety, depression, and enhancing psychological well-being in college student samples [25]. To pinpoint the exact elements of these therapies that help lower college students' levels of anxiety, sadness, and psychological well-being, more thorough research is still required [25].

Elphinston RA et al. conducted a comprehensive study to look at the UX, viability, and effectiveness of VR-based psychological treatments for driving fear [40]. Treatments can be made more widely available and possibly more affordably by using telemedicine services to conduct VR exposure therapy sessions and practice outside of therapy sessions. Treatments can be made more widely available and possibly more affordably by using telemedicine services to conduct VR exposure therapy sessions and practice outside of therapy sessions. VR-based therapies have drawbacks too; Some patients find it difficult to fully immerse themselves in the virtual environment and develop nausea or discomfort associated with cybersickness. Other forms of treatment might be more appropriate for these patients. Measures of experience of presence and immersion, as well as unpleasant symptoms like nausea and vertigo, should also be considered in such studies. With less obvious equipment, it is now feasible to obtain more realistic stimuli thanks to recent advancements in VR technology. This could allow for a more comprehensive experience and longer therapy sessions as needed by making the scenarios more realistic while lowering the risk of cybersickness in the patients. The capacities of VR technology, the skills of therapists, and access to software and equipment can all have an impact on the scope and effectiveness of treatment.

People can consciously alter their physiological condition through a technique called biofeedback (BF). Highly precise sensors identify physiological markers, such as body temperature, breathing, or heart rate, and concurrently provide the subject with this information through visual or auditory channels. BF learning is shaped by motivation [32]. VR may elicit substantial levels of attention and engagement through the use of interactive elements and multimodal stimulation. By incorporating VR, it may be possible to overcome challenges related to traditional BF, including low treatment motivation, attentional difficulties, and the difficulty of implementing newly learned skills in day-to-day activities. Results of the 2022 study by Luddecke R et al. point to potential benefits for motivation, user experience, participation, and attentional focus with VR-BF [32]. However, currently, there's no conclusive evidence that VR-BF performs better than traditional BF.

4.1.2.3 VR in Rehabilitation

VR has a bright future in the development of personalized, motivating, and supervised rehabilitation experiences. The feasibility and safety of a rehabilitation system should be weighed against its functionality. These two requirements, along with immersion, engagement, and usability, influence user satisfaction, realism of the experience, and the efficacy of the rehabilitation intervention.

Chronic obstructive pulmonary disease (COPD), a common chronic illness, is a substantial global contributor to morbidity and mortality. Because it allows for tailored care, constant performance evaluation, quantitative measurement, and the integration of external devices and sensors, VR is a powerful tool for improving exercise training. When a patient is exercising, VR might distract them from unpleasant sensations such as weariness and shortness of breath. VR is particularly well suited for physical and respiratory training in the rehabilitation of COPD [9].

Another review in 2020 by Koutsiana E et al. aimed to evaluate how SGs are currently used in upper extremity rehabilitation. Despite significant efforts to create gamified rehabilitation systems, it is still unclear whether playing a serious game is an effective way to enhance upper extremity performance [41].

While increased morbidity and comorbidity may be associated with disability, aging is a process that can be defined by a loss of physical, sensory, and mental capacities. VR is a useful technology for the assessment and rehabilitation of older people. A crucial consideration in the development of therapeutic virtual systems for older people is usability. Tuena C. et al.'s systematic review findings show that some senior groups have assessed non-immersive VR's usability with an emphasis on motor/physical rehabilitation. In order to improve engagement and boost older people’s adoption and use of VR therapeutic applications, the results support the importance of UX and usability [21].

Ijaz K. et al. provide a scoping review of the literature on immersive VR apps designed for those over the age of 65. The findings indicate that immersive VR systems have high usability and acceptance among senior users [20]. Some difficulties include discomfort caused by VR headgear, cybersickness, and trouble understanding how to manage IVR systems.

4.1.2.4 VR in Ophthalmology

VR technologies create a synthetic world in which to have a seemingly real and potentially participative experience. AR technologies, on the other hand, enhance our experience by superimposing digital data, such as images, over the real world. Popular digital technologies such as VR and AR focus on real-time communication between people and virtual items. In the healthcare profession, VR and AR have been widely employed for some applications, including cognitive rehabilitation following a stroke, surgical training, and laparoscopic and robotic procedures. Numerous research projects have proposed the use of VR for glaucoma screening and diagnosis. VR, according to Saha C. et al, can be used in diagnosing and screening ophthalmology [42].

VR and AR have the potential to improve clinical diagnostic and testing services in ophthalmology by addressing current problems like underdiagnoses, inaccurate diagnoses, and a shortage of skilled staff. Over the past ten years, a range of studies and solutions have been produced employing VR and AR principles to establish clinical testing for ophthalmology. These include AR biomicroscopy for retinal illnesses, VR perimeter for glaucoma, and VR testing for binocular vision. VR and AR technologies possess certain shortcomings that have prevented their wider application in clinical settings, despite their potential to become standardized, automated, and reasonably priced assessments that offer a favorable UX. These shortcomings consist of hardware limitations, inadequate validation, and low accuracy [42].

4.1.3 VR Tools and Models

Smart wearable technologies are rapidly changing our interaction with the real and virtual worlds through a variety of VR and AR systems. Improving UX is critical for mobile AR/VR systems to keep the product functional. The user of interactive VR/AR systems can provide data via touch sensors and receive signals via a variety of modalities, including visual, aural, and haptic inputs. VR solutions that use computer-based interactive simulations to allow users to interact with environments that look and feel like the real world are regarded to be particularly beneficial for rehabilitation. The same is true for AR systems, which can enrich the real world by adding interactive virtual elements. Conversely, the majority of VR/AR systems mainly provide aural and visual feedback, which does not result in equally immersive experiences. For people with impaired senses, such as the blind and deaf, this is especially problematic [43].

The survey that assessed VR glasses from four perspectives—hardware, mobile app, simulator sickness caused by the device, and interaction operation performance — was examined by Lanyi CS et al. The results show that a higher-quality UX could significantly reduce simulator sickness [44].

The three qualities that characterize interaction and explain how much the user may change the mediated environment are speed, range, and mapping. Current VR controllers can instantly translate user input into actions in the virtual world. The built-in functions of the controller set a limit on the range, which is determined by the number of probable actions at any given time. The term mapping refers to how user activity influences how the mediated environment operates. Wearable gadgets have demonstrated the intuitive nature of human-computer interactions [45]. While mapping to the function being performed can be random, it is best to utilize a natural action mapping when the function has a direct real-world counterpart because our perceptual system was designed to interact with the real world.

Unlike VR, which fully submerges the viewer in a created world, AR overlays digitally generated content onto the physical world. AR blends the virtual and the actual environment in real-time interaction. The input devices must be able to recognize and register items in the actual world as well as the actions of the user in real-time as 3D information for the user to interact with the virtual component of AR. The output devices should ideally generate responses from real items that are both subject to virtual influences and sensory stimuli.

To build a virtual world, VR environments require a smooth user interface and high levels of immersion. However, because of the nature of high-resolution 360-degree films, real-time streaming creates some challenges, such as a high bandwidth requirement, a high CPU requirement, and a low latency tolerance. 360-degree video streaming is regarded as the major resource for assisting students with research and project completion while also encouraging technical innovation. The 360-degree video also provides a more active learning environment than the traditional passive learning environment, which is suited for embedding learning and taking education to new heights, potentially assisting in the improvement of understanding of more difficult topics, ideas, or concepts. Consequently, students are more motivated to learn more about the subject they are learning. Wong et al. summed up the advantages of 360-degree video as follows [46].

- Boosting the creativity and involvement of students in the classroom
- Generating a wide range of virtual world business and job opportunities
- Providing a virtual platform for conversation that is very similar to in-person interactions
- Offering top-notch entertainment, such as concerts, gaming, and other activities.

The extremely high bandwidth needs of 360 video streaming over the Internet make it especially difficult to provide customers with a high-quality QoE. In order to overcome the latency and make up for the high bandwidth requirements of 360-degree video through increased network availability, edge computing, network caching, and MEC—which bring the content closer to the client and address the intensive computing requirement on the client-side—will be crucial [46].

The majority of VR applications are now used to create composite content for gaming and entertainment. Most contemporary VR apps have the poorest interactivity since they are connected for operation, greatly limiting the mobility and interactivity of VR devices in remote communication contexts. To lead society into the envisioned VR future, which requires a break from conventional network solutions, current networked VR difficulties and technical constraints must be solved. As VR technology evolves and improves, the performance gap between networked VR requirements and current and forthcoming network technologies is expected to grow. To support new applications, networked systems must provide a new era of network technology with higher bandwidth rates or shorter transmission delays. The large amounts of data that VR video requires to be transmitted in high quality provide a challenge to the network's capacity and real-time capabilities. Ruan J. and Xie D.'s study from 2021 states that advanced coding and streaming techniques are necessary for VR video transmission to meet current and upcoming application and service needs. In VR 360-degree video transmission, the user sees only a section of the 360-degree video at a time. As a result, bandwidth is wasted by broadcasting the complete scene. To ensure smooth playback, the client needs to pre-download the video content, which requires assuming the user's future viewpoint [47].

Multi-user virtual environments (MUVEs) allow two or more users to communicate and participate within a single simulation. Avatars—personalized graphical representations of people—are utilized in MUVEs to enable communication and interaction between users, and their real-time motions are directly controlled by the user’s real-time motions.

The systematic use of CAD software has become critical in the development of new goods. Nonetheless, they continue to rely heavily on traditional keyboard and mouse interfaces. As a result, the 3D modeling process is less organic and intuitive. Multimodal interfaces make human-computer interaction more effective and expressive. The word "multimodal" refers to the use of all five senses to enhance the UX of digital content and facilitate human capacities like comprehension and engagement. To complete this task, sensory technologies such as VR, AR, and haptic displays are employed. Human-computer interfaces (HCIs) that are multimodal have emerged as the next generation of interaction paradigms. Natural interactions in 3D modeling can be achieved in more ways when a multimodal HCI is included. In 2022, Niu H. et al. reviewed the literature on multimodal HCI for CAD [48]. The efficiency of 3D modeling has risen in several industrial domains, such as mechanical and aeronautical engineering, thanks to recent advancements in CAD technology. It is necessary to shift to user-centered natural HCI technology to make CAD modeling easier to use and understand [48]. To meet this demand, multimodal interfaces that use gesture detection, eye-tracking technologies, natural language processing, and brain signal recording approaches have been developed. Because it resides at the intersection of numerous subject areas, such as artificial intelligence, computer vision, and many others, the discipline of multimodal HCIs for CAD requires a solid theoretical foundation. New input channels, such as gesture or sight, are now examined and combined entirely during the application stage. This overlooks several issues that can develop when using any one modality alone, but more importantly, it ignores the different roles that different CAD-related modalities play and how they interact with one another. Furthermore, a one-size-fits-all approach to these modalities leads to programs that disregard user preferences. In the future, a crucial research goal in interactive environment design will be to enable several users to communicate in bigger physical locations and universal forms, including pointing to a common display surface, gesturing concurrently, and having reasonable conversations. Because existing interfaces typically assume that a specific device provides input from a single user at any given time, several special technological challenges will need to be addressed to achieve a multiuser environment, such as how to capture data from multiple users at the same time and identify an individual user's contribution to the total multi-user interactive environment, as well as transitioning between different interactive themes. Because of the rapid rise of network and VR/AR technology, distributed collaborative design will be an important trend in the future. Because technology enables data interchange and communication, users can efficiently share a resource whether they are co-located or distributed. Multimodal interface-based AR/VR should also be developed to enable solid modeling and collaborative design activities, so several users can view and interact with real and virtual elements simultaneously in a remote setting.

Researchers and artists work together to present the visualization platform developed for the METIS-II project in the study by Martin-Sacristan D. et al. in 2018 [49]. It is a 3D visualization tool that lets users interact with 5G-enabled scenes and facilitates the intuitive evaluation of simulation-driven data [49]. The platform is a configurable game-based tool that enables quick integration of novel ideas, real-time communication with distant 5G simulators, and a VR-based immersive UX. According to METIS-II, a VR implementation of the visualization platform was necessary to fully immerse the user in 5G concepts and deliver scientific knowledge. The immersive experience creates a sensation of presence, which has several advantages. The first is VR's ability to keep the user's attention focused on the visualization platform. The second benefit is the opportunity to try out some 5G functions firsthand, which is more realistic than simply looking at images on a screen and listening to noises via speakers. Experiencing a realistic 3D world aids in giving the user a sensation of presence. To create this realistic design, nonscientists, artists, and designers must focus on creating scenarios that give the user the impression that they are in the real world. One additional advantage of VR is its economic impact. More people will see an SG-based demonstration than one that makes use of posters or pre-recorded movies. However, it is undeniable that adding VR to the demonstration greatly heightens public interest and offers more channels for disseminating the notions that are depicted. The METIS-II specified three important prerequisites for VR deployment to produce a completely immersive experience [49].

- The ability to perceive the triggers produced in a virtual setting around the user
- The ability to engage with the environment in real-time
- The ability to swiftly acquire feedback from the virtual environment.

Today's head-mounted displays (HMDs) have promising technology. Because of their low cost and versatility, HMDs are attracting interest from a wide range of sectors. Unfortunately, there are times when users of these technologies report negative experiences. Numerous HMD users describe feeling a range of physical aches and pains in addition to symptoms like headaches, nausea, and disorientation. These symptoms, which develop during or after exposure to virtual environments, are known as simulator sickness. Researchers Grassini S. and Laumann K. reviewed the gender differences in simulator sickness susceptibility in the context of modern head-mounted displays (HMDs) in 2020 [50]. The results showed that it is difficult to come to a consensus regarding whether gender affects a person's propensity to have simulator sickness; most of the studies that were reviewed found no connection between gender and simulator sickness [50]. In general, there were no differences in task performance and cognitive abilities in VR environments between male and female individuals. Other research, however, has indicated that female participants outperformed male participants on assignments. According to the researchers, this disparity may be due to female participants in HMD-mediated VR perceiving a higher sense of presence on occasion. The systematic review's diverse findings disprove the notion that there are universally "sexist" components of human experience in HMD technology [50].

Soft Organic Robotics, which creates intelligent soft machines with naturally soft actuators and sensors for more lifelike VR/AR experiences, may enable the next generation of haptic devices. Soft actuators offer low-profile wearables with conformal skin and joint contact, as well as significant amplitude and sustained deformation for kinesthetic feedback and large frequency bandwidth vibrotactile feedback, enhancing haptic feedback capabilities [45]. Soft haptic devices may be cost-effective due to low-cost building materials and manufacturing procedures. The industry initially focused on and made tremendous progress in providing realistic visual and aural feedback to generate interactive multimedia in which the user feels present in a virtual environment. Haptics, on the other hand, is a less developed technology; nonetheless, in the actual world, the feeling of touch is functionally and emotionally vital for human perception [45].

Haptics and VR are the most common immersive technologies across all industries [51]. Though VR remains the most widely used, haptic contact is starting to appear in more applications. Except for medical, where haptics is more frequently used, VR is the most widely used technology in all application domains (concepts and overviews, physics, transportation, cultural heritage, industry, and UX). AR is most widely applied in cultural heritage studies, and haptics is the second most popular technology type in most areas (concepts and overviews, physics, transportation, industry, and UX). Even though AR is frequently employed, most applications utilize multimedia devices such as smartphones, HMDs, and screens [51].

Web-based simulations, according to researchers Franke L. and Haehn D., are a potential way of VR and AR visualizations, while much work remains to be done [52]. Users can obtain the information they require by simply visiting a website and using web-based visualizations. To deliver high-quality, practicable remote visualizations of growing and more complex scientific data sets, new methods must be created. Recent web-based visualization tools, on the other hand, may suffer network capacity and latency issues. Research demonstrates that WebGL is being used more and more in 3D web-based representations in a variety of scientific fields [52]. The advantages of WebGL are particularly frequently utilized in physics and medicine, while chemistry and biology are following suit with an increasing number of studies published each year. For example, adaptive solutions can be utilized on several devices or new advancements for integrating VR or AR into a web-based setting, and open-sourced research is crucial for this utilization [52].

4.1.4 VR in Coal Mining

Coal mining, a high-risk industry, has a significant demand for VR to complete safety and emergency rescue training. VR technology has significant benefits in numerous sectors related to coal mining, including miner safety training and emergency rescue drilling, in addition to fate-producing process simulation, catastrophic event simulation, and mechanical operation training [53]. Over the last two decades, the United States, Australia, and the United Kingdom have adopted VR as an instructional tool for mining simulation, disaster reconstruction, examination, and safety training. Over the last decade, VR technology has improved miner training across hardware and software components. VR training has a long history of development and implementation, particularly in the United Kingdom. Furthermore, a typical element in coal mines is the 3D visualization system, which includes functions like a 3D physical demonstration, ventilation simulation, immediate data inspection, and emergency reaction. Over the past ten years, several coal mine companies have built underground networks and made attempts to integrate cloud computing, the Internet of Things, and possibly artificial intelligence into mining, ventilation, safety, and training programs. Traditional mining has given way to intelligent mining in the mining business. However, it has several drawbacks, including pricey and unreliable technology, a poor user experience, no direct browser access, and a shortage of intelligent and humanized design. Some of the disadvantages mentioned by Li et al. are as follows [53].

- The vast majority of current VR-based teaching solutions offer a subpar learning experience. Even though these systems contain educational features via a single-player setting and a question-answer pattern, there is no complex AI man-machine interaction. The emphasis of VR training systems is typically on professional computing, catastrophic 3D simulation, or communication via voice or text. Thus, the learning process should be improved.
- VR has great promise for creativity, interactivity, and immersion; nevertheless, these possibilities have not yet been completely realized.
- Direct browser access is not possible with traditional VR teaching tools. A wide variety of lightweight devices, including laptops, smartphones, tablets,

and headsets, will be supported by cloud rendering. These devices will enable real-time transmission in a fully immersive environment, enhancing cyber-physical and social interactions. Because virtual learning and gamification have become more and more common in education, VR training software ought to include both of these features.

Li et al. presented a cloud-based VR system for mine safety instructions, leveraging the benefits of cloud rendering and AI [53]. AI guiding is utilized to explore the underworld and replicate disasters. To provide appropriate computing capabilities, online cloud-rendered video streaming is used, resulting in a superior browser-based user experience. Furthermore, game AI is integrated into the system to improve the emotional exchange between the system and users. Unlike normal VR training software, this solution creates two virtual miners to enhance learners' experience.

The first virtual miner is a non-player character who helps players operate underground and gives them general mining knowledge. The second virtual miner is a character that gets people ready for typical calamities. The system was successfully put into use in a lab environment, and its functionality was confirmed. To encourage fresh, innovative uses of VR-based miner training and catastrophe drills, more procedures are needed [53].

4.1.5 VR in Virtual Museums

The UX of VR-based Museum Exhibitions (VRME) is becoming increasingly important as digital technology develops and human-centered approaches to museum display design get more popular. The current framework for designing museum exhibitions, on the other hand, does not expressly address the difficulties unique to VRME. Researchers Zou et al. conducted a literature review in 2021 before proposing a "rose model" of VRME [27]. This model is made up of four sections and can be applied to different VR applications. The idea is centered around virtual exhibition technology, which delivers immersion and interactivity. The model's second layer reflects the many sensory experiences, such as aural, kinesthetic, or visual, as well as their interactions. As the primary sensory experience, vision has a role in every aspect of UX. Different UX layers, including the creation, artifact, spiritual, and behavior levels, are represented by the third layer. The fourth and last layer displays several aspects of how a person interacts with the display, including usability, emotion, and cognitive learning. As a result, the levels of UX in the rose model correlate to different sensory experiences and human-exhibition interaction aspects [27].

4.1.6 VR in Engineering Design Review

Although VR technology is continually evolving, systems currently offer increasingly advanced types of interaction and visualization to enhance the engineering design review process. The traditional design review technique is usually carried out on a computer using CAD software tools. However, testing the functionality and usability of complex 3D objects on a screen is not always practical. Wolfartsberger presented the development and evaluation of "VRSmart," a VR-based tool for engineering design review, in 2019 [54]. "VRSmart" offers a straightforward user interface and visualizes CAD data. A real-world design review analysis of VRSmart revealed that users were able to discover more faults. It has also been demonstrated that VR increases the participation of additional professional groups in the design review process. Furthermore, it was discovered that the intuitiveness of the VR system interface made it much faster to enter the design review process. The study concludes that while VR is a useful tool for engineering design reviews, the traditional design review method will still need to be used in addition to VR [54].

4.1.7 VR in Architectural Design Review

Lee et al. evaluated the effects of VR and AR on architectural design review from the user's perspective in 2020 [24]. The findings indicate that AR is ranked highest in terms of UX and level of adoption and that AR systems may be a superior option for examining visual aspects of a building such as texture or color. Users also found AR systems to be unique and inventive. Even though AR was the most widely accepted technology, users also reported physical discomfort. VR technologies are more widely accepted than 2D systems, although they have issues with user satisfaction and mental comfort. The fields of architecture, engineering, and construction can efficiently implement AR systems once physical discomfort has been handled, and VR systems once mental discomfort has been resolved [24].

4.1.8 VR in Gaming

Makransky and Terkildsen's 2019 article investigates physiological measures as indicators of presence in games [29]. Users who felt a strong sense of presence within the game had a stable physiological condition at the end of the game [29].

Emotion is an important UX aspect in VR gaming since it contributes to entertainment; making the game more enticing and pleasurable for the players leads to a better gaming experience. Another important factor that demonstrates the relevance of the user's interaction with VR tools within a game is engagement. UX in games improves when the user can engage with more content within a VR gaming environment, giving the user a sense of accomplishment. Emotion and engagement are closely followed by usability and technology adoption factors. Gaming systems, like other VR systems, must provide an adequate level of usability so that the user does not feel cybersickness. Presence is another important factor in VR games because the user's opinions and evaluation of the game mirrors how present the user feels within the VR system. It can be expected that presence causes users to react to emotional events as if they were real [29].

4.1.9 Heuristics and Ethics of VR

Heuristics are powerful instruments that can be employed to direct a design process or support decision-making. The purpose of usability heuristics is to confirm that a system's user interface is simple to use. Researchers Mohammad and Pedersen [13] examined the use of heuristics in a variety of virtual learning environments (VLEs) that incorporate VR learning activities. It was discovered that to comply with particular VLE system components, tailored heuristics unique to each domain were required [13]. Therefore, a well-defined methodology is needed to create and validate these kinds of domain-specific heuristics. Numerous variables, such as the tools and approaches or the application settings, affect how effective the heuristic evaluation method is [13].

4.1.10 VR and UX

According to ISO, UX refers to a person's perceptions and actions as a result of using or anticipating utilizing a system, product, or service. This encompasses users' sentiments, beliefs, physical reactions, and psychological reactions **(ISO, 2010).** It also considers, among other things, the user's internal and physical state as a result of prior encounters, brand image, presentation, system performance, attitudes, skills, and personality. Evaluation, which refers to the use of various methodologies and instruments to ascertain the perception of the usage of a system or product, is an important component of UX research [35].

A VR system should have two main features: immersion and interaction. The type and quantity of motor and sensory channels used define the degree of immersion. The sensation of presence is impacted by immersion. The input provided to the user and the platform that makes it possible determine how interactive the experience is. The increased degree of ecological validity that follows from more lifelike interactions is one more advantage of VR. The ability of the immersive VR environment to imitate a real environment is referred to as ecological validity, and it indicates the ability to make general conclusions from experimental findings that are analogous to those made in real-world contexts. Researchers can examine the ecological validity of their findings by comparing the results of an experiment done in both a real-world and virtual context. The lack of a statistically significant difference in the data supports the virtual environment and allows researchers to apply their findings to other contexts [19]. The third issue that needs to be considered is usability. Since the entire UX should be pleasurable and appealing, evaluating numerous characteristics such as enjoyment, interest, and acceptance is essential to producing solutions that are positively evaluated by the users. All of these technical factors have an impact on the experience's realism as well as the user's satisfaction.

There is frequent disagreement regarding the best method for measuring UX in a virtual setting. Ten UX components evaluating presence, engagement, immersion, flow, usability, competence, emotion, experience consequence, judgment, and technology adoption are defined by Niu H. et al. in 2022 [48]. The narrative employed throughout or before using VR has a significant impact on UX. For instance, to engage subjects and improve their experience, numerous researchers conducted brief demo virtual sessions for volunteers before the actual trial.

Jang Y. and Park E. investigated how user groups (satisfied or unsatisfied) and domains (game or non-game domain) impact UX, including attachment, usability, and perceived usefulness in 2022 using two-factor theory and review comment analysis [55]. Using the substance of their remarks, users were categorized as either satisfied or unsatisfied. Two distinct linguistic approaches were employed to examine the content of the comments. The results showed that when statistical evaluations were coupled with natural language processing methods, domains affected all three UX components. Reviewers of non-gaming mobile AR applications highlighted usability, utility, and emotional difficulties more often than those of gaming programs. When it came to mobile AR applications, dissatisfied users reported more usability issues than satisfied users, while satisfied users reported more affection issues than dissatisfied users. There was no difference in usefulness between satisfied and dissatisfied users, implying that usefulness does not equate to user satisfaction in mobile AR applications. Furthermore, the data suggest that mobile AR applications have a considerable impact on the parameters that contribute to user satisfaction and dissatisfaction. Regarding the usability and utility of mobile AR game applications, more dissatisfied users than satisfied users voiced their complaints. Conversely, users in non-gaming sectors reported more challenges with usability and usefulness than dissatisfied users. Even after accounting for differences in the game domain, satisfied users of mobile AR non-gaming applications indicated noticeably more affection-related issues than dissatisfied users [55].

People with autism spectrum disorder (ASD) tend to enjoy interacting while interacting with computers because these interactions take place in a safe and reliable environment [56]. Valencia et al.'s thorough analysis of the literature from 2019 shows how systems and applications for people with ASD have a lot of potential. Virtual agents, artificial intelligence, virtual reality, and augmented reality are just a few examples of technological advancements that undoubtedly provide a pleasant and learning-oriented environment for those with ASD [56]. For people with ASD, the integration of technology innovations like virtual agents, artificial intelligence, VR, and AR unquestionably creates a comfortable environment that encourages continuous learning.

The VR system is composed of various components, which can be classified as contextual aspects that influence UX, such as users, devices, and interactions. Because there are different device pairings and interaction methods that can be employed with the VR system, the interactions that take place within it vary. VR services are in high demand, and service providers must ensure a positive user experience. Thus, both academia and industry are focusing more on the quality of the VR user's experience.

Since the concept of SGs was developed, professionals have shown interest in them. Although the original purpose of gaming was entertainment, it has subsequently evolved to encompass problem-solving and the exploration of thought-provoking scientific concepts through interactive gameplay. The concepts of playability and usability are grouped in the principles of game interaction, providing a better UX in a simpler setting. A system's design features like functionality and complexity, a user's mental state such as motivation or expectations, the media on which the interaction takes place, or the organizational context, all contribute to the wide range of experience possibilities. Today's UX is driven by the user's feelings and the overall positive experience during a product interaction. UX in games is highly influenced by game mechanics, user interface, and storytelling, but it also evolves from gameplay. The varied emotions delivered to the player, together with the game's aims and a mix of success and failure, are essential components of gaming. Challenges, emotions, and narrative can all be employed to keep players engaged throughout a game. Motivation can also be explained using rewards and successes. Games have provided a distinctive take on how UX tackles the emotional components of interaction through the traits of immersion and motivation.

Following Kosmadoudi Z. et al.'s review in 2013, the following UX components are likely crucial for future advancement and improvement of the usability issues in computer-aided design [33].

- Providing a variety of experiences

- Motivation and participation
- Emotional pull
- Immersion
- Presence
- Metaphors and cognitive frameworks

Immersive Virtual Reality (IVR) is a cutting-edge tool that is finding increasing application in numerous study domains. Researchers look into important questions about how people interact with and interpret their indoor environment in response to several environmental cues—like temperature, auditory, and visual cues—using IVEs. An IVR environment can be characterized by four main components: UX, immersion, presence, and ecological validity. The level of immersion in a VR environment reflects how well computer displays can replicate the outside world while simultaneously creating a convincing sensory illusion for the user. Immersion is also related to how frequently the user interacts with the displayed scenes and is proportional to how realistic the study is, which adds to the validity of its conclusions. The participant's freedom of movement and control within the VR environment is another important component in determining the level of immersion. Presence is a description of how a person perceives the surrounding virtual environment, and it is conceptually related to immersion. Presence can be measured subjectively, objectively, or using a combination of the two ways to get more reliable conclusions. Subjective techniques such as self-reporting questionnaires and interviews are used to learn more about the user's preferences and opinions. The duration of a task, electromyograms, and electroencephalograms are a few instances of objective techniques that track the user's behavioral and physiological reactions.

The symptoms that VR users may have during or after their immersion, such as headaches, nausea, or dizziness, are referred to as cybersickness (CS). Simulator sickness, often known as visually induced motion sickness, is a term used to describe CS. Its symptoms are similar to those of illnesses caused by driving simulators. Before using a VR system, researchers may conduct illness surveys to weed out people who suffer motion sickness or have difficulty using the HMD, which could skew the results.

With the advancement of technology, IVEs are becoming increasingly plausible. Technology adoption is being fueled by the ease with which such IVEs may be developed using inexpensive technology and basic authoring tools. IVEs can now be produced at such a reasonable cost that they can be used to support professional education. The key to extracting the best IVEs within the constraints placed on them is resource optimization. It is critical to understand which elements of objective realism contribute to an improved UX in IVEs, how many studies support the conclusions, and which areas remain unexplored. According to Goncalves G. et al., users who have a better sense of presence in a virtual world are more inclined to act naturally in that environment [10]. As a result, people can perceive an immersive virtual environment as real even when they are not aware of its presence, and vice versa. Even in the simplest virtual environments, users can experience a sensation of presence [10].

It's necessary to improve the UX components that VR aims for, such as presence, immersion, and engagement. The sense of presence is one of the most important components of the VR UX. A VR system that provides a stronger sense of presence and immersion also enhances task performance [30]. Because they may have an impact on the UX overall, the drawbacks of the VR experience need to be kept to a minimum. In contrast to the advancement of VR technology, more research on UX in VR is required, mainly from two perspectives: those connected to VR devices and technology and those related to the research methodology [30].

The term "vividness" refers to the ability to offer a sensory-rich environment, which is described by two factors: (i) sensory breadth, or the number of sensation channels stimulated, and (ii) sensory depth, or the presentation quality of each perception channel. While the quality of visual and auditory feedback has increased significantly in recent years, substantially less attention has been paid to the other perceptual channels. The range and depth of sensory experiences, according to Bai et al., are proportional to the sense of presence [45]. As a result, even if individual sensory input quality is low, simultaneous engagement of multiple perceptual channels may be quite effective in establishing a sense of presence [45].

The use of audio in VR is often underestimated, and there is currently a dearth of research specifically focused on the effect of audio on VR UX. Bosman et al.'s scoping review focused mostly on the usage of audio in HMD-based VR and how it affects UX [57]. The findings show that audio can affect a range of affective, cognitive, and motivational variables in a context-specific manner, but they also point out that common factors such as presence and emotion are not standardized [57]. The usage of VR in diverse situations opens up many new possibilities, but it also introduces new challenges. Some of these challenges can be overcome by making good use of audio. Accessibility emphasizes the capacity to provide audio-only experiences for those with visual impairments. The most frequently studied aspects of UX are presence, realism, immersion, and user satisfaction. One of the most prominent findings is the effect of audio on user satisfaction, or whether one hears pleasant or unpleasant soundscapes depending on whether they are natural or artificial. Realism is boosted by the presence of audio and the impact of audio on realism is very consistent. The addition of audio alone largely does not affect the sense of presence [57], [58].

Ambisonics is a full-sphere surround sound format that incorporates sound sources above and below the listener in addition to the horizontal plane. Ambisonic microphones are more widely employed to capture sound fields because the ambisonic signal obtained by the recording device can be easily converted to numerous formats or adjusted in a variety of post-processing. VR and AR have a big impact on the adoption of immersive audio [58]. It is often acknowledged that ambisonic can be used to enhance object audio when presenting ambient or as a powerful renderer option in the gaming industry, where VR experiences are high in demand. Most gaming engines and middleware, such as Unreal and Unity, support both object audio and ambisonics quite effectively. Because these devices are often battery-powered, the computing power of the hardware is the limiting factor in the delivery of advanced audio systems [58].

The term QoE refers to metrics that analyze the efficacy of a service from the perspective of a user. Ruan J. and Xie D. give an in-depth examination of the current status of quality-of-experience (QoE) technologies employed in VR video streaming [47]. Because VR apps are focused on offering immersive experiences, the perceived

QoE for VR end users' services is a critical measurement. With the proliferation of new VR devices and the increasing demand for converged networks to offer VR apps, providing consumers with a high-quality multimedia service experience while allowing users to perceive and analyze the quality of VR streaming services has become problematic. According to research, evaluating QoE for VR necessitates an interdisciplinary approach. The system, user, and context-specific QoE influencing factors were thoroughly described by researchers Ruan J and Xie D. Generally, QoE multidimensional influencing elements serve as the basis for the entire QoE study [47]. The continuing development and updating of VR services has not resulted in the complete unification of QoE effect variables. When assessing QoE based on platform data, the complex interplay between VR user traits and streaming system features is considered. Two common QoE assessment strategies for VR and the related assessment platforms are subjective and objective assessment methods (Ruan & Xie, 2021a). The purpose of QoE optimization is to improve QoE by implementing QoE-focused elaboration adjustments.

Vlahovic S. et al. give an overview of many influencing factors and dimensions that may affect the overall QoE, with an emphasis on presence, immersion, and discomfort [15]. User acceptability of VR applications is contingent upon several aspects, such as cybersickness, enjoyment, and usability. In addition to being more immersive, VR use differs from less intrusive platforms due to higher levels of discomfort. Despite a substantial amount of study on cybersickness, recent findings encourage researchers to concentrate on other uncomfortable symptoms, such as digital eye strain, problems with the ergonomics of headset design, interaction and fatigue, and negative impacts of VR use on cognitive performance [15].

Cattan G. et al. proposed using a Brain-Computer Interface (BCI) in VR gaming environments. Researchers used P300-based BCI because it offers the optimum balance between usability and transfer rate [22]. The BCI should only be used for insignificant activities in the game. When dealing with software constraints, it is critical to use activities that are logically included in the virtual environment. A cooperative game is also a potential alternative because it allows for multiple activities while improving social connection and entertainment. Furthermore, it appears that the use of passive BCIs is required to provide VR technology with a distinct perspective. A BCI can provide information about the user's mental state. Turn-based games such as strategy, artificial life, simulation, puzzle, and society games that require a high level of concentration and reasoning are typically better at utilizing BCI. Among these games, the best adaptations to VR games are simulation and adventure games, provided that they don't have slow gameplay and restricted movement. However, P300-based BCI technology can also be used to control a specific game action and enhance UX in other types of games, such as role-playing or sports games [22].

4.1.11 Discussions

VR systems are immersive, which makes it possible to measure UX by testing levels of realism, presence, and reality. Overall, the novel VR technology gives a favorable UX; however, several concerns must be addressed in terms of UX factors usability, and competence, which results in technical challenges and cybersickness. Across a range of industries, VR and haptics are more prevalent than AR. The most important UX elements that will contribute to the VR system's enhancement are presence, immersion, usability, emotion, and engagement. Therefore, enhancing these UX components will result in an improved UX overall. While many people have positive opinions about most UX features since VR technologies are immersive, to offer the best UX possible, a VR system's drawbacks should be kept to a minimum. To improve UX and lead to a more successful system overall, VR systems need to be easy to use.
While VR systems provide a great level of immersion, they may also cause a high level of discomfort. The leading negative component in UX with VR systems is cybersickness. Cybersickness can be reduced by providing higher-quality animations and allowing for more natural movements, or it can be avoided by the user taking frequent rests. Currently, the most popular approach to dealing with cybersickness is through surveys; nevertheless, simulator design needs to be enhanced further to completely remove this problem. Because all UX elements are related in some manner, addressing all equally and striving to improve all would be the best practice.

We looked at several systems that employed immersive technology for various objectives. According to the review, VR systems received the best feedback from users when compared to other systems, rated in terms of UX factors. Immersion, presence, usability, competence, emotion, judgment, experience consequence, engagement, and technology adoption are among the major UX characteristics in VR systems that are most frequently addressed. Technical and non-technical research is still needed to strengthen these elements, though.

Users sometimes also report poor VR experiences, which has an impact on overall UX. Users report poor experiences for a variety of reasons, including cybersickness, usability issues, and technological challenges. Thus, to deliver better experiences for users, it is critical to address technological concerns that may arise as a result of a range of factors, such as dizziness from VR headsets or choppy animations.

4.2 Results of the Questionnaire on the UX factors of immersive technologies from the eyes of dental students (RQ2)

To assess the underlying structure of the 14 items in the questionnaire (see Table 3.3), a Principal Axis Factoring analysis was conducted. Promax rotation with Kaiser normalization was used in the analysis. Oblique rotation was found to be the most appropriate method for this analysis, since there are various correlations among multiple items and the first two factors, as seen in Table 4.6. The type of oblique rotation used was Promax rotation, with the Kappa value of 4. Factors were extracted based on eigenvalue, following Kaiser criteria.

As seen in Table 4.1, the sampling adequacy for the analysis was 0.897; which is deemed to be “meritorious”, only .003 less than being marvelous [59]. Bartlett’s test of sphericity shows significance since it produces a value less than 0.001.

Table 4.1 KMO and Bartlett’s Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.897
Bartlett's Test of Sphericity	Approx. Chi-Square	8173.667
	df	91
	Sig.	.000

The determinant of the correlation matrix was .00001809, which is larger than the necessary limit of .00001, proving that there is no multicollinearity among the 14 items.

All KMO values for each item were larger than 0.656, which is above the required limit of 0.50 [59]. The KMO values for each item are shown in bold in Table 4.2.

Table 4.2 Anti-image Correlation Matrices

	Item 7	Item 11	Item3	Item5	Item 12	Item 13	Item6	Item2	Item4	Item8	Item 10	Item 14	Item9	Item1
Item7	**.920**[a]	-.088	-.050	-.163	.086	-.007	-.463	-.065	.058	-.113	-.056	.122	-.222	.004
Item11	-.088	**.944**[a]	.090	-.006	-.076	-.014	-.074	-.031	-.081	.055	-.354	-.092	-.219	-.014
Item3	-.050	.090	**.931**[a]	-.199	.004	-.008	-.090	-.136	-.465	.041	.007	-.025	-.123	.040
Item5	-.163	-.006	-.199	**.914**[a]	.094	-.032	-.008	-.009	-.572	-.035	-.049	.067	-.072	-.034
Item12	.086	-.076	.004	.094	**.656**[a]	-.574	-.044	-.116	.009	-.300	.000	-.097	-.005	.028
Item13	-.007	-.014	-.008	-.032	-.574	**.668**[a]	.082	.083	.010	-.234	.029	-.080	-.049	-.027
Item6	-.463	-.074	-.090	-.008	-.044	.082	**.916**[a]	-.028	.015	-.088	-.063	-.223	.067	-.035
Item2	-.065	-.031	-.136	-.009	-.116	.083	-.028	**.882**[a]	.003	-.050	-.048	-.112	.144	-.338
Item4	.058	-.081	-.465	-.572	.009	.010	.015	.003	**.885**[a]	-.041	-.037	-.061	.021	-.070
Item8	-.113	.055	.041	-.035	-.300	-.234	-.088	-.050	-.041	**.773**[a]	.078	.021	.017	.088
Item10	-.056	-.354	.007	-.049	.000	.029	-.063	-.048	-.037	.078	**.916**[a]	-.149	-.459	.064
Item14	.122	-.092	-.025	.067	-.097	-.080	-.223	-.112	-.061	.021	-.149	**.914**[a]	.026	.024
Item9	-.222	-.219	-.123	-.072	-.005	-.049	.067	.144	.021	.017	-.459	.026	**.917**[a]	-.141
Item1	.004	-.014	.040	-.034	.028	-.027	-.035	-.338	-.070	.088	.064	.024	-.141	**.905**[a]

a. Measures of Sampling Adequacy (MSA)

Both initial and extraction communalities for each of the 14 items were larger than .245, which is larger than the adequate amount (see Table 4.3). The average of the communalities after extraction is .634 and the sample size is 755, which exceeds 250. Therefore, Kaiser’s criterion for extracting factors, which states that factors with eigenvalues larger than 1 should be retained, is suitable for this dataset and analysis.

Table 4.3 Communalities

	Initial	Extraction
Item7	.733	.694
Item11	.701	.754
Item3	.819	.843
Item5	.862	.871
Item12	.581	.782
Item13	.541	.640

Item6	.629	.567
Item2	.335	.254
Item4	.875	.882
Item8	.383	.420
Item10	.792	.854
Item14	.321	.281
Item9	.790	.794
Item1	.312	.245

Three factors had eigenvalues over the Kaiser's criterion of 1 [60] and accounted for 63.433% of the total variance, as seen in Table 4.4. The scree plot, shown in Figure 4.2 also supports retaining three factors from the results of the principal axis factoring analysis.

Table 4.4 Total Variance Explained

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	6.692	47.801	47.801	6.423	45.875	45.875	5.760
2	2.284	16.317	64.118	1.914	13.672	59.547	5.687
3	1.002	7.155	71.273	.544	3.886	63.433	1.910
4	.822	5.868	77.141				
5	.658	4.697	81.839				
6	.591	4.220	86.059				
7	.490	3.497	89.556				
8	.403	2.882	92.438				
9	.281	2.006	94.444				
10	.229	1.634	96.078				
11	.196	1.399	97.477				
12	.145	1.033	98.510				
13	.128	.917	99.427				
14	.080	.573	100.000				

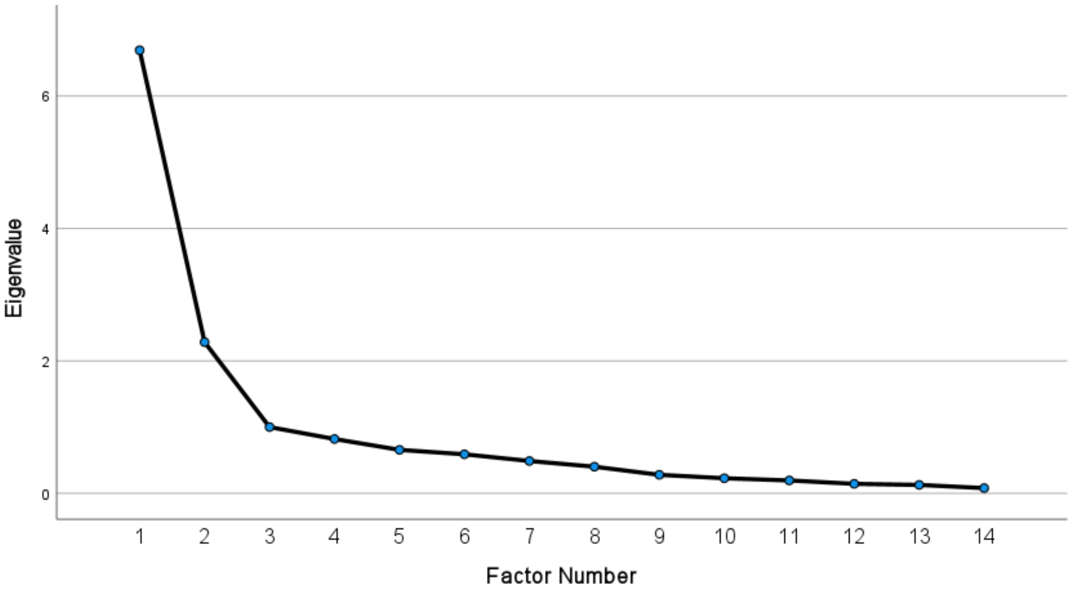

Figure 4.2 Scree Plot

Table 4.5 demonstrates the obtained factor loadings on each item after rotation. Factor loadings above 0.3 are shown in bold.

Table 4.5 Principal Axis Factoring Results

	Factor		
	1	2	3
Item4	**.926**	.017	.000
Item3	**.898**	.026	-.001
Item5	**.868**	.081	-.032
Item2	**.464**	.040	.119
Item1	**.414**	.098	-.031
Item10	.019	**.910**	-.077
Item11	-.004	**.872**	-.002
Item9	.152	**.770**	-.054
Item7	**.362**	**.524**	-.016
Item6	**.310**	**.487**	.061
Item14	.075	**.417**	.217
Item12	-.095	.058	**.874**
Item13	-.006	.034	**.798**
Item8	.162	-.082	**.651**

Table 4.6 Structure Matrix

	Factor		
	1	2	3
Item4	**.939**	**.721**	-.053
Item5	**.932**	**.739**	-.079

Item3	**.918**	**.709**	-.052
Item1	**.490**	**.411**	-.050
Item2	**.488**	**.399**	.094
Item10	**.715**	**.921**	-.034
Item9	**.740**	**.883**	-.025
Item11	**.659**	**.868**	.040
Item7	**.761**	**.798**	-.011
Item6	**.677**	**.726**	.067
Item14	**.379**	**.484**	.233
Item12	-.102	.028	**.882**
Item13	-.026	.068	**.800**
Item8	.062	.072	**.638**

4.2.1 Reliability Analysis

Reliability analysis is conducted on each of the three factors to measure the soundness and consistency of each factor. For each factor individually, Cronbach's alpha was larger than .812, proving that all factors are highly reliable [61]. Cronbach's alpha for all 14 items was calculated as .883.

As seen from Table 4.5, two factors fall under multiple factors: Item 6 and Item 7. For these factors, the difference between the two correlations with each factor is calculated. Item 7 loads highly on Factor 2 and the difference between the two loadings is .162, which is less than .200. Thus, the loading on Factor 2 is considered rather than the loading on Factor 1. Similarly, Item 6 also correlates highly with Factor 2, with a difference of less than .200 from Factor 1. Hence, Item 6 is also categorized under Factor 2.

4.2.2 Factor 1: Knowledge and Outcome (Experience Consequence, Judgment, Competence)

The items in Table 4.7 all clusters under the first factor. Cronbach's alpha was calculated as .860 for this factor, which demonstrates that it is a highly reliable factor [61]. Item 1 and Item 2 are related to the student's judgment of AR systems and competence in using AR systems. Item 1 and Item 2 both have loadings of approximately .45, as seen in Table 4.5. Item 3 and Item 4 have the highest loading on this factor. Item 4 is about the student's perception of the effect of AR on improving the courses, which has a loading of .926 on Factor 1. Item 3 is related to the positive effect of AR on understanding, which has a loading of .898 on Factor 1. Item 5, which is related to the embodiment in AR, also loads highly on the first factor with a value of .868.

These items represent judgment, competence, and experience consequence factors that were extracted from RQ1. Item 3, Item 4, and Item 5 are about the outcomes of using AR systems, which are related to the factor of experience consequence. Item 1 is a question about the student's knowledge of AR technologies, which is related to the judgment factor, and it has a loading of .414 on Factor 1. Item 2 asks students to rate their capabilities in using AR in learning practices, which is related to the UX factor of competence, and it has a loading of .464 on Factor 1. The results of the principal axis factoring analysis show that judgment, competence, and experience consequence factors are correlated.

Table 4.7 Items Explained by Factor 1

Item1	I have knowledge regarding Augmented Reality (AR)
Item2	I am capable of using AR in learning
Item3	I can understand better when learning using AR
Item4	Using AR in learning improves the courses
Item5	I can embody better while learning using AR

The items clustered under knowledge and outcome are further analyzed according to gender, grade level, and the attended university. Table 4.8 demonstrates the mean value of the response that the students gave to each item, based on gender. For Item 4 and Item 5, the total mean value was around 3.8 where the difference between female students and male students was approximately .1, with a higher value for female students. For Item 3, Item 4, and Item 5, which represent the experience consequence factor, female students scored higher than male students. Item 3 had a mean value of 3.7, with a very small difference of .05 between male and female students. For Item 1 and Item 2, male students responded with a higher value than female students, which demonstrates that male students have more knowledge than female students about AR and they believe that they are capable of using AR in learning more than female students do. The average of Item 2 was 3.02, where there was a .2 difference between the two genders, whereas the average value of Item 1 was 3.2, with a difference of .1 between male and female students.

Table 4.8 Factor 1 Gender Dispersion

Gender		Item1	Item2	Item3	Item4	Item5
Male	Mean	3.2802	3.1280	3.7301	3.7785	3.8062
	N	289	289	289	289	289
Female	Mean	3.1630	2.9549	3.7875	3.8519	3.9184
	N	466	466	466	466	466
Total	Mean	3.2079	3.0211	3.7655	3.8238	3.8754
	N	755	755	755	755	755

Table 4.9 demonstrates the mean values of the items clustered under Factor 1, categorized according to the different universities that respondents attend. Ankara University students responded higher than the mean value of all items and the highest among the three universities for all items. For all items except Item 2, the smallest mean value was produced in Eskisehir Osmangazi University. Item 2 is related to the student's capability of using AR, which is related to the competence factor. The lowest response to Item 2 was from the students of Ankara Yildirim Beyazit University, which could be attributed to the lack of previous experience with AR technologies.

Table 4.9 Factor 1 University

University		Item1	Item2	Item3	Item4	Item5
Ankara Uni.	Mean	3.3228	3.1942	3.9257	3.9685	4.0085
	N	350	350	350	350	350
Ankara Yıldırım Beyazıt Uni.	Mean	3.1818	2.8295	3.8693	3.9431	3.9943
	N	176	176	176	176	176
Eskişehir Osmangazi Uni.	Mean	3.0524	2.9039	3.4410	3.5109	3.5807
	N	229	229	229	229	229

Total	Mean	3.2079	3.0211	3.7655	3.8238	3.8754
	N	756	756	756	756	756

As seen in Table 4.10, students in the third grade produced the best responses to Item 1 and Item 5, whereas they gave the lowest scores for Item 2. Second and third-grade students' responses were almost equal and highest for Item 3 and Item 4. This shows that even though third-grade students have knowledge about AR, their scores on their capability of using AR in learning applications are comparatively lower. The reason for such a low score in Item 2 may be due to the student's lack of knowledge and competence according to the context of the application. Even though students rate knowledge about AR higher, they rate their competence in using AR in learning applications lower. Thus, the context of the AR application affects student's rating of their competence level.

Table 4.10 Factor 1 Grade Dispersion

Grade		Item1	Item2	Item3	Item4	Item5
1	Mean	3.1409	3.0837	3.6563	3.6563	3.6960
	N	227	227	227	227	227
2	Mean	3.1960	3.1617	3.8872	3.9313	3.9999
	N	204	204	204	204	204
3	Mean	3.3538	2.7769	3.8769	3.9307	4.0846
	N	130	130	130	130	130
4	Mean	3.1917	2.9533	3.6839	3.8290	3.8082
	N	193	193	193	193	193
Total	Mean	3.2079	3.0211	3.7655	3.8238	3.8754
	N	755	755	755	755	755

4.2.3 Factor 2: Emotive Submersion (Emotion, Engagement, Immersion, Presence)

Six items cluster under this factor where Cronbach's alpha is .899, which demonstrates that it's a highly reliable factor [61]. The items encompass various factors defined from the literature review: engagement, emotion, immersion, and presence.

Item 6 and Item 7 correlate with Factor 1 and Factor 2, as seen in Table 4.2. These two items explain the outcome of using AR tools in dentistry education. These items represent the engagement factor, which explains the interaction of the student with AR tools. These two items also correlate to Factor 1, as seen in Table 4.5. Thus, it can be concluded that engagement with AR tools also affects the outcome of AR activities, namely the experience consequence factor.

Item 9 and Item 14, given in Table 4.11, are related to the realism and replacement face-to-face education, which concern presence and immersion factors. In order to replace face-to-face education, AR activities must allow students to be submersed within the AR environment, providing a sense of presence within the system. Item 9 is concerned with the sense of realism, which is provided through immersion and presence.

Item 10 and Item 11 are related to the student's feelings while using AR activities, which is explained by the emotion factor. Item 10 is about the student's eagerness to use AR activities, and Item 11 is related to the enjoyment of using AR activities outside a classroom setting.

Therefore, the results of the Principal Axis Factoring analysis show that the UX factors emotion, immersion, presence, and engagement can be considered under the same category and grouped under the same factor. Thus, Factor 2 is named emotive submersion, since it encompasses emotional factors and includes presence and immersion as well.

Table 4.11 Items Explained by Factor 2

Item6	AR can help students to better improve their hand skills
Item7	Learning using AR helps me for using the special devices better
Item9	Three-dimensional objects provide a sense of realism in AR activities.
Item10	I am more eager to come to class when AR activities are used.
Item11	I enjoy studying at home using AR activities.
Item14	AR replaces face to face education.

The mean values of the items that are clustered under Factor 2 are categorized according to gender in Table 4.12. Female students gave higher scores on all items except Item 14.

Table 4.12 Factor 2 Gender Dispersion

Gender		Item6	Item7	Item9	Item10	Item11	Item14
Male	Mean	3.4602	3.7128	3.8512	3.6782	3.6193	2.9031
	N	289	289	289	289	289	289
Female	Mean	3.6094	3.9227	3.9549	3.7982	3.7768	2.7446
	N	466	466	466	466	466	466
Total	Mean	3.5523	3.8423	3.9152	3.7523	3.7165	2.8052
	N	756	756	756	756	756	756

The mean values of the items clustered under Factor 2 are categorized according to universities in Table 4.13. Students of Ankara University scored highest for all items in Factor 2. The lowest score for all items was produced by the students of Eskisehir Osmangazi University, except Item 14.

Table 4.13 Factor 2 University Dispersion

University		Item6	Item7	Item9	Item10	Item11	Item14
Ankara Uni.	Mean	3.7485	3.9885	4.0200	3.8600	3.8485	2.9857
	N	350	350	350	350	350	350
Ankara Yıldırım	Mean	3.4034	3.8465	3.9999	3.7613	3.7500	2.5511

Beyazıt Uni.	N	176	176	176	176	176	176
Eskişehir Osmangazi Uni.	Mean	3.3668	3.6157	3.6899	3.5807	3.4890	2.7248
	N	229	229	229	229	229	229
Total	Mean	3.5523	3.8423	3.9152	3.7523	3.7165	2.8052
	N	756	756	756	756	756	756

Table 4.14 demonstrates the mean values of items in Factor 2, categorized according to their grade levels. Third-grade students scored the highest responses to Item 7 and Item 9, whereas three other items (Item 2, Item 10, Item 14) received the highest score from second-grade students. Fourth-grade students gave the highest response to Item 11.

Table 4.14 Factor 2 Grade Dispersion

Grade		Item6	Item7	Item9	Item10	Item11	Item14
1	Mean	3.4977	3.7092	3.7444	3.5814	3.5330	2.8546
	N	227	227	227	227	227	227
2	Mean	3.7303	3.9068	3.9607	3.8725	3.7549	2.8823
	N	204	204	204	204	204	204
3	Mean	3.4153	3.9307	4.0923	3.8076	3.7769	2.5769
	N	130	130	130	130	130	130
4	Mean	3.5129	3.8652	3.9430	3.7823	3.8445	2.8082
	N	193	193	193	193	193	193
Total	Mean	3.5523	3.8423	3.9152	3.7523	3.7165	2.8052
	N	755	755	755	755	755	755

4.2.4 Factor 3: Ease of Use (Usability, Technology Adoption)

The third factor has loadings from three items: Item 8, Item 12, and Item 13. Cronbach's alpha was calculated as .812, demonstrating a reliable factor [61].

Item 8 is related to the complexity of AR, which in turn causes discomfort to students. Item 12 asks the students if the confusion caused by AR complicates the learning process. Item 13 is related to the difficulty of using AR activities. These items are related to the system's complexity, usability, and the confusion due to AR. The common characteristic among these items is related to the functionality of the system. The difficulty of using AR systems, the confusion that students may experience which leads to hardships in learning, and the complex nature of AR technology compared to traditional methods of learning are grouped under Factor 3. Usability and technology adoption factors are grouped under this factor.

Table 4.15 Items Explained by Factor 3

Item8	The complexity of the AR technology makes me uncomfortable
Item12	AR activities make it more difficult for me to learn because AR confuses me.
Item13	It is difficult to use AR activities.

Table 4.16 shows the mean values of the student responses to items clustered under Factor 3, categorized according to the gender of the students. For every item, male students had lower responses than female students. Thus, it was found that male students were more comfortable with AR than female students. Additionally, male students found AR to be less confusing than female students. Even though the variation between genders for Item 13, which asks the students if they find AR activities difficult, is very little (.0577), male students find the usage of AR less difficult than female students.

Table 4.16 Factor 3 Gender Dispersion

Gender		Item8	Item12	Item13
Male	Mean	2.7058	2.4359	2.6332
	N	289	289	289
Female	Mean	2.9549	2.5429	2.6909
	N	466	466	466

Total	Mean	2.8596	2.5019	2.6688
	N	755	755	755

Table 4.17 demonstrates the categorization of the responses from the students to the items clustered under factor 3. Students from Ankara Yildirim Beyazit University gave the lowest responses to these items, which means that they find AR to be less confusing, and less difficult, and they are not as uncomfortable with the complexity of AR as the students from other universities. Students from the other two universities responded in higher numbers to these questions, meaning that they are more uncomfortable with the complexity of AR, and they find AR technologies to be more confusing and difficult than the average value of all students. Students from Ankara University find AR to be more difficult and they are more uncomfortable with the complexity of AR than the students of Eskisehir Osmangazi University. There's only a slight difference of .006 between these two universities in terms of the confusion due to AR.

Table 4.17 Factor 3 University Dispersion

Universities		Item8	Item12	Item13
Ankara Uni.	Mean	2.9742	2.5742	2.7114
	N	350	350	350
Ankara Yıldırım Beyazıt Uni.	Mean	2.6306	2.2556	2.5397
	N	176	176	176
Eskişehir Osmangazi Uni.	Mean	2.8602	2.5807	2.7030
	N	229	229	229
Total	Mean	2.8596	2.5019	2.6688
	N	756	756	756

Table 4.18 demonstrates the mean value of the student responses to items in the questionnaire that are represented by the third factor, organized according to the grade that the respondent student was currently in. Item 8, which asks the students whether the complexity of AR makes students uncomfortable has a total mean value of 2.85. 193 students in the fourth grade, 227 students in the first grade, and 204 students in the second grade responded approximately the same as the total average value. 130

third-grade students responded with an average value of 2.5 to this item, which is slightly lower than the overall average.

A similar pattern is observed with Item 12, where students in the first, second, and fourth grades responded approximately the same as the total mean value, whereas third-grade students' responses had a lower mean value than the overall average. Therefore, it can be deduced that third-grade students are less confused by AR, according to Item 12, and they are also not as uncomfortable with the complexity of AR as other students.

Another pattern that can be deduced from Table 4.18 is the mean value decreasing as the student's grade level goes from the first grade to the third grade. First-grade students are more confused by AR, more uncomfortable with the complexity of AR and they find AR to be more difficult than second and third-grade students. Fourth-grade students, however, responded with a higher value to these items, where the average value for all three items was higher than third-grade students, approximately the same as second-graders. The reason for this may be that the fourth-grade students, being almost at the end of their education, have never been familiarized with AR technologies. However, the definitive reason cannot be deduced from only this analysis.

Table 4.18 Factor 3 Grade Dispersion

Grade		Item8	Item12	Item13
1	Mean	2.9559	2.6696	2.7665
	N	227	227	227
2	Mean	2.9215	2.5049	2.6274
	N	204	204	204
3	Mean	2.5461	2.0692	2.6000
	N	130	130	130
4	Mean	2.8808	2.5803	2.6321
	N	193	193	193
Total	Mean	2.8596	2.5019	2.6688
	N	754	754	754

4.2.5 The correlation between three factors

After answering the second research question and discovering three factors, the next step was to analyze the associations between the three factors to determine the correlations among them. For this purpose, the bivariate correlation analysis was conducted, and Pearson correlation coefficients were calculated.

A Pearson correlation coefficient was performed to evaluate the relationship between the three factors that were obtained from principal axis factoring. The result is shown in Table 4.19. There was a significant, positive, and strong relationship between Factor 1 and Factor 2, where Pearson's Correlation value is at a highly strong number of .816, and $p < .001$, as seen in Table 4.19.

The correlation between Factor 1 and Factor 3 was not significant, r([753]) = -.053, p = .147. Similarly, the relationship between Factor 2 and Factor 3 was also weak, as seen in Table 4.19. The Pearson Correlation between Factor 2 and Factor 3 is at a very weak level of .022, and the significance is very high at a value of .541, thus it can be concluded that these factors are not correlated.

Table 4.19 Bivariate Correlations

		Factor 1	Factor 2	Factor 3
Factor 1	Pearson Correlation	1	**.816****	**-.053**
	Sig. (2-tailed)		.000	.147
	N	755	755	755
Factor 2	Pearson Correlation	.816**	1	**.022**
	Sig. (2-tailed)	.000		.541
	N	755	755	755
Factor 3	Pearson Correlation	-.053	.022	1
	Sig. (2-tailed)	.147	.541	
	N	755	755	755

**. Correlation is significant at the 0.01 level (2-tailed).

Factor 1 represents knowledge of AR systems and the outcomes of using AR systems, while Factor 2 represents the submersion and immersion provided through emotional responses. These factors are highly correlated with each other, which means that they have a closely tied relationship. The literature review is also supportive of this outcome, where Factor 3 representing usability and technology adoption is mostly independent of other factors while the other factors correlate with each other.

CHAPTER 5

DISCUSSION

Firstly, a systematic review study was conducted to answer RQ1, which is about identifying UX factors in immersive technologies. According to the findings, the most investigated UX factors in immersive systems are engagement, usability, immersion, technology adoption, emotion, presence, experience consequence, judgment, and competence. Identifying these nine factors provides a foundation for answering the second research question, as we can then research how they are related to one another.

Performing principal axis factoring on the questionnaire administered to dentistry students answers RQ2 about the UX factors most relevant to dentistry education while also clustering related items under each of the three factors. There is a slight difference between the results of the literature review and the results of the principal axis factoring analysis on the questionnaire, related to the number of extracted factors. The factors extracted from the literature can be represented using three factors since some of the factors from the literature review are too closely related for the user to distinguish between them. For instance, presence and immersion are defined as two very closely related factors in the literature. According to the results of the principal axis factoring analysis, immersion and presence are represented by the items that cluster under the same factor. Thus, the findings of the principal axis factoring analysis support the results of the literature review.

Factor 1 is knowledge and outcome, and it comprises three factors identified from the literature review: experience consequence, judgment, and competence. This result shows that judgment, competence, and experience consequence factors are interrelated, following the common underlying theme of encounters with immersive systems and the user’s understanding of the system. The factor loadings (see Table 4.5) show that experience consequence is the main subfactor of Factor 1 since these items have higher factor loadings. Therefore, it can be concluded that variations in experience consequences produce variations in competence and judgment.

Factor 2 is emotive submersion, and it comprises four factors identified in RQ1: emotion, engagement, immersion, and presence. Obtained factor loadings (see Table 4.5) show that immersion, presence, and emotion factors are dominant since they produced higher factor loadings. This finding is in alignment with the findings of RQ1, which showed that immersion is closely tied to presence, and presence is closely tied to emotion. More immersive systems allow users to feel more present within the system, and as users feel more and more present, they develop more emotional responses as well. Additionally, the results of the principal axis factoring show that engagement is closely tied to these three factors as well. The user's engagement with the system and collaborators seems to change in line with immersion, presence, and emotion. It is logical that the user engages more with a system that provides immersion, makes the user feel present, and triggers emotional responses since engagement covers the user's interactions with other users within the system, which is boosted through better immersion and presence. As the system's offered immersion, presence, and emotion factors are improved, the user's engagement within the system becomes more natural and seamless. Furthermore, Table 4.5 shows that items related to engagement also have high loadings on Factor 1. Thus, it can be concluded that engagement is also aligned with knowledge and outcome since engagement also covers the user's interaction with technical equipment. The observed results of that interaction are improved as engagement improves, and vice versa.

Factor 3 is ease of use, and it comprises two factors that are identified in RQ1: usability and technology adoption. Both of these subfactors have similar loadings on Factor 3. It can be concluded that improving usability will produce an enhancement in technology adoption. This finding is supported by the literature review, which showed that usability issues, especially regarding cybersickness, historically limited acceptance and adoption of immersive technologies. Thus, developing immersive systems that offer better usability will improve the technology adoption of these systems. Conversely, more problems with usability will result in lower adoption of immersive technologies.

The identification of these factors has great implications for educational immersive systems. For example, developers may consider improving presence, which would also improve other factors grouped under Factor 2 such as emotion, engagement, and immersion. Another example may be given for Factor 3, which covers usability and technology adoption. According to our results, enhancing usability will also enhance technology adoption.

The answer to RQ2.1 shows that Factor 1 and Factor 2 are strongly positively correlated, while Factor 3 has no correlations to the other two factors. This finding does not suggest that there is a causational relationship between Factor 1 and Factor 2, only that there is evidence of a statistical relationship between them. Such a strong positive correlation offers predictability, changes to one of these factors can be used to predict changes in the other factor with some reliability. Since the correlation is positive, Factor 1 and Factor 2 will change in the same direction, meaning that if one of them increases, the other one also tends to increase. Therefore, it can be concluded that as knowledge and outcome of AR systems for dentistry education are improved, emotive submersion will improve in an approximately linear incrementation, and vice versa. For example, if immersion or presence levels increase, users' competence in using immersive systems and judgments of using them will also improve. Additionally, users will be more engaged and immersed within the virtual environment if their judgments of immersive systems are positive. However, understanding the underlying reasons for this correlation requires further research. The weak negative correlation between Factor 1 and Factor 3 suggests that changes in one factor are not reasonably associated with changes in the other. Similarly, there exists a weak positive correlation between Factor 2 and Factor 3, suggesting that changes to one factor may not be reliable in predicting changes in the other. Therefore, we cannot safely predict the relationship between Factor 3 and Factor 1 or Factor 3 and Factor 2. However, we can make predictions based on the strong relationship between emotional submersion and knowledge and outcome, where a change in one of them is reflected on to the other.

Dentistry education is a composite area combining clinical skills with scientific knowledge and using specialized tools that are unique to dentistry. Since this study only surveyed dentistry students, our results may vary for students studying different subjects. For example, Item 6 (AR can help students to better improve their hand skills) would not produce a similar result if other domains such as engineering, since the profession does not require improved hand skills. Students of software or computer engineering may give higher responses to items that are related to Factor 1 since their domain knowledge is presumably more extensive than dentistry students in immersive technologies. Similarly, for Factor 3, these students may be more knowledgeable about the use of AR technology. The outcome of principal axis factoring may be completely different if that is the case. Furthermore, results may vary because of the unique perspective that dentistry students have. Other fields require excellent hand skills such as surgical education, but their expectations may be a lot different than dentistry students since they are completely different fields. However, the expectations of dentistry students of an immersive educational system can be identified. It is crucial to improve upon the third factor, which students rate the lowest. Students have high expectations from the immersion, presence, emotion and experience consequence factors, while their competence and judgments of immersive systems are low. Competence and judgment factors can be improved upon by the developers of the systems and the instructors by providing demo sessions to students or giving an introductory lesson on how to use the tools of immersive technologies. Students' high expectations of immersion and experience consequence are reflective of the nature of immersive technologies that aim to provide educational experiences. Presence and emotion are both psychological responses that the students rated highly, however this outcome may differ based on the students that answer the questionnaire.

Future research should explore the difference between the outcome of the provided analysis on dentistry students and students of other professions to enhance our understanding of the usage of immersive technologies in education. Investigating this discrepancy can improve future implementations and provide better educational prospects to students. While our sample size was sufficient for detecting 3 UX factors, generalizing these findings to educational AR systems should be done cautiously. Future work may focus on developing a prototype of an AR system for dentistry education while considering these results, to offer a satisfactory user experience and enhance dentistry education.

CHAPTER 6

CONCLUSION

Immersive technologies provide incredible prospects for various domains, one of which is education. Such prospects need to be developed meticulously if they are to have a successful influence on education. The successful implementation of immersive educational programs calls for seasoned developers who will direct the development process while considering UX because UX has a profound effect on the acceptance and adaptation of immersive technologies. Thus, the first goal of the study was to define UX terms that play a crucial role in the user's encounters with immersive technologies. A systematic review was conducted, which revealed 9 underlying factors in UX with immersive technologies: engagement, usability, immersion, technology adoption, emotion, presence, experience consequence, judgment, and competence. The next objective was to evaluate the validity and importance of each factor. For this purpose, a questionnaire was conducted on dentistry students' regarding their opinions and experience with AR systems. Principal Axis Factoring was conducted on the questionnaire results, which revealed three underlying factors: emotive submersion, knowledge and outcome, and ease of use. The questionnaire items that cluster under emotive submersion were questions related to experience consequence, judgment, and competence factors defined in the literature. Immersion, presence, emotion, and engagement-related items clustered under emotive submersion, while ease of use comprised items related to technology adoption and usability as defined in the literature. Lastly, the Pearson correlation coefficient was performed to evaluate the relationship between the three factors that were obtained from principal axis factoring analysis, which revealed a strong correlation between the two factors emotive submersion and knowledge and outcome. These results provide a valuable guideline to developers looking to enhance UX in educational immersive systems.

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