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# Virtual Reality for Education From a User Experience Perspective: A Bibliometric Analysis

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## ABSTRACT

**Purpose:** Education is shifting from traditional multimedia to immersive Virtual reality (VR) environments. Despite numerous reviews on VR in education, few focus on user experience. Existing reviews mainly use qualitative methods, limiting objective analysis due to small sample sizes. Quantitative analysis can address this by covering more studies. This study explores VR in education from a user experience perspective (VR-E-UEP) using bibliometric methods.
**Methods:** We used the Web of Science (WOS) core collection database and employed VOSviewer and CiteSpace for keyword, evolutionary, and co-citation analyses.
**Results:** VR-E-UEP research hotspots are divided into four clusters: 1) specific VR applications in education, 2) advantages and key concepts of VR in education, 3) data analysis techniques, and 4) key factors affecting user experience. Evolution analysis shows early research focused on VR technology and applications, mid-term research emphasized human factors, and recent studies highlight machine learning. Frequently co-cited research falls into five categories: 1) Definitions and Technologies of Virtual Reality and Augmented Reality, 2) Advantages and Effectiveness Evaluation of Virtual Reality Technology in Education, 3) Applications of Immersive Virtual Reality in Learning and Training, 4) User Experience Measurement, 5) Statistical Analysis Methods and Theoretical Models. Finally, future research directions are discussed.

**Keywords:** Virtual reality, Education, User experience, Bibliometric analysis

## INTRODUCTION

Currently, education is shifting from traditional multimedia to more immersive, interactive, intuitive, and engaging Virtual reality (VR) learning environments (Marougkas et al., 2024). With a wide array of VR software and hardware, users are active participants, enabling exploration-based learning. VR technology has great potential, attracting much research interest in education (Radianti et al., 2020). Scholars have conducted numerous systematic literature reviews. Pellas, Mystakidis and Kazanidis (2021) used systematic mapping to identify VR application design elements in higher education, finding gaps such as neglect of learning theories in development and evaluation. Checa and Bustillo (2020) reviewed 135 recommendations on serious games in immersive VR, analyzing various aspects and setting factual standards. Hamilton et al. (2021) examined I-VR as an educational method, finding its advantages. Kavanagh et al. (2017) analyzed academic literature on VR education applications, motivations, and reporting issues, showing most researchers use VR to boost students' intrinsic motivation and introduced recent VR technologies. These studies review VR in education, updating knowledge, but lack a user - experience perspective. Existing reviews mainly use qualitative analysis for periodic summaries, making it hard to objectively analyze trends. Quantitative analysis, however, can analyze a large number of literatures, compensating for qualitative shortcomings. This study aims to provide insights into the application of VR in education from the user experience perspective (VR-E-UEP) using bibliometric methods.

## MATERIALS AND METHODS

### Data Collection

The sample data sources are from the Web of Science (WOS) database, utilizing the three major citation indexes commonly used: SSCI, SCI-Expanded, and A&HCI. The retrieval period is set to cover all years (i.e., from 1900 to July 2024). The retrieval date is July 2024. The retrieval strategy is as follows:

TS=(((educat) or (learn) or (teach) or (class) or (student)) and (Virtual Reality) and ((User Experience) or (Usability)))

To ensure no interdisciplinary literature was overlooked, the sample data was left unpruned. As a result, a total of 1,459 articles on VR-E-UEP were obtained.

### Bibliometric Analysis

This study employs bibliometric methods, which involve mathematics and statistics, for the quantitative analysis of publications (Pritchard, 1969). Bibliometrics uncovers domain knowledge from bibliographic data, revealing knowledge relations (Chen, 2006). Many tools exist for bibliometric analysis; this study selects VOSviewer for its ability to handle large datasets effectively (Van Eck and Waltman, 2010) and CiteSpace (developed by Chen's team at Drexel University) for its capacity to visualize topic trends and its widespread use in the field (Chen, 2006). The study examines VR-E-UEP in terms of its basic characteristics, keywords, hotspots, and co-citation patterns.

## RESULTS

### Keyword Analysis

Co-occurrence analysis is key in bibliometrics. Literature keywords summarize research. In 1,459 articles, 5,399 keywords were found. After VOSviewer filtering/merging (the frequency is set to 10), 153 keywords formed 4 clusters: 1) Specific applications of virtual reality technology in education, as well as psychological and behavioral factors commonly measured, including attention, cognitive load, and behavior. 2) Key concepts in virtual reality education, such as flow, gaming, and immersive learning.

3) Quantifying, Predicting, and Classifying Indicators Using Machine Learning and Meta-Analysis. 4) Key Factors in Assessing User Experience Quality in VR Educational Applications: Reliability, Safety, and Self-Efficacy (Figure 1).

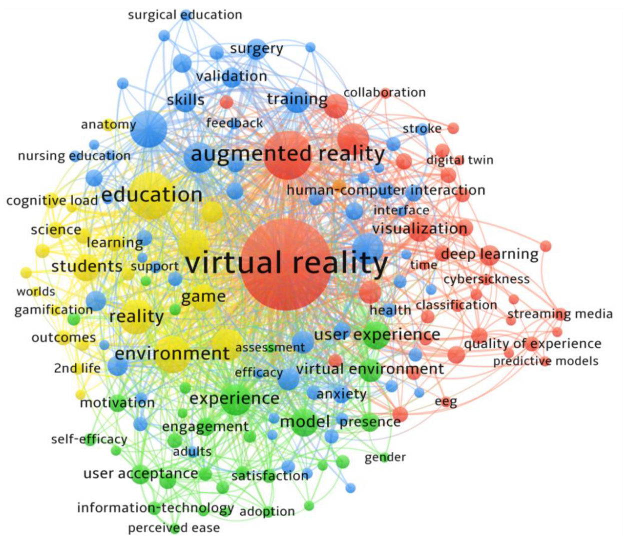


**Figure 1:** Co-words network of VR-E-UEP.

**1) Specific Applications of Virtual Reality Technology in Education**

Simulations are widely used in healthcare education, as seen in anatomy, architecture, care, and the context of COVID-19. Nursing students gain immersive user experience (UX) via VR headset simulations (Mäkinen et al., 2023). In AEC training, terms like "digital twin" and "construction" signal VR-digital twin integration. Digital twins model cyber-physical systems virtually, and VR enables immersive equipment-behavior viewing. Martínez-Gutiérrez (2023) integrated them for industrial mobile robot operation learning. Tarng et al. (2024) developed a system for controlling a physical robot's digital twin and observing synced virtual-physical movements.

**2) Key Concepts in Virtual Reality Education: Flow, Gaming, and Immersive Learning**

VR in education has key interrelated concepts (emotion, immersion, immersive learning, immersive VR) that enhance learning compared to traditional methods. These concepts suggest that immersive learning offers better emotional experiences. For instance, Williams et al. (2021) at North Carolina State University developed a VR organic chemistry lab where students experienced more positive emotions and less frustration. Keywords such as "game," "game-based learning," "gamification," and "flow" suggest that VR games based on flow theory can help students achieve a flow state. Akman and Çakır (2019) created an educational VR game (Kefet Kurtul) with flow-theory guidance, providing flow in most tasks.

3) **Quantifying, Predicting, and Classifying Indicators Using Machine Learning and Meta-Analysis**

Machine learning and meta-analysis are used to quantify, predict, and classify factors like intrinsic motivation, learning outcomes, and perceived ease of use. Machine learning algorithms can identify surgical factors for classifying VR surgical participants by expertise (Winkler-Schwartz et al., 2019). Dynamic gesture recognition has been incorporated into classroom teaching (Juan, 2021). In the VR-E-UEP area, meta-analysis merges results from multiple studies for more accurate training and learning outcome conclusions (Coban, Bolat and Goksu, 2022).

4) **Key Factors in Assessing User Experience Quality in VR Educational Applications: Reliability, Safety, and Self-Efficacy**

Hardware and software reliability are essential for assessing user experience quality in VR applications, which often involve complex systems. For instance, an HTC Vive-based VR system with a waist tracker measures positional information through sensor data, with reliability and validity evaluated for postural stability (Liang et al., 2020). Safety is also critical, with studies examining VR acceptability and safety for individuals with persecutory delusions (Fornells-Ambrojo et al., 2008). Self-efficacy is another key factor. For example, the impact of a virtual product dissection environment on students' design-learning self-efficacy is significant (Toh, Miller, and Simpson, 2015).

## EVOLUTION ANALYSIS OF HOTSPOTS

Evolution analysis shows VR-E-UEP research trends. Early on, it mainly centered on educational uses and usability. Mid-term, more focus was on human factors, assessing VR application effectiveness via learners' psychology and behavior analysis. In recent years, machine and deep learning are popular (Figure 2).


**Figure 2:** Keyword co-occurrence time zone map for VR-E-UEP.

Early VR-E-UEP research hotspots were on VR's educational application and implementation. Keywords like "Skill," "Technology" etc. showed focus on specific-field VR implementation. For example, Chang and Lin

(2014) developed a Kinect-based Chinese-cultural-festival learning system. Choi (2010) applied VR to ophthalmic surgery simulation. Mid-term, research factored in more "human" elements, evaluating VR effectiveness via learners' psychology and behavior. Keywords like "Children," "Gender" showed user individual differences were considered. Hite et al. (2019) studied the link between cognitive development and presence in VR science teaching for adolescents. Dayarathna et al. (2020) evaluated VR teaching module efficacy by gender. Keywords about cognitive aspects indicated what determined VR user experience quality. Also, "Serious Games"-related keywords showed their educational role, with VR enhancing learning through immersive experiences. Examples include 4D VR games (Salovaara-Hiltunen, Heikkinen, and Koivisto, 2019) and VR serious games in architecture education (Fonseca et al., 2021). In recent years, machine and deep learning are new hotspots. Feature extraction aids personalized learning and better user experience, and automated meta-analysis reveals effectiveness. Predictive models use learners' behavior, traits, and feedback to predict learning outcomes. For example, an AI-based intelligent recognition method can boost vocal music teaching efficiency (Jing, 2022).

## CO-CITATION ANALYSIS

The most frequently co-cited research on VR-E-UEP is divided into five categories: 1) Definitions and Technologies of Virtual Reality and Augmented Reality; 2) Advantages and Effectiveness Evaluation of Virtual Reality Technology in Education; 3) Applications of Immersive Virtual Reality in Learning and Training; 4) User Experience Measurement; 5) Statistical Analysis Methods and Theoretical Models to Understand Complex Phenomena and Relationships Among Multiple Factors (Table 1).

**Table 1**: The top 3 classical literatures of each category related to VR-E-UEP.

| Group | Title | Year | Citations |
|---|---|---|---|
| 1 | A Survey of Augmented Reality | 1997 | 56 |
| 1 | Virtual reality technology | 2003 | 33 |
| 1 | Current status, opportunities and challenges of augmented reality in education | 2013 | 31 |
| 2 | A review of immersive virtual reality serious games to enhance learning and training | 2020 | 58 |
| 2 | What are the learning affordances of 3-D virtual environments? | 2010 | 56 |
| 2 | A literature review on immersive virtual reality in education: state of the art and perspectives | 2015 | 46 |
| 3 | Virtual reality: how much immersion is enough? | 2007 | 97 |
| 3 | Effects of different types of virtual reality display on presence and learning in a safety training scenario | 2018 | 52 |

Continued

**Table 1:** Continued

| Group | Title | Year | Citations |
|---|---|---|---|
| 3 | How immersive is enough? A meta-analysis of the effect of immersive technology on user presence | 2016 | 41 |
| 4 | An empirical evaluation of the system usability scale | 2008 | 77 |
| 4 | Determining what individual SUS scores mean: Adding an adjective rating scale | 2009 | 67 |
| 4 | Using thematic analysis in psychology | 2006 | 56 |
| 5 | User acceptance of computer technology: A comparison of two theoretical models | 1989 | 72 |
| 5 | Perceived usefulness, perceived ease of use, and user acceptance of information technology | 1989 | 48 |
| 5 | Evaluating structural equation models with unobservable variables and measurement error | 1981 | 33 |

**1) Definitions and Technologies of Virtual Reality and Augmented Reality**

Cluster 1 articles set a theoretical base and research framework for Augmented Reality (AR) and VR by discussing their definitions and technologies, highlighting their educational potential. “A Survey of Augmented Reality” is a foundational AR review. It systematically sums up AR’s definitions, applications, technical challenges, and future directions (Billinghurst, Clark, and Lee, 2015). “Virtual Reality Technology” comprehensively overviews VR basics, advancements, hardware, software, human factors, and applications, with a Unity 3D lab manual, serving as an important VR reference (Burdea and Coiffet, 2024). Wu et al.’s (2013) work on AR in education finds its potential in boosting student interest and active learning. However, it points out challenges like high costs, low device penetration, and lack of teacher training, suggesting solutions and future research directions.

**2) Advantages and Effectiveness Evaluation of Virtual Reality Technology in Education**

Cluster 2 articles analyze VR’s educational advantages and effectiveness evaluation research progress and limits, guiding future evaluation. Checa and Bustillo (2020) find immersive VR serious games boost learner engagement and motivation, aid in knowledge retention and skill training. They also note a lack of long-term studies and standard evaluation tools. Dalgarno and Lee (2010) show 3D virtual environments offer immersive, interactive, and collaborative learning experiences, enhancing spatial and problem-solving skills. However, technology complexity and cost may limit its spread. Freina and Ott (2015) highlight VR’s potential in education, but also point out high costs, low device penetration, and lack of teacher training. Future research should address these issues.

**3) Applications of Immersive Virtual Reality in Learning and Training**

Immersive Virtual Reality (I-VR) is an advanced virtual reality technology. Using high-fidelity graphics and immersive content via devices like HMDs, it simulates near-real-world experiences, fully immersing users in a virtual environment (Hamilton et al., 2021; Antonopoulos, Fokides and Koutromanos, 2024). Cluster 3 articles cover I-VR applications in learning and training. Bowman and McMahan (2007) question if full immersion is always needed in VR. Empirical evidence shows different immersion components impact presence and outcomes differently. Buttussi and Chittaro (2017) compare desktop, narrow, and wide field-of-view VR in aviation safety training. Display type affects engagement and presence, but training benefits are consistent. Cummings and Bailenson (2016) meta-analyze immersive tech's impact on user presence, finding a medium-sized effect.

**4) User Experience Measurement**

Cluster 4 presents tools and methods for measuring user experience, laying a theoretical groundwork for such measurements in VR-E-UEP research. Bangor, Kortum and Miller (2008) analyzed a decade's worth of data on the System Usability Scale (SUS). They found SUS to be reliable and versatile for product usability evaluation and proposed a modification to link SUS scores with adjective ratings for better interpretation. In 2009, the same authors added a seven-point adjective-anchored Likert scale to the SUS questionnaire. The adjective ratings correlated highly with SUS scores ($r = 0.822$), helping non-human-factors pros understand results (Bangor, Kortum, and Miller, 2009). Braun and Clarke (2006) introduced thematic analysis as a flexible and easy-to-use qualitative analysis method. They detailed how to conduct it, discussed its advantages and disadvantages, and emphasized its importance across various fields.

**5) Statistical Analysis Methods and Theoretical Models**

Cluster 5 covers common statistical methods and theoretical models in the VR-E-UEP field, useful for understanding complex factor relationships. Davis et al. (1989) compared the Technology Acceptance Model (TAM) and Theory of Planned Behavior (TPB) for predicting computer tech user acceptance. They found perceived usefulness and ease of use as key, laying the groundwork for TAM, which became vital for predicting user behavior. In the same year, FD Davis developed and validated scales for perceived usefulness and ease of use. He found they're fundamental to user acceptance, with usefulness having a greater impact on usage, further solidifying TAM's foundation and providing research tools (Davis, 1989a). Fornell and Larcker (1981) explored SEM statistical testing for unobservable variables and measurement error. They proposed a shared-variance-based test system, supporting SEM's application in causal research.

## CONCLUSION AND DISCUSSION

VR-E-UEP research hotspots cluster into four: 1) specific VR educational applications, 2) VR's educational advantages and key concepts, 3) data analysis techniques, 4) factors affecting user experience. Evolution analysis reveals early focus on VR technology and applications, mid-term on human factors, and recent on machine learning. Frequently co-cited research falls into five categories: 1) VR and AR definitions and technologies, 2) VR's educational advantages and effectiveness evaluation, 3) immersive

VR applications in learning and training, 4) user experience measurement, 5) statistical methods and theoretical models. Based on this study, three questions merit further attention:

1) Multidisciplinary Integration: VR-E-UEP research mainly draws on computer science, design, and cognitive psychology. But classroom models, teaching methods, etc., impact application effectiveness. Thus, interdisciplinary theories, especially from educational theory, are needed.
2) User Experience Optimization: Positive experience enhancement, mostly on visual and auditory senses currently, could benefit from multisensory research. Also, negative factors like device stability and motion sickness need resolution (Liu et al., 2017).
3) Machine Learning: Despite much research, its recent explosive growth means it has great potential for further VR-E-UEP study.

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