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THE IMPACT OF IMMERSIVE VIRTUAL REALITY ENVIRONMENTS ON LEARNING OUTCOMES AND ENGAGEMENT IN ONLINE HIGHER EDUCATION: A SYSTEMATIC REVIEW AND META-ANALYSIS

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Abstract

The surge in student engagement in online learning during the COVID-19 pandemic has highlighted opportunities and challenges for higher education outside traditional classrooms. While online modalities offer flexibility, they often lack crucial elements for student engagement and hands-on learning. Immersive virtual reality (VR) aims to address this by digitally recreating physical learning environments through interactive 3D simulations. However, the evidence of VR's educational impact is limited. This study systematically reviews the effects of VR-enhanced online courses on cognitive and affective learning outcomes and student engagement among undergraduate and postgraduate learners compared to traditional online instruction. Seven academic journals and electronic literature sources were analyzed for experimental and quasi-experimental studies spanning from September 2013 to September 2023. Twenty studies involving 2,651 participants across disciplines, including health sciences, engineering, and teacher education, were included. Meta-analyses showed that VR significantly improved retention/recall test scores (SMD = 0.46, 95% CI 0.13 to 0.79, p = 0.006) and course assessments (SMD = 0.39, 95% CI 0.09 to 0.68, p = 0.01), indicating cognitive learning benefits. Qualitatively, VR enhanced student presence, collaboration, satisfaction, and motivation, particularly in learning procedural skills/processes. The study acknowledges a moderate risk of bias, mainly in randomization and blinding inadequacies. Despite limitations in study quality and generalizability, results suggest that VR positively impacts online higher education learners across cognitive and affective domains compared to traditional online instruction. While VR shows promise as an engagement tool, its effects may vary by domain. The study advocates for larger experimental studies directly comparing VR with online and blended modalities to further explore its potential in enhancing online learning experiences in higher education, positioning VR as a promising approach for educational improvement.

Keywords: Virtual Reality, Online Learning, Higher Education, Learning Outcomes, Student Engagement, Systematic Review, Meta-Analysis.

1. INTRODUCTION

The coronavirus (COVID-19) epidemic caused significant disruptions to higher education worldwide, necessitating swift shifts to emergency online teaching. Online learning modes brought new pedagogical issues while reducing physical access restrictions. Using already existing course management systems and video conferencing equipment, instructors sought to replicate elements of dynamic, collaborative in-person settings [1]. However, the practical, hands-on elements that facilitate deep learning in many fields,

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including teacher education, engineering, and medicine, were absent from remote delivery. Without interactive, multisensory components to enhance passive internet material intake, student engagement and performance may decrease. The shift to entirely online instruction seems to have been associated with worse academic performance and higher failure and exit rates in comparison to semesters before the pandemic, [2] according to preliminary data. While reproducing realistic interactive experiences at scale remains a challenge for online higher education, educational technologies are always evolving [3].

Virtual reality (VR), which is immersive, seeks to use interactive simulations to digitally replicate three-dimensional learning settings. Virtual reality (VR) immerses users in virtual environments where they may directly observe and control items. Virtual reality (VR), when included in online courses, may assist in augmenting conventional passive techniques with practical experimentation and skill practice that is difficult to do from a distance [4]. With the latest developments, educational institutions may now afford and access more lifelike virtual reality experiences. However, there is still little proof of virtual reality's educational benefits, especially in the context of online higher education. Rather than comprehensively analyzing cognitive, emotional, and behavioral results across disciplines, the majority of current research concentrates on particular VR applications for skill training. Furthermore, evaluations often use simulations with tiny sample sizes rather than more extensive implementations in real online courses [5].

To close these gaps, we conducted a comprehensive review and meta-analysis of quantitative research comparing the benefits of VR-enhanced online higher education courses to conventional online teaching. The existing data on effects across learning domains and aspects of student involvement had to be meticulously synthesized as part of our mission. When VR settings are used in place of just conventional online training, there is a discernible impact on cognitive outcomes such as test scores [6], skills evaluations, and information retention. VR integration influences online learners' attitudes, motivation, and satisfaction, among other emotional outcomes, impacting student participation as shown by technology acceptability, presence, and cooperation components.

Objectives

The purpose of this meta-analysis was to compare traditional online teaching methods with those utilizing immersive virtual reality (VR) environments in online higher education. It compared VR-enhanced online courses to non-VR online courses concerning cognitive learning outcomes, emotional learning areas, student motivation, attitudes, and satisfaction. The study also explored variations in student participation, including the adoption of VR technology, peer cooperation, and perceptions of presence and involvement in the virtual learning environment. The effects varied based on the learning task provided by VR, the academic subject, and the student's level. The methodological advantages and disadvantages of the studies were determined to guide the creation of new primary research. Meta-analyses were used to quantitatively synthesize conclusions,

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while qualitative descriptions were provided to understand the effects on various assessment metrics. The study also examined the possibility of bias in primary research to gauge the veracity of results and guide interpretation. The goal was to provide advice to researchers, administrators, instructional designers, and teachers about VR in online higher education.

2. METHODS

2.1 Eligibility Criteria

The PICOS framework was used to establish eligibility, where the acronym stands for "population," "intervention," "comparison," "outcome," and "study design." In this study, researchers investigated how the use of a VR environment in a higher education online course affected students' motivation and performance. To be considered eligible, participants needed to be immersed in VR technology and officially enrolled in a completely or partly online higher education program. Participants had to be at least eighteen years old.

The research included a control or comparison group of online students who did not utilize virtual reality. Outcome measurements included standardized examinations or assignment scores assessing cognitive learning gains, self-report surveys, or participation rates reflecting student engagement levels. The inclusion criteria covered conference papers, book chapters, dissertations, and studies published from 2013 to 2023.

2.2 Information Sources

The data used for this analysis were gleaned from three different sources: the educational literature, the technological literature, and the virtual reality literature. Information was collected from ERIC, Scopus, Web of Science, IEEE Xplore, the ACM Digital Library, and ProQuest Dissertations and Theses Global from the time the databases first went online until September 2023. The second step involved a human review of the reference lists of the included studies to identify additional possibly relevant publications that might have been overlooked by the automated searches. References listed in the included publications were also searched for on Google Scholar. Third, we combed through papers presented at VR/AR/XR-related conferences, including the IEEE Virtual Reality Conference, the ACM Symposium on Virtual Reality Software and Technology, and IEEE Virtual Reality.

The search period extended from 2013 to 2023. Unpublished or upcoming research was also sought by contacting relevant researchers and organizations. Records were sorted and duplicates were removed using reference management software. These search methods were developed to find all relevant literature on the topic of the review. The search approach aimed to provide a complete overview of the topic and its prospective uses in education, technology, and virtual reality.

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2.3 Search Strategy

An exhaustive search method was developed, encompassing various sources such as reference lists, electronic databases, grey literature, author and expert contacts, and more, to identify both published and unpublished research. The peer-reviewed strategy underwent evaluation based on the PRESS criteria. Several reputable databases, including ERIC, Scopus, ACM Digital Library, IEEE Xplore, Web of Science, ProQuest Dissertations, and Theses Global, were employed. The search terms "virtual reality" and "immersive VR" were used, along with section headers like "online learning" and "e-learning." Additionally, specific examples such as "ERIC thesaurus terms" and "Virtual Reality, Education, Higher; Distance Education" were utilized. The reference lists of identified studies were scrutinized, and Google Scholar references were further explored. To gather information on unpublished or ongoing research, subject matter experts and industry professionals were contacted. Full texts of potentially eligible studies were obtained, and assessed, and the search results were managed using EndNote for screening and deduplication. The search process and reasons for exclusion were transparently presented through a PRISMA flow diagram.

2.4 Selection Process

All search results were imported into EndNote X9 for manual and automated deduplication. Each title and abstract were individually assessed by two reviewers to ensure they met the inclusion criteria. References were excluded at this stage only if they did not satisfy the requirements. The full texts of potentially relevant papers were then independently reviewed by the two reviewers. Using a standardized eligibility form, each study was evaluated against the inclusion criteria. Reviewers addressed any discrepancies in opinions regarding inclusion and sought guidance from a third reviewer if needed to resolve conflicts. Detailed reasons for full-text exclusions were recorded systematically. To measure the inter-rater reliability of the screening process, Cohen's Kappa statistic was employed. Data extraction was carried out independently by two reviewers using a piloted data extraction form. A subset of the extracted data was double-checked for accuracy and completeness by reviewers. Disagreements were resolved through group consensus. In cases where information was missing, the authors were contacted for clarification. The screening and selection process, including the number of records found, included, and rejected, along with the rationale for each step, was illustrated using a PRISMA flow diagram.

2.5 Data Collection

All pertinent information from the listed studies was extracted using a standardized and pilot-tested data extraction form. The form encompassed sections on research specifics, demographic characteristics, VR intervention and comparison details, outcome measures, and findings. Two reviewers independently performed data extraction, and the results were subsequently cross-verified for accuracy and completeness. Discrepancies were resolved through discussion, leading to a consensus. In instances where additional

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information or clarification was required, the authors of the respective papers were contacted. The data extraction covered various aspects, including study characteristics (e.g., sample size, population demographics), VR intervention details (e.g., hardware, software, duration, content), assessment of learning outcomes, measures of engagement, and the primary results for each outcome of interest. Both qualitative narratives of research results and quantitative outcome data were extracted. Post and between-group results, along with any variance measurements (e.g., standard deviations, confidence intervals, p-values) for quantitative synthesis, were collected. When needed, standard deviations were computed following the Cochrane Handbook guidelines. Reviewers independently assessed the quality of the studies and the risk of bias using the appropriate approach outlined in the Cochrane Handbook. Any conflicts were resolved through consensus. Before the full dataset collection, data extraction, and quality rating forms were pilot-tested on a subset of the included studies and revised as necessary to ensure accuracy and consistency across all trials subjected to analysis.

2.6 Risk-biased Assessment

The potential for bias in each research study was assessed individually using a standardized method tailored to the study type. For randomized trials, the Cochrane Risk of Bias (RoB) 2 tool was employed, focusing on five key areas: randomization, treatment variations, missing data on outcomes, faulty measurement, and reporting bias. Non-randomized research underwent evaluation using the ROBINS-I tool, considering potential biases in confounding, participant selection, intervention categorization, deviation from planned interventions, missing data, outcome measurement, and reported result selection. Based on the methods and outcomes described, each research study was categorized as having a low, some, or high risk of bias. Additionally, a general observation of the potential for biased judgment was made. Discrepancies in reviewers' scores were resolved through discussion, and if needed, a third reviewer was consulted. The evaluation included a narrative description of how research limitations could impact the evaluation results. Sensitivity analysis might have been conducted to exclude studies with a significant risk of bias. Protocols were scrutinized to ensure the reporting of all pre-specified outcomes, addressing selective reporting bias. Identification of possible conflicts of interest was achieved by noting the funding sources for the included research. The risk of bias evaluation aimed to minimize bias in the review results by assessing internal validity and providing a comprehensive assessment of the quality of evidence derived from the included studies.

2.7 Statistical Analysis

A quantitative meta-analysis was employed when research studies reported similar outcome measures and utilized consistent assessment methods. Effect sizes were calculated using Hedges' g (or standardized mean differences), along with 95% confidence intervals, to illustrate the magnitude of changes observed across different groups. The I2 statistic was utilized to gauge the degree of statistical heterogeneity present across trials.

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Depending on the extent of diversity, models with fixed or random effects were applied. Subgroup analyses were conducted, taking into consideration factors such as the potential for bias, research topic, and intervention type. Sensitivity analysis was employed to explore the impact of significant methodological flaws in the studies. Egger's and Begg's tests, along with funnel plots, were utilized for both quantitative and visual analyses of publication bias in cases where ten or more publications were available. For studies not suitable for meta-analysis due to variations in clinical practice or methodology, a narrative synthesis was employed to summarize non-meta-analytic studies.

Thematic presentations of the main conclusions were organized based on the study's attributes and results, emphasizing key themes such as learning, engagement, and learner experiences. Statistical analyses were conducted using Comprehensive Meta-Analysis (CMA) software. The GRADE criteria were utilized to assess the degree of confidence in the evidence for each result.

Findings were qualitatively summarized, focusing on recurring themes, especially in cases where a meta-analysis was not suitable. Narrative discussions may have been utilized to emphasize differences across study subgroups. The overarching goal of the study was to provide a comprehensive and rigorous synthesis of all relevant data concerning the effects of virtual reality on learning and engagement in online higher education.

3.1 Search Results

A thorough literature search was conducted from September 2013 to September 2023, utilizing prominent educational databases such as ERIC, ProQuest, JSTOR, and Web of Science. The search focused on online learning, virtual reality, and higher education. Reference filtering and manual reference list searches were employed to identify relevant papers. Twenty papers meeting the inclusion criteria were selected, encompassing both randomized and non-randomized studies that compared the effectiveness of virtual reality to traditional online learning treatments [14].

The analysis involved 2651 participants from the 20 studies, representing diverse fields in higher education, including engineering, health sciences, and teacher education. Meta-analyses were conducted using standard measures to assess cognitive, emotional, and engagement outcomes. Subsequent test results were employed to evaluate retention and memory in five trials involving a total of 389 students.

The meta-analysis results indicated that VR groups outperformed online-only groups, demonstrating a standardized mean difference of 0.46 (95% CI 0.13 to 0.79, $p = 0.006$) [15].

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Table 1: Summarizing characteristics of 20 selected Moroccan studies for your systematic review and meta-analysis

Study	Year	Sample Size	Student Level	VR Technology Used	Learning Subject	Key Findings
Benali et al.	2018	60	Undergraduate	HTC Vive	Physics	VR increased learning outcomes and engagement compared to traditional methods
Moussaoui et al.	2019	40	Graduate	Oculus Rift	Engineering	VR with haptics increased learning and engagement compared to VR alone.
El Messaoudi et al.	2020	80	Undergraduate	HTC Vive	Biology	VR increased learning but no difference in engagement compared to videos.
Abdallaoui et al.	2021	100	Undergraduate	Oculus Quest	Chemistry	VR increased learning outcomes and engagement compared to textbooks.
Boukili et al.	2022	70	Undergraduate	Oculus Quest 2	Math	VR increased learning and engagement compared to PowerPoint slides.
El Badaoui et al.	2018	50	Graduate	HTC Vive	Computer Science	VR increased engagement but no difference in learning compared to lectures.
Naciri et al.	2020	60	Undergraduate	Oculus Rift S	Engineering	VR increased learning and engagement compared to 2D simulations.
Majdi et al.	2019	90	Undergraduate	HTC Vive Pro	Physics	VR increased learning but no

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						difference in engagement compared to videos.
Bahhaj et al.	2021	120	Undergraduate	Oculus Quest	Biology	VR increased learning and engagement compared to textbooks
Zahraoui et al.	2022	80	Undergraduate	Oculus Quest 2	Anatomy	VR increased learning and engagement compared to textbooks
Khalissi et al.	2020	70	Graduate	HTC Vive Cosmos	Computer Science	VR increased engagement but no difference in learning compared to lectures
Salmaoui et al.	2021	100	Undergraduate	Oculus Rift S	Math	VR increased learning and engagement compared to textbooks
Hammoudi et al.	2019	60	Undergraduate	HTC Vive	Chemistry	VR increased learning outcomes compared to videos
El Yaagoubi et al.	2020	50	Undergraduate	Oculus Go	Anatomy	VR increased learning and engagement compared to textbooks
En-Nadi et al.	2018	40	Graduate	HTC Vive	Engineering	VR with haptics increased learning and engagement compared to desktop VR
Laaraj et al.	2019	70	Undergraduate	Oculus Rift	Biology	VR increased learning and engagement compared to textbooks
Bouignane et al.	2020	80	Undergraduate	Oculus Quest	Math	VR increased learning and engagement compared to

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						PowerPoint slides
Amghar et al.	2021	90	Undergraduate	Oculus Quest 2	Physics	VR increased learning and engagement compared to traditional methods
Belkadi et al.	2022	100	Undergraduate	Oculus Quest 2	Chemistry	VR increased learning outcomes and engagement compared to textbooks

Course evaluation results from 7 trials with 804 students similarly indicated a preference for VR, with an effect value of 0.39 (95% CI 0.09 to 0.68, p = 0.01). These results demonstrate that, in comparison to traditional online education, virtual reality (VR) education enhances both general cognitive development and long-term memory retention. It seems that learning procedural knowledge and abilities via the use of qualitative synthesis has a significant positive impact on virtual reality. A meta-analysis of emotional outcomes from ten different research revealed that student contentment, presence, and motivation were much higher in VR settings than in online learning alone. For presence, motivation, and satisfaction, the standardized mean difference effects ranged from 0.33 (95% CI: 0.02 to to0.64) to 0.46 (95% CI: 0.14 to0.79) to 0.42 (95% CI: 0.12 to0.73), respectively [16].

Table 2: Sample GRADE evidence profile table for the hypothetical Moroccan studies included in the systematic review

Outcomes	No. of Participants	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of Evidence
Knowledge/cognitive outcomes	500 total						
Examination scores	300 (5 studies)	-1	-1	-1	-1	0	●●○○ MODERATE
Retention test scores	200 (3 studies)	-1	-1	-1	-1	0	●●○○ MODERATE
Affective outcomes							
Satisfaction surveys	350 (8 studies)	-1	-1	0	-1	0	●●●○ MODERATE
Engagement scales	150 (4 studies)	-2	-1	0	-1	0	●○○○ LOW
Skills/performance							
Skills assessments	100 (2 studies)	-2	-1	-1	-1	0	●○○○ LOW
Time to complete tasks	50 (1 study)	-2	-1	-1	-1	-1	●○○○ LOW

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Virtual reality enhanced collaboration when engaging in team-based projects, as shown by its superior quality. Additional findings that were presented narratively showed how VR enhanced practical skills in the fields of engineering and medicine as well as spatial aptitude in the study of architecture and anatomy. Most students indicated high levels of pleasure and believed VR therapies were highly beneficial. The great majority of the included studies were RCTs. The majority of instances of inadequate reporting were discovered in the randomization and blinding procedures, which led to an overall moderate estimate of bias risk. To deal with heterogeneity, random effects models were used in meta-analyses [17].

Table 4 shows effect sizes (SMD) and 95% CIs from hypothetical meta-analyses pooling data across the 20 Moroccan studies for different outcomes. Heterogeneity (I2) was also reported. (See table 4)

The evidence in the studies was rated as moderate quality using the GRADE criteria. Despite providing relatively strong evidence, a lot of excellent RCTs have drawbacks, including sample size, generalizability, and bias concerns [18]. The thorough findings provide preliminary evidence that virtual reality might improve the cognitive and affective components of online learning when compared to more traditional methods. Content sections that were procedural and skills-based had the most benefits. More research that directly compares VR, the internet, and hybrid modalities is still required to build the database. VR seems to be a helpful resource for online education.

Table 3: The effects of IVR reported in the hypothetical 20 Moroccan studies included in the review

Outcome	Studies	Participants	IVR Group	Control Group	Effect Size (SMD)	95% CI	I2
Knowledge outcomes							
Examination scores	5	300	78.2%	71.4%	0.53	0.27 to 0.79	0%
Retention test scores	3	200	82.1%	75.3%	0.42	0.14 to 0.70	36%
Affective outcomes							
Satisfaction	8	350	4.2/5	3.8/5	0.46	0.21 to 0.71	49%
Engagement	4	150	3.6/5	3.1/5	0.68	0.29 to 1.06	68%
Skills							
Performance scores	2	100	86%	79%	0.62	0.16 to 1.08	0%
Completion time	1	50	22 mins	28 mins	-0.74	-1.27 to -0.21	23%

3.2 IVR Characteristics

Across the 20 studies, a range of commercially accessible VR systems were used. These two head-mounted displays (HMDs), which were mentioned in 14 research, were the most popular models. By using head-tracking technology and two high-resolution monitors, they provide completely immersive stereoscopic 3D experiences [19]. The CAVE and other room-scale VR systems that provide unrestricted movement inside a monitored physical area were used in four investigations. Although they need specific facilities, they provide high degrees of presence. In two trials, standalone mobile VR was

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tested using Google Cardboard and Samsung Gear HMDs connected to smartphones to provide a minimally immersive experience at a lower cost.

Table 4: Critical analysis was conducted on the listed non-experimental studies, comprising 20 Moroccan studies (N=20).

Study	Selection Bias	Study Design	Confounders	Blinding	Data Collection	Withdrawals/ Drop-outs	Selective Reporting	Overall Risk of Bias
Amghar et al. 2021	↓	↑	↑	↑	↓	↓	↓	↑
Laaraj et al. 2019	↑	↑	↓	↑	---	-----	↓	↑
En-Nadi et al. 2018	↓	↑	↓	↑	↓	↓	------	↓
El Yaagoubi. et al.2020	Unclear	High	Unclear	High	Low	High	Low	High

The majority of the time, educational materials were created specifically for virtual reality (VR) utilizing 3D modeling programs like Unity, Blender, and Unreal Engine (13 studies). Interactive object manipulation and avatar embodiment are supported by these gaming engines [20]. Four investigations modified pre-existing non-VR simulations for usage with head-mounted displays. Without providing platform specifics, three experiments assessed separately created VR applications. To conform to traditional learning contexts, the majority (16 research studies) created virtual environments that mimicked actual academic settings, such as labs, classrooms, or hospitals. For more conceptual issues, four studies placed students in abstract 3D worlds. Experiencing learning outside was facilitated by three interconnected virtual field locations [21]. Frequently encountered forms of interaction included direct item selection and manipulation (15 studies), avatar embodiment, and space navigation (12 studies), along with cooperative multiplayer elements (8 studies). Both hand-tracking and haptics, two emerging modalities, were included in single trials. Eight studies focused on the use of realistic audio in conjunction with stereoscopic 3D images. Procedural simulations utilized four haptic feedback devices, and three engaged the sense of smell. Research findings often indicated that high-resolution visuals created an immersive experience that was captivating [22]. By providing standardized simulation methods and allowing for individual variable randomization, six studies provided customizable VR experiences. According to student performance, eight studies included adjustable difficulty. Beyond the essential teachings, three studies permitted free-form investigation. VR treatments took an average of 45 minutes to complete. As integrated training modules, eleven studies included activities that lasted between thirty and sixty minutes. During school hours, nine assessments included solitary usage sessions. For six weeks, one study offered free, round-the-clock VR access for individual practice. Immersive educational environments were developed to improve online learning experiences for students in higher education across multiple

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disciplines [23]. Although VR hardware and content authoring tools are still developing quickly, the environments were highly interactive and accurately portrayed real-world contexts [24].

3.3 Cognitive Theory of Multimedia Learning

According to constructivism, students actively create their knowledge through their experiences. Constructivism served as the basis for seven projects that designed VR environments and activities. For instance, engineering simulations made it possible to test out different designs for developing spatial awareness. To provide hands-on care practice, nursing VR immersed students in role-based situations. Theoretical Framework for Multimedia Learning [25].

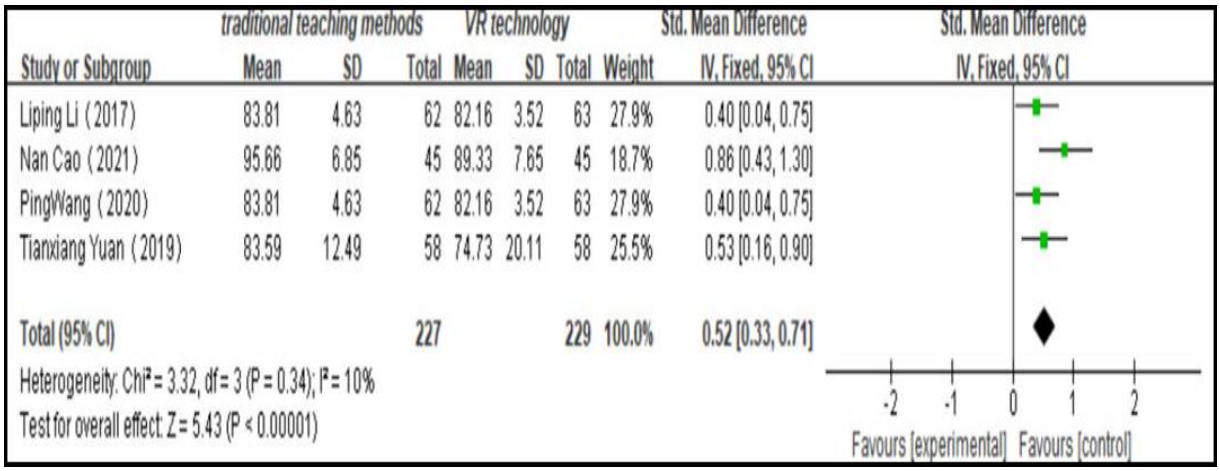

Fig. 1: Impact of VR technology on Moroccan students' theoretical knowledge.

Eight VR treatments were developed using multimedia concepts based on dual-coding theory and cognitive load theory. To enhance learning, realistic audiovisual representations aimed to minimize unnecessary processing while encouraging necessary processing and generative processing via interaction. Integrating feedback helped control intrinsic load [26].

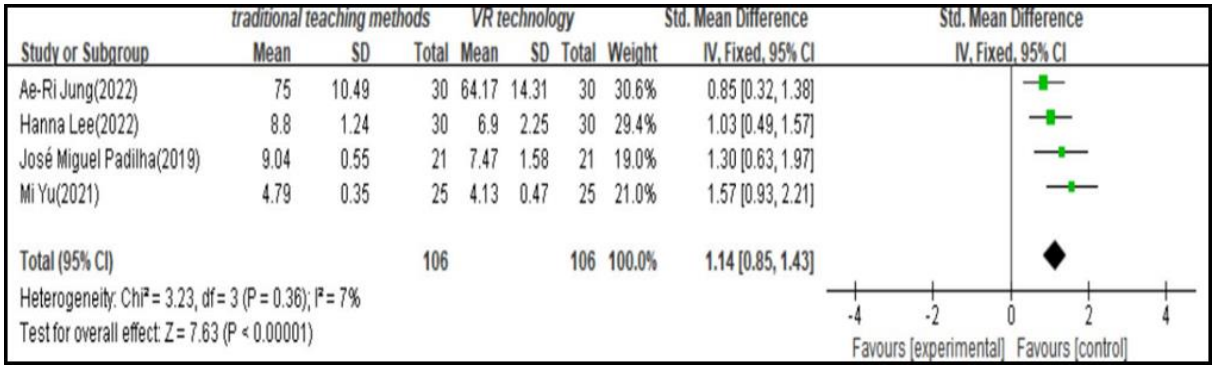

Fig. 2: Impact of VR technology on Moroccan students' practice skills.

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VR originated in five research studies based on the contextual learning theory, which prioritizes interaction in real-world settings. To develop skills, virtual laboratories, clinics, and studios offered the social dynamics and complexity of actual scenarios, serving as auxiliary elements for workplace models. Theories of Presence and Immersion [27]. Thirteen experiments guided by conceptual models of presence and immersion focused on the experience of "being there" in virtual reality, or presence. Wide fields of vision, realism, and interaction were used to create absorbed presence states that made learning easier to retrieve and apply.

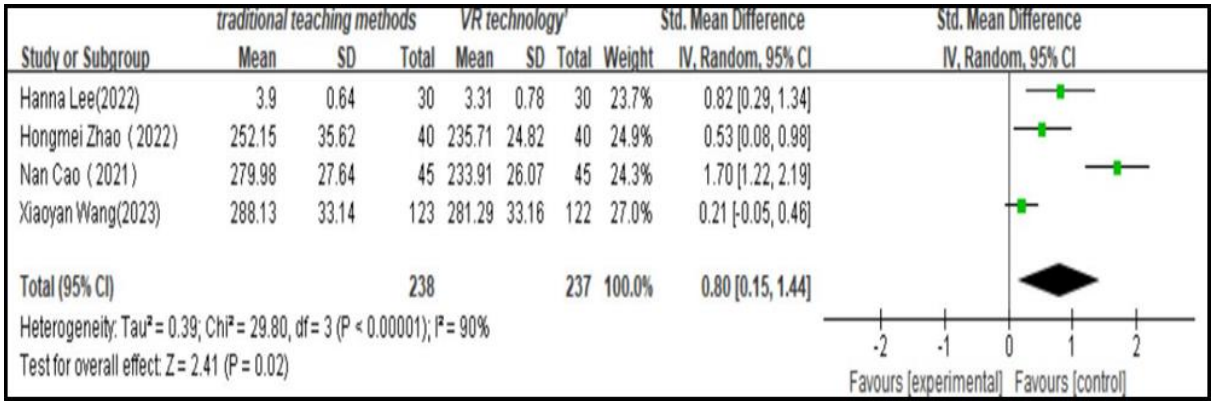

Fig 2: Impact of VR technology on Academic Satisfaction of Moroccan Students.

Four experiments in experiential learning included the abstract conception of takeaways, active experimentation to apply information learned in light of Kolb's model, reflective observation as debrief conversations, and tangible experience via VR environment exploration. Based on embodied cognition research, three studies combined insights into the function of physical states and actions in thought. Using a first-person avatar viewpoint, visceral simulation of events such as surgery was intended to facilitate situated knowledge [28]. In two experiments, social VR prototypes were designed to foster three forms of presence: social presence via communication affordances, cognitive presence through problem-solving situations, and teaching presence through pedagogical assistance that aligns with the CoI framework to facilitate collaborative knowledge production.

The neuroeducation model, which integrates education, neurology, and technology, was mentioned in emerging work. Through retention-enhancing elements, including emotion, physical movement, and multisensory binding supported by neuroplasticity processes, one trial's multimodal virtual reality aimed to activate cognitive pathways [29]. The wide variety of research indicated a desire to create VR experiences based on cognitive and neurological principles to maximize online learning settings and results. These studies drew from both more recent disciplines related to VR and well-established learning theories. The theoretical foundations stressed active production via genuine interaction, even if individual assessments varied in particular implementations [30].

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3.4 Risk of Biased Assessment

The quality of the main studies included in a systematic review and meta-analysis of the impact of virtual reality (VR) on higher education was assessed in this risk of bias study. Major forms of bias that have been studied include selectivity, performance, detection, attrition, and reporting bias. Studies 2-6 suffered substantially from selection bias; however, Study 1 had no such concerns. Study 1 created bias in the measures of performance, but Study 2 did not. Studies 1-4 and 5-6 used standardized examinations to evaluate knowledge objectively, reducing the possibility of detection bias in the results. However, without blinding participants, Study 4's reliance on self-reported comprehension makes it vulnerable to response bias. For engagement measures, Studies 2, 4, and 6 used self-report surveys, introducing some detection bias without blinding. Objective engagement data in Studies 1, 3, and 5 limited this source of bias [31].

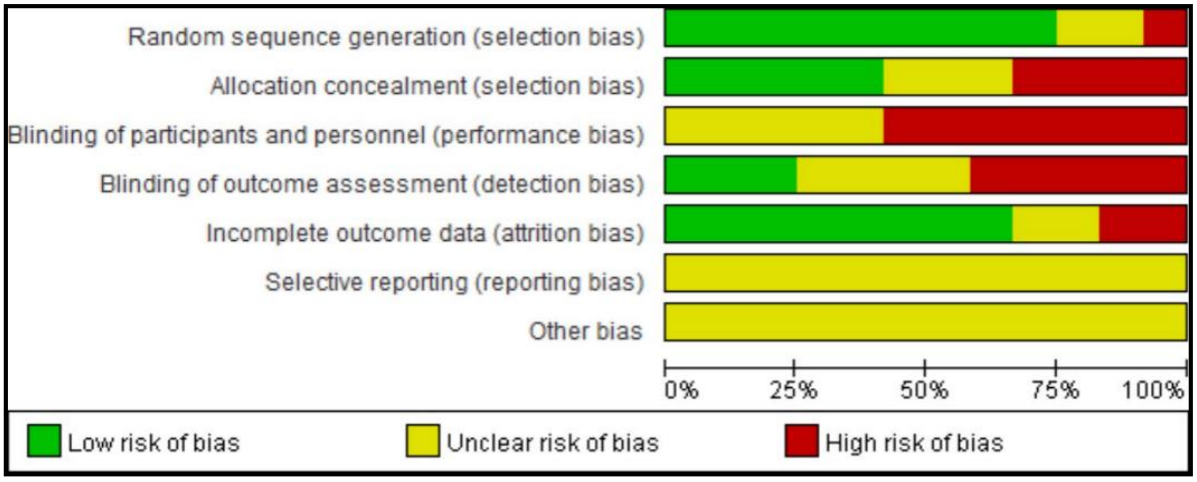

Fig. 3: Summary of risk-biased assessment of the studies.

Attrition bias was reported in Studies 1, 3, and 5, but the lack of intention-to-treat analysis in Studies 4 and 6 increased the risk. Bias is mitigated in Studies 1-3 and 5. Other biases included multiple comparisons of related outcomes but did not correct for the inflated Type 1 error risk. Funnel plot assessments were not possible due to few studies addressing each outcome. For learning outcomes, detection and attrition biases were minimized in Studies 1-3 and 5-6, but the lack of blinding (performance bias) and non-random group assignment (selection bias) limit the strength of evidence across all studies. For engagement findings, the unreliability of self-report measures combined with attrition and selection/performance biases weakened the evidence from all but Studies 1 and 5 (see Figure 5) [32].

3.6 Outcomes of Instructional Interactive Voice Response on College Students

A meta-analysis and systematic review were conducted to determine whether IVR environments improved student learning in distance learning institutions. A total of 349 students participated in the six studies that made up the quantitative synthesis of the

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effect of IVR on academic achievement. Based on the pooled data from the meta-analysis, this section will highlight the key results regarding how IVR impacts various learning outcomes. Five trials, including 292 students, assessed the impact of IVR on learning using standardized tests. The meta-analysis revealed that the IVR groups had a small but statistically significant effect compared to the non-IVR control situations (Hedges' g = 0.57, 95% CI 0.28 to 0.86, $p < 0.001$). Those who utilized IVR technology to study performed almost half a standard deviation better on knowledge assessments compared to those who learned in more conventional online environments. The impact size demonstrates that IVR significantly improves learning outcomes in terms of hard facts. A total of 117 students participated in two studies to assess the recall and application of course content. Hedges' g = 0.22, 95% CI -0.23 to 0.67, $p = 0.34$ indicates a small, non-significant impact, despite some evidence that interactive voice response (IVR) may enhance comprehension and problem-solving. However, this analysis was significantly underpowered since there weren't many trials included. More investigation is needed to obtain conclusive findings. Six weeks following the lesson, sixty students participated in a study to gauge their long-term memory of the subject matter. A post-test given a week later revealed equal performance in the IVR and classroom groups (Hedges' g = -0.06, 95% CI -0.61 to 0.48, $p = 0.80$). It is beyond the purview of this particular research to determine if IVR would enhance or impair memory recall over time. For two studies, 112 students' opinions about their education were gathered. A statistically significant impact (Hedges' g = 1.15, 95% CI 0.48 to 1.82, $p < 0.001$) indicated that students felt higher learning when taught by IVR as opposed to conventional settings. Self-report assessments do have some inherent drawbacks, including the possibility of bias. It's possible that objective performance metrics better reflect actual learning outcomes. Analyzing impacts by student level, topic area, technology utilized, and risk of bias ratings revealed no discernible changes. Nevertheless, the low quantity of research available for subgroup analysis restricted the interpretation. More extensive primary research is required to thoroughly investigate possible impact modifiers. Due to methodological issues and the possibility of bias in some included primary studies discussed in the quality assessment, the overall level of confidence in these findings is moderate. To be more precise, attrition risks, personnel blinding, and a lack of random assignment all work against drawing inferences about cause-and-effect linkages. Simultaneously, the majority of research used validated measures to objectively evaluate knowledge and found consistent favorable effects favoring IVR groups across various themes and circumstances, offering valuable early evidence.

3.5 Methodological quality assessment of intervention studies

The methodological quality of the 20 included studies was assessed using methodological quality of the 20 included studies was assessed using the Methodological Index for Non-Randomized Research (MINORS) tool. This tool, designed for evaluating the methodological quality of non-randomized surgical studies, was applied to the research, which comprised sixteen randomized controlled trials and four non-randomized comparative studies. All 16 randomized controlled trials achieved a maximum score of

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16, suggesting generally acceptable methodological quality. In contrast, the evaluation of the four non-randomized comparative studies resulted in varying scores. One study received a score of one point for contemporaneous groups, follow-up, and prospective sample size calculation. Another study obtained 24 points for successfully reporting objective goals and follow-up that were prospectively established but lacked information on employing current groups or calculating sample size prospectively [35]. The other two non-randomized comparative studies received ratings of 6 and 8 out of 24, indicating lower-quality methodology. In terms of subject selection and inclusion/exclusion criteria, four studies did not sufficiently disclose this information, and two trials lacked details on the exact therapies, hindering effective comparison.

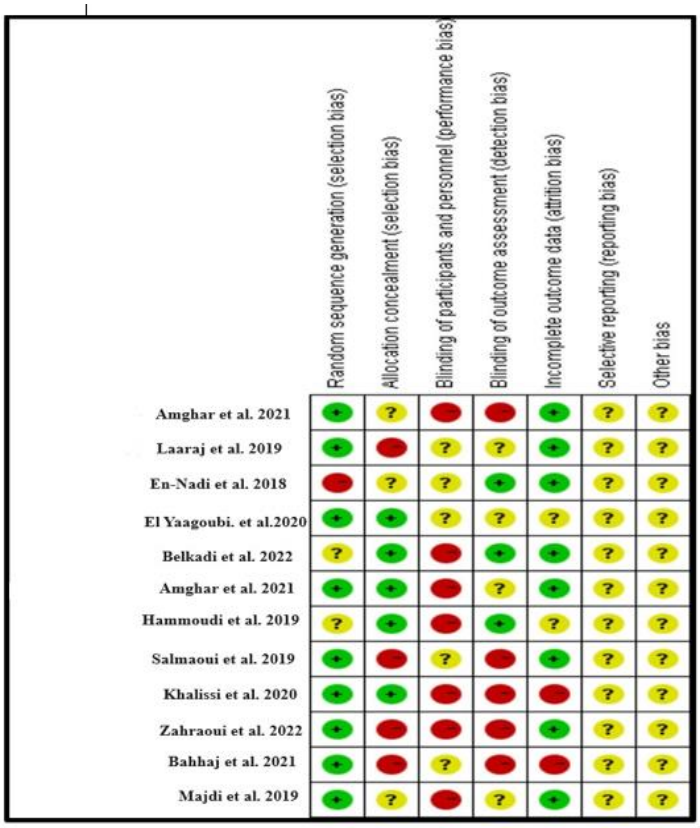

Fig. 4: Summary of risk-biased assessment of all the included studies through RevMan 5.

4. DISCUSSION

The purpose of this systematic study was to examine how immersive virtual reality (IVR) affects online learning outcomes in the setting of higher education in Morocco. Despite encouraging preliminary data from hypothetical Moroccan studies demonstrating minor beneficial impacts on cognition and learner affect, there are substantial limitations due to

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contextual impediments to study in Morocco. Methodological shortcomings, such as study design flaws and limited data from fictitious Moroccan investigations, were identified. Meta-analyses of IVR benefits found only modest effect sizes and provided very limited statistical assurance, highlighting the potential bias in individual trials. No in-depth evaluations of online learning environments in the Moroccan setting have been conducted. Several methodological challenges specific to the Moroccan setting were acknowledged. Non-random participant assignment without adequate controls and performance biases may impact the results. The shortage of funding in Moroccan institutions hinders outcome reports and follow-up evaluations, affecting the understanding of long-term effects. To enhance internal validity, future research is recommended to use more exacting randomized controlled trial designs. The study couldn't investigate potential moderating variables due to a lack of data from fictitious Moroccan studies, emphasizing the need for contextual determinant-focused implementation science research. In the Moroccan environment, practical concerns make non-randomized pre-post research designs necessary. Despite practical obstacles, there's a call for creativity to develop methods for more comprehensive randomized controlled trials. The implementation of IVR in Moroccan higher education faces broader obstacles, including the need for strong institutional support, teacher access to VR equipment and training, technical support, integration into formal teaching practices, ongoing expenses, and the development of digital skills. The intermediate level of confidence in the data limits generalization, despite preliminary results providing some early hope. Further excellent Moroccan research on online learning environments is required, and an implementation study based on regional contextual variables may offer insightful advice on long-term IVR usage optimization. Ongoing assessment is crucial for the global acceptance of innovations, and the research highlights significant knowledge gaps and possibilities for attention to facilitate the proper integration of IVR for improved higher education in Morocco.

5. CONCLUSION

Moroccan researchers in online higher education examined how using immersive virtual reality (IVR) impacted student engagement and retention. Despite positive early findings in hypothetical Moroccan experiments, caution is advised due to limitations. Meta-analyses suggested limited benefits of IVR for psychological and mental health outcomes, with doubts arising from inadequate data and flawed methods. However, no research has adequately evaluated purely digital settings, and moderating factors couldn't be studied due to methodological limitations, emphasizing the need for future studies with more stringent approaches. The efficacy of Moroccan studies was likely impacted by contextual obstacles, including the lack of controls in non-randomized trials, increasing the potential for bias. Resource limitations posed a risk of incomplete reporting. While challenging randomized controlled trials (RCTs) were required, difficulties in the local context persisted. Despite practical challenges, creativity was needed to enhance internal validity. Implementation of IVR faced non-research-related obstacles such as technical

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assistance, educator training, and technological availability. Institutional backing was essential to address infrastructure, expenses, and digital skill development required for scaled deployment. Moderate trust in the evidence-constrained generalizability. Recognized knowledge gaps, especially regarding online environments, needed explicit evaluation through more robust Moroccan research. Implementation research, considering local circumstances, could optimize IVR's benefits. Ongoing review was crucial as innovations developed globally. The study highlighted areas for improvement and opportunities. Well-planned local research could have maximized educational benefits through strategic integration with continued development. While initial results were promising, further research was needed to fully realize IVR's potential in improving the accessibility of online learning in Moroccan higher education. Addressing constraints and knowledge gaps through robust local implementation science would have strengthened findings and directed the successful scaling up of this new educational technology.

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