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DEVELOPMENT ARTICLE

Immersive virtual reality–based manual therapy training: a mixed-methods trial

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Abstract

Manual therapy mobilizations are common therapeutic practices for musculoskeletal conditions, but their acquisition presents significant challenges as it requires the precise, coordinated, and safe execution of specific movements. Traditional teaching approaches often rely on subjective feedback and offer limited real-time guidance, which may hinder skill acquisition. In recent years, immersive Virtual Reality (iVR) has emerged as a promising educational tool, showing potential to enhance learning experiences and increase student motivation. This study aimed to develop and validate a novel teaching approach for manual therapy mobilizations by integrating iVR as a complementary tool in undergraduate education, allowing students to practice techniques with greater precision and efficiency. A mixed-methods cluster randomized controlled trial was conducted with undergraduate students who had no prior experience with the technique. An iVR application for head-mounted displays was developed to teach a knee mobilization technique. Students in the experimental group used the iVR application alongside a traditional instructional session, while the control group received traditional teaching only. Quantitative and qualitative data related to usability, iVR experience, and learning experience were collected after the session. Results showed that students in the experimental group reported higher engagement and motivation when learning manual therapy techniques, although some perceived the traditional method as simpler. Learning experience outcomes indicated improved coordination of translational and rotational movements among iVR users, which is essential for effective manual therapy mobilization. Overall, these findings suggest that iVR can serve as an effective supplementary tool to conventional teaching methods, contributing to enhanced learning and performance outcomes.

What is already known about this topic
- Manual therapy is fundamental in treating musculoskeletal disorders
- Traditional Teaching for manual therapy lacks real-time feedback, hindering skill gain
- iVR has shown benefits in health and education

What this paper adds
- First RCT evaluating iVR in manual therapy education

Extended author information available on the last page of the article

- iVR improved movement coordination and technique performance
- Students reported high motivation and engagement using iVR

Implications for practice
- iVR can complement traditional manual therapy teaching
- Educators should balance innovation with hands-on practice

Keywords Virtual reality · Education · Learning process · Manual therapy · Immersive

Introduction

Musculoskeletal conditions

Musculoskeletal conditions are the second-highest ranked cause of non-fatal disability, which include pathologies such as low back pain or osteoarthritis (James et al., 2018). They frequently arise from trauma or chronic degenerative conditions and can affect individuals of all ages, although the risk increases with age. Within various diseases and disabilities, musculoskeletal conditions rank among the leading causes of global years lived with disability (Ferrari et al., 2024). Thus, health professionals must address these issues and prevent symptoms from developing and decreasing quality of life (Flynn et al., 2018). Manual therapy is a type of intervention widely used in various healthcare settings to treat musculoskeletal conditions, typically presenting pain and dysfunction as main symptoms (Blanpied et al., 2017; Carlesso et al., 2014; Van Lunen & Welch, 2010). Through controlled inputs, such a practice reduces clinically relevant dysfunctional symptoms and induces analgesic effects (Quevedo García et al., 2023). Indeed, manual therapy mechanically stimulates tissues and other physiological mechanisms that influence the patients' peripheral and central nervous systems, varying pain intensity (Bialosky et al., 2018).

Manual therapy

Therefore, manual therapy plays a fundamental role in the rehabilitation process, serving as one of the main pillars of health professionals, as well as physiotherapy, osteopathy, and chiropractic. It requires integrating complex clinical skills, including clinical reasoning, manual and functional assessment, palpation, communication skills, and individualised and specialised patient management (Farrell & Jensen, 1992; Michels et al., 2012). Within all manual therapy techniques, joint mobilisation techniques are amongst the most important, as such a method is aimed at decreasing the pain and restoring normal overall joint motion by maintaining or enhancing the proper interaction of the articular surfaces. Good results are accomplished through movements characterised by low velocity and a wide range of motion (Falla et al., 2024; Manske et al., 2019). Health professionals specialised in manual therapy operate these techniques routinely, and they are well tolerated by patients (Manske et al., 2019). Joint mobilisation integrates angular or physiological movements—such as flexion/extension, abduction/adduction, and internal/external rotation—within each joint's cardinal planes and translational or accessory movements within the joint structure. Both translational and angular movements are essential for achieving a complete and optimal range of motion (Falla et al., 2024; Manske et al., 2019). Therefore, it is essential to understand and master passive movements and biomechanics with synchronised joint mobilisations performed in a specific plane at a controlled pace and velocity (Falla et al., 2024; Kolb et al., 2020).

Manual therapy education

The main challenge in teaching manual therapy is to ensure that students develop the required psychomotor skills for joint mobilisations, integrating all the specialised movements to perform the techniques safely and effectively. Education in Health Sciences frequently apply the cognitive apprenticeship principles which emphasize guided learning through modeling, coaching, feedback, and reflection (Lyons et al., 2017; Stalmeijer et al., 2013). Commonly, the students attend a theoretical lecture observing the technique being demonstrated while the instructor performs on a student, a plastic anatomical model, or a patient (Bugaj & Nikendei, 2016; Easton et al., 2012; Kotsis & Chung, 2013). Afterwards, each student practices the techniques while the instructor assesses their performance and provides subjective feedback on the implementation of the technique (Bugaj & Nikendei, 2016; Easton et al., 2012; Flynn et al., 2006; Kotsis & Chung, 2013). By providing subjective feedback and guidance, instructors were believed to facilitate students' understanding of various techniques, physical examination skills, palpation, and treatment (Speirs & Brazil, 2018). This approach relies on the effectiveness of supervision, where teachers should demonstrate expertise, provide meaningful feedback, and show genuine care towards their students, as the quality of the supervisor-student relationship would be just as important as the supervision process itself (Kam, 1997).

Nevertheless, this teacher-centred approach has been considered inadequate for ensuring safe and effective technique instruction due to limited supervision, a lack of reflective practice, and ineffective methods for evaluating technical performance (Kotsis & Chung, 2013; Rodriguez-Paz et al., 2009; Romero et al., 2018). Additionally, a notable limitation concerns instructors' challenges in accurately detecting and analysing errors in students' motor techniques (Enebo & Sherwood, 2005; Flynn et al., 2006; Schmidt, 1979). Identifying and correcting such errors is critical for effective skill acquisition and the successful transfer of learning. However, the lack of structured, individualised feedback often hinders this process, particularly in contexts where the student-to-teacher ratio is high (Enebo & Sherwood, 2005; Flynn et al., 2006; Schmidt, 1979).

Technological innovations in manual therapy education

Some studies looked at alternative solutions to reduce the identification of errors, complementing the learning process with motion capture instruments like inertial sensors. Inertial sensors are placed on the subject and can detect the acceleration and rotations when a movement occurs. Such tools provide real-time feedback through objective kinematic parameters, such as glenohumeral or knee joint manipulations (Trinidad-Fernández et al., 2024; Wholohan et al., 2021). Although inertial sensors can provide valuable information during training, these may be unreliable due to an incorrect placement on the patient or the noise caused by skin movement and muscle contractions, which usually affect the quality of the readings (Morgado Ramírez et al., 2013; Weygers et al., 2021). A more recent digital technology, Immersive Virtual Reality (iVR), has shown positive educational results improving the learning experience and increasing motivation (Hamilton et al., 2021). iVR creates a virtual and controlled environment where the user is fully immersed, providing greater disconnection from the real world than usual Virtual Reality applications on computers. Such an immersion is achieved through head-mounted displays (HMDs) and haptic controllers interacting with the virtual world (Hamilton et al., 2021; Muhanna, 2015). Evidence shows that iVR in educational settings can enhance cognitive skills related to recalling and understanding information, improve psychomotor skills, reduce task completion times, increase engagement, minimise errors, and boost student motivation for learning (Allcoat & von Mühlenen, 2018; Jensen & Konradsen, 2018).

While Virtual Reality remains an emerging technology in health sciences education, (Lie et al., 2023), a recent scoping review highlighted positive outcomes across four areas of application: passive, non-surgical clinical skills, surgical and dexterous, and interpersonal (Philip & Savundranayagam, 2025). These 3D technologies are perceived by students as valuable complements to traditional methods and learning approaches, facilitating the acquisition of more complex skills, particularly psychomotor skills (Mat Sanusi et al., 2025). However, a practical iVR-based technology for manual therapy training has yet to be developed (Kovanur Sampath et al., 2023). Since such technology shows excellent potential as an educational tool, we hypothesise that it may also improve current teaching and support students in learning, practising and refining joint mobilisation techniques. Contrary to inertial sensors, iVR is entirely safe since it does not require peers to train and can provide better real-time feedback on performance (Kirkman et al., 2014).

Research questions

Therefore, the main objective of this project is to develop and test a new advanced teaching method for manual therapy mobilisations using immersive virtual reality as a complementary tool, allowing students to practice techniques more efficiently. To address this objective, we defined three Research Questions: (1) Does integrating iVR as a complementary tool to traditional teaching methods improve undergraduate physiotherapy students' performance in manual therapy joint mobilization techniques? (2) Which technical skills are improved through the use of iVR in executing joint mobilization techniques? (3) How do undergraduate manual therapy students perceive the use of iVR compared to traditional teaching? To answer these questions, we conducted a study with 43 students from the university to assess the effectiveness of our iVR application as a complementary tool to traditional teaching methods.

Femorotibial mobilization technique

Restrictions, stiffness, or misalignments in the femur (thighbone) and tibia (shinbone) usually reduce patients' mobility and fluid circulation, which increases pain and the possibility of ligament injuries (Lansdown & Ma, 2018). The femorotibial mobilisation technique aims to restore or enhance the functional mobility of the knee joint by coordinating two complementary movements, which are angulation and translation. The technique is a combination of movements alternating flexion and extension of the knees and a slight rotation and gliding, which impact both inside (translation) and outside (angulation) the joints.

To achieve the technique, the patient lies supine (face up) while the physiotherapist stabilises the malleoli (bony prominences located on either side of the ankle) of the affected knee between the physiotherapist's legs (see Fig. 1, left). The palms of the hands are positioned on either side of the tibial tuberosity (bony prominence located on the frontal surface

Fig. 1 Execution of the technique and placement of the therapist's hands

of the tibia, just below the knee joint), and the fingers are then placed on the soft tissue just below the popliteal fossa (diamond-shaped depression located on the back side of the knee joint) (see Fig. 1, right). From such a position, the physiotherapist will manipulate the leg with consistent and firm support throughout the exercise to ensure controlled movements.

Then, the physiotherapist induces flexion (up to around 90º) and extension (up to around 5º) of the patient's knee. The natural rotational motion of the knee during flexion is not restricted during the manipulation. As the knee flexes around 90º, the physiotherapist applies pressure on the anterior tibial surface to induce a posterior tibial translation. Oppositely, the therapist extends the knee from the maximal knee flexion range while supporting the anterior translation of the tibial plateau. Both combinations of movements must be synchronised at an adequate sequence between one repetition and another (1 iteration per second approximately).

Immersive virtual reality learning experience

The main objective of the iVR Learning Experience is to provide a safe and controlled environment where users can learn and practice the Femorotibial mobilization technique described in the previous section.

Hardware

The Immersive Learning Experience was developed for the Meta Quest 2 Virtual Reality device (Meta Platforms, Inc., Menlo Park, CA, USA). The device comprises a wireless headset and two manual controllers (see Fig. 2, left). Key technical specifications include

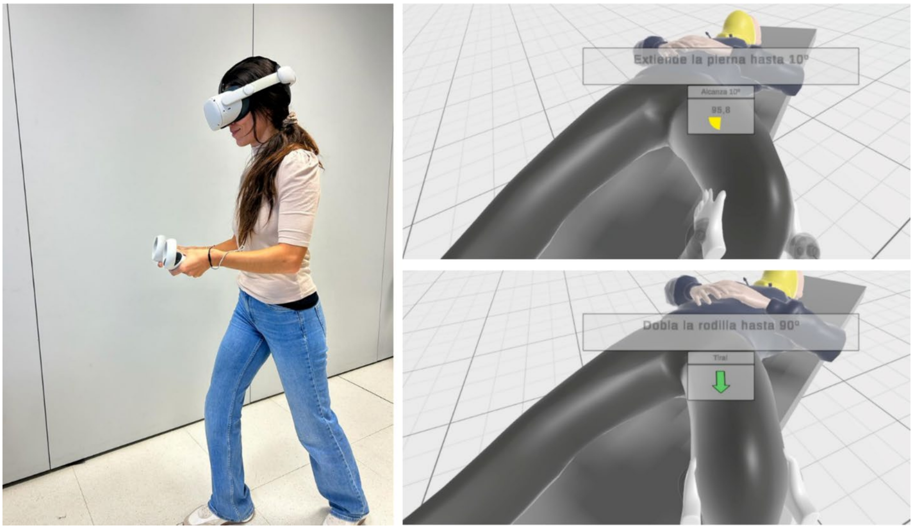

Fig. 2 iVR device placement and application showing knee angle and push timing/location for movement guidance.

an LCD display with a resolution of 1832 × 1920 per eye, a refresh rate of up to 90 Hz, a Qualcomm Snapdragon XR2 processor, 6 GB of RAM, 128 GB of storage, four infrared cameras, and built-in speakers. The accuracy of data position and orientation obtained from the headset and controllers have been validated as candidates for rehabilitation (Carnevale et al., 2022; Trinidad-Fernández et al., 2023).

Software

Users are immersed in the virtual world with a first-person perspective as if they were themselves in the room (see Fig. 2, right). They are transported to a clinician's room with a table, and an articulated avatar representing the patient laid down in the supine position (face up). The users can freely observe the environment by moving their heads and can move within a range of approximately 1 m to position themselves comfortably near the patient. Users can only interact with the patient's left leg using the controllers, which are represented in the world with virtual hands mirroring position and orientation. Once the users grasp the avatar's leg, all the movements are calculated following physical principles to provide a manipulation as if it were real, wherever the leg is grasped.

Tutorial

During the tutorial phase, the system entirely controls the interaction, and the user cannot move to the next step until completing the current one. The system offers visual feedback to guide the user step-by-step. On the one hand, specific areas are highlighted to show where to place the hands (step ii) or move the leg (step iii), a panel with an interactive semi-circle that indicates the angulation (see Fig. 1 top right), which turns green when reaching the adequate angle range (step iv and vi), the same panel will show an arrow pointing towards the direction where the push movement should be performed (step v and vii) (see Fig. 1 bottom right). At any time, another panel will indicate what to do with short instructions such as “flex the knee until reaching 10º” or “push the knee towards the ground”.

Practice

During the practice phase, the system provides freedom of interaction to the users. They will still receive feedback and instructions but can manipulate the legs freely. The frequency was added in this phase since the technique should be performed in a minute, including 30 iterations of knee flexion–extension. Therefore, new feedback is provided with an indication of whether they are performing too fast or too slow.

Methods

This study was designed as a Mixed-Methods Cluster Randomized Controlled Trial. The cluster-randomized controlled trial refers specifically to the quantitative experimental component of the mixed-methods design. Cluster randomization was applied at the class level, rather than the individual level, to accommodate the educational setting and avoid contamination between participants. This approach is commonly used in educational research when intact groups are involved. The mixed-methods framework combines this quantitative design with qualitative data collection to provide complementary insights into students’ experiences; however, the cluster-randomized trial itself is not a qualitative method. The reporting of the quantitative trial component follows the CONSORT guidelines for cluster-randomized trials (Campbell et al., 2012). A flow chart was added as Supplementary Material 2.

Participants

The participants were recruited at the University of Málaga, Spain and were students pursuing a bachelor’s degree in Physiotherapy. Students with prior experience in knee manual therapy, a history of upper or lower limb surgery or fractures within the year preceding the study, or joint dislocations within six months before the study began were excluded. The participants were in four pre-established classes, and each class was referred to as a cluster (Cluster 1 n = 11, Cluster 2 = 10, Cluster 3 = 9, and Cluster 4 = 13). In total, 43 students participated in this study. Participants’ age was 21.4 (SD = 2.8), which included 28 males and 15 females.

All the final participants were asked to sign a written informed consent. The study was approved by the Ethical Committee of the University of Málaga (55-2023-H) and developed following the Ethical Principles for Medical Research Involving Human Subjects (Helsinki Declaration). The European Union’s General Data Protection Regulation (GDPR, 2016) was followed to protect data, ensuring robust privacy and data security standards.

The clusters were randomly assigned using a computerized random number generator (Random.org): Control Group (CG) followed by the traditional teaching Methods Group (12 males and 9 females) and the Experimental Group (EG) (16 males and 6 females) who combined traditional teaching methods with the iVR experience. No significant differences were observed between the groups in the age ($p = 0.665$) in the one-way ANOVA test and the gender ($p = 0.426$) in the Pearson Chi-Square test.

Protocol

The study was conducted in January 2024 in a skills laboratory at the university. Both control and experimental groups received the traditional teaching methods first. A full professor with over 20 years of experience in manual therapy taught the complete execution of the technique step by step and performed a visual demonstration to the whole class. Afterwards, the students practised with each other, alternating roles as therapist and patient for the remaining session time. Meanwhile, the professor supervised the students, providing specific guidelines and adjusting the execution of the technique when necessary.

While all the participants of the CG practised for the whole 90 min, the students from EG took turns two by two in a different room to put on the two available virtual reality headsets for the iVR experience. The iVR experience lasted 10 min, beginning with a brief explanation of the key concepts of technology, followed by the tutorial mode, and concluding with the practice mode. All the participants of EG finished the iVR intervention.

Data was collected at the end of the session when all participants completed an online questionnaire about their learning experience and the following week, when a different professor, also an expert in manual therapy, evaluated the execution of the technique by all participants based on specific criteria, which are described in the following section.

Data collection

User experience

We collected data from both groups regarding their feelings about the overall experience. For that purpose, we used the software Limesurvey (The LimeSurvey Project Team), which was installed on the university's servers and allows the participants to fill in questions from their devices (phones, tablets or laptops).

Regarding user experience, all the participants were asked to answer the Spanish version of the Short Version of the User Experience Questionnaire (UEQ-S) (Rauschenberger et al., 2013; Schrepp et al., 2017). The questionnaire consists of 8 items on a 7-point Likert scale, where each item is a pair of opposite adjectives. It measures two dimensions: pragmatic quality (obstructive-supportive, complicated-easy, inefficient-efficient and clear-confusing) and hedonic quality (boring-exiting, not interesting-interesting, conventional-inventive and usual-leading Edge). The higher the item score, the more the student's opinion aligns with the term on the right, which is the most positive, and vice versa. The short version has shown adequate internal consistency (Cronbach's $\alpha = 0.81–0.85$) (Schrepp et al., 2017).

Furthermore, all the participants from both groups were asked to conduct an ad-hoc survey providing a response based on a 5-point Likert scale, where 1 represented "Not at all" and 5 "Very much" of three specific questions about the intervention: (1) Do you feel that you effectively retained and understood the concepts of manual therapy? (2) How satisfied are you with the learning methodology you experienced today? and (3) Did you feel highly motivated by today's methodology to learn the manual therapy technique?

iVR experience

The participants from the experimental group (EG) were asked to fill in the Spanish version of the Simulator Sickness Questionnaire (SSQ) to measure motion sickness after the experience (Stanney et al., 1997). This questionnaire analyzes the possible adverse effects that iVR experiences may cause, including dizziness, nausea, and visual impairments. It consists of 16 items rated from "None" (0) to "Severe" (3) and categorized into three dimensions: nausea, mobility disorders, and disorientation. The total score can be classified into five categories: negligible (<5), minimal (5–10), significant (10–15), concerning (15–20), and bad simulator (>20). The original version has shown adequate internal consistency (Cronbach's $\alpha = 0.94–0.95$) (Sevinc & Berkman, 2020).

The participants from EG were also asked to answer open questions (OQ), designed through consensus among the research team members, to help understand their lived experience with the VR intervention. The questions were: OQ1) How would you describe your experience using virtual reality in learning manual therapy? OQ2) What virtual reality elements did you find most beneficial for learning manual therapy concepts? OQ3) In what ways did virtual reality exceed expectations or fall short compared to traditional teaching methods?

Learning experience

Both groups were evaluated one week after the intervention based on a specific ad-hoc rubric for the femorotibial mobilization technique taught in the course. The criteria were qualitatively developed by a group of expert manual therapy professors at the university and assess various characteristics that students need to perform and consider for optimal execution, using a scale from 1 (Unacceptable) to 4 (Excellent): Patient and therapist placement (10% of the final score); Position of the therapist's hands (10% of the final score); Position of the patient's lower limb (10% of the final score); Height of the stretcher (10% of the final score); Quantity of angulation movement (20% of the final score); Synchrony of angulation and translation (20% of the final score); and Cadence of repetitions (20% of the final score). The rubric was added as Supplementary Material 1.

Statistical analysis

The sample size was calculated a priori with R Studio software. Parameters included in the calculation were: significance level $\alpha = 0.05$, number of cluster $K = 4$, effect size $\delta = 0.90$, intra-class correlation coefficient $\rho = 0.01$, statistical power $(1–\beta) = 0.80$. A final sample size of at least 44 participants was estimated.

The responses of the qualitative study were imported into "Atlas.ti" (version 9) through a set of open questions about the iVR experience to assist in managing and organizing the information during the analysis. An inductive and qualitative content analysis was performed following these steps: (1) Repeated reading of the transcribed responses to gain a general impression of the information; (2) Identifying meaning units or phrases that convey the same meaning; (3) Open coding of the meaning units with codes that summarize the content; (4) Grouping these codes into categories and subcategories; (5) Synthesizing and describing the categories and subcategories; (6) Reviewing the categories and reorganizing them if necessary (Elo & Kyngäs, 2008).

The rest of the quantitative data about user experience (UEQ-S, 3 specific questions), iVR experience (SSQ) and learning experience (Grades) were all presented by their mean and standard deviation. The Statistical Package for Social Sciences (SPSS 21) was used for the statistical analysis. A multilevel linear model was conducted to evaluate between-group differences in outcome variables following a cluster-randomized controlled trial. The design included four clusters, with two allocated to the experimental group and two to the control group. Given the hierarchical structure—participants nested within clusters—and the availability of post-intervention data only, a two-way mixed nested ANOVA/ANCOVA was applied. Group (experimental vs control) was entered as a fixed effect and random intercepts were specified for clusters to account for intra-cluster correlation.

Results

A total of 43 participants took part in the intervention of this study. The average age in the CG was 22.0 (± 3.3), with 42.8% females, while in the EG, the average age was 20.9 (± 2.2), with 27.2% females.

User experience

Table 1 presents the user experience outcomes from this study. Regarding the UEQ-S, both groups selected the most positive rating for all the categories (> 4 points). While the traditional methodology was significantly perceived as easier ($p = .015$, $d = 0.57$), more efficient ($p = .049$, $d = 0.73$), and clearer ($p = .043$, $d = 0.84$) than the innovative methodology, the latter was better described as inventive ($p < .001$, $d = 0.88$) and leading-edge ($p < .001$, $d = 0.91$).

Regarding the key satisfaction questions, both groups were satisfied with their learning experience regardless of the methodology received (> 3 points). However, the CG showed a significantly higher feeling of having effectively retained and understood manual therapy concepts ($p = .008$, $d = 1.02$). In contrast, the EG significantly felt more motivated to learn manual therapy ($p = .045$, $d = 0.79$).

iVR experience

The motion sickness experienced by the group using iVR was categorised as negligible, with a final SSQ score of 3.8 (± 3.4). Nevertheless, two participants felt significant discomfort with the technology (10–15 points).

All participants in the experimental group (EG) answered the three open-ended questions, and the synthesised and analysed responses are presented in Tables 2–4 for the three open questions (OQ1, OQ2 and OQ3), respectively. The results for each question are divided into categories and subcategories, along with the occurrences and percentages, with a representative quote associated with it.

Regarding OQ1, "How would you describe your experience using virtual reality in learning manual therapy?", the main categories were defined as positive and negative aspects, where positive aspects (86.5%) outweighed negative aspects (13.5%). The most frequently mentioned positive aspects were that it was curious and original (45.9%),

Table 1 Mean and standard deviation for usability outcomes

		CG M (SD)	EG M (SD)	−2LL	F	p	Cohen's d
UEQ-S *(1–7)*	Obstructive—Supportive	5.4 (1.4)	5.2 (1.3)	146.2	0.2	.618	0.11
	Complicated—Easy	5.6 (1.2)	4.5 (1.5)	146.6	6.4	**.015***	0.57
	Inefficient—Efficient	6.2 (1.0)	5.1 (1.3)	139.3	8.4	**.049***	0.73
	Confusing—Clear	6.2 (1.0)	5.1 (1.2)	134.5	9.0	**.043***	0.84
	Boring—Exiting	5.4 (1.1)	5.5 (1.1)	132.2	0.1	.740	0.09
	Not interesting—Interesting	5.9 (1.1)	5.9 (1.1)	130.8	0.0	.884	0.04
	Conventional—Inventive	5.0 (1.8)	6.5 (0.7)	147.2	15.1	**<.001***	0.88
	Usual—Leading edge	4.7 (2.0)	6.6 (0.5)	155.2	19.2	**<.001***	0.91
Usability Question 1—Do you feel that you retained and understood manual therapy concepts effectively? *(0=Nothing, 5=A lot)*		4.5 (0.6)	3.8 (0.9)	106.1	7.7	**.008***	1.02
Usability Question 2—How satisfied are you with the learning methodology you experienced today? *(0=Nothing, 5=A lot)*		4.1 (0.7)	4.1 (0.7)	95.2	0.1	.701	0.16
Usability Question 3—Did you feel very motivated with today's methodology to learn the manual therapy technique? *(0=Nothing, 5=A lot)*		3.8 (0.9)	4.3 (0.6)	103.0	4,2	**.045***	0.79

CG Control group, *EG* experimental group; *UEQ-S* short version of the user experience questionnaire, *M* mean, *SD* standard deviation, *–2LL* −2 log likelihood

*p < .05

Table 2 Categories, subcategories, and textual quotes for the open question 1

(OQ1) How would you describe your experience using virtual reality in learning manual therapy?

Category	Subcategory	Mentions of the code (%)	Representative quotations of the code
Positive aspects		32 (86.5%)	
	Curious and original	17 (45.9%)	"Something new since I had never experienced it before"
	Learning aid	5 (13.5%)	"It can help us when learning a certain technique"
	Motivating	4 (10.85)	"Very interesting and motivating"
	Funny	3 (8.1%)	"Fun and original"
	Difficult at first and then easy	2 (5.4%)	"At first it leaves you a little strange, but then when you get used to it and get the hang of it, it's fun to do."
	Related to physiotherapy	1 (2.7%)	"I liked that it was about physiotherapy."
	To practice at home	1 (2.7%)	"Very useful when it comes to practicing at home"
Negative aspects		5 (13.5%)	
	Doubts about the transfer to reality	2 (5.4%)	"I felt it was not really close to reality."
	Confusing	1 (2.7%)	"Confusing, really"
	Some problems in usability	1 (2.7%)	"Sometimes it causes problems with hand colocation in the segment or registering the movement."
	Uncomfortable	1 (2.7%)	"The glasses were quite uncomfortable."

helpful for learning (13.5%), and motivating (10.8%). The most repeated negative aspect (5.4%) was the doubt about real-world transferability (see Table 2).

For OQ2, "What virtual reality elements did you find most beneficial for learning manual therapy concepts?" codes and subcategories were unified based on the characteristics of the intervention as described by students. The beneficial characteristics were grouped into three categories: feedback (54.5%), learning process (24.2%), and iVR-specific features (6.0%). The most frequently mentioned codes fell under the feedback category, with the following subcategories: real-time feedback (30.2%), knee angle practice (15.1%), and hand grip practice (12.1%) (see Table 3).

The OQ3 "In what aspects did virtual reality exceed expectations or fall short compared to traditional teaching?" led to a categorisation of responses into "Exceeded Expectations" and "Did Not Exceed Expectations." Most of the responses (70.5%) indicated that iVR exceeded expectations. The most frequently mentioned subcategories under this category were feedback (11.7%), sensitivity (11.7%), its value as a practical tool (8.8%), and the motivation and ease of learning it provided (8.8%). On the other hand, the most repeated concern (20.5%) under "Did Not Exceed Expectations" was that iVR was not realistic enough (see Table 4).

Learning experience

The execution of the technique was graded for both groups, where the EG showed a significantly higher overall evaluation score of 8.3/10 against 7.2/10 ($p = .010$, $d = 0.65$) (see Table 5). While most of the rubrics did not show a significant difference between both groups, EG obtained a significantly higher score in synchronising angulation and translation of the technique ($p < .001$, $d = 1.88$). There was a trend favouring the EG in repetition cadence ($p = .056$, $d = 0.81$).

Discussion

This study aimed to integrate a novel and interactive approach to complement traditional teaching on manual therapies with an iVR application. Previous studies showed positive results with the use of iVR applications in education (Speirs & Brazil, 2018), even in health education, showing good acquisition of technical knowledge (Kovanur Sampath et al., 2023; Philip & Savundranayagam, 2025). This research is the first mixed-method experimental study that applies such an approach to teaching manual therapy techniques.

The learning outcome was evaluated for both control (CG) and experimental (EG) groups a week after the corresponding lesson with an execution of the technique. One of the most relevant findings is that students in EG achieved a higher final score, directly addressing RQ1. Only two out of eight parameters were significantly different. The technique's specificity emphasizes the deformation of tissues at precise locations, also considering the limb's weight (Kerry et al., 2024), which cannot be felt in a non-haptic virtual experience. The results suggest that manual therapy requires hands-on practice in its learning process, and thus, the iVR experience, as a standalone intervention, should not seek to replace traditional training but complement and ensure an optimal learning experience (Allcoat & von Mühlenen, 2018). Recently, the integration of external haptic devices with head-mounted displays has been explored to support learning of tissue stiffness perception, enabling more realistic hands-on practice through synchronized visual and haptic

Table 3 Categories, subcategories, and textual quotes for the open question 2

(OQ2) What virtual reality elements did you find most beneficial for learning manual therapy concepts?

Category	Subcategory	Mentions of the code (%)	Representative quotations of the code
Regarding feedback		18 (54.5%)	
	Real-time feedback	10 (30.2%)	“The fact that it gives you visual feedback on all the parameters, for example, knowing how many degrees you’re bending your knee at the moment, is very useful. It’s very appreciated to have that feedback when performing the technique.”
	Knee angulation movement practice	5 (15.1%)	“Practice the angles you apply to the patient and get feedback.”
	Practice hand colocation	4 (12.1%)	“The use of the controls simulates very well where the hands should be placed when doing the therapy.”
Regarding learning		8 (24.2%)	
	Learning with VR	2 (6.0%)	“Especially learning through virtual reality.”
	Independent learning	2 (6.0%)	“The possibility of learning without patients”
	Better learning of prior knowledge	2 (6.0%)	“Learning motor patterns without the need for a second person reinforces the knowledge we have learned in class, and by doing so we learn more.”
	Preparation for the exam	1 (3.0%)	“Being able to take pre-tests where you can practice for an exam.”
	Motivation	1 (3.0%)	“Fun combined with learning greatly influences motivation and the desire to work and learn.”
Regarding the characteristics of the iVR		6 (6.0%)	
	Immersion	3 (9.0%)	“I felt like I was part of the game, and that’s what motivated me the most.”
	Fluency	1 (3.0%)	“The quality of fluidity when performing the technique”

Table 4 Categories, subcategories, and textual quotes for the open question 3

(OQ3) In what aspects did virtual reality exceed expectations or fall short compared to traditional teaching?

Category	Subcategory	Mentions of the code (%)	Representative quotations of the code
Expectations exceeded		24 (70.5%)	
	Feedback	4 (11.7%)	“She surpassed him in that he knew at all times how far to take his leg and perfectly indicated the parameters of the technique, when to pull, with what intensity to push.”
	Sensitivity	4 (11.7%)	“The controls are very sensitive”
	Practical tool	3 (8.8%)	“I see it as a very useful tool for integration.”
	Motivation and ease of learning	3 (8.8%)	"It exceeded expectations in terms of motivation compared to the traditional approach, as I was able to focus much longer and be eager to teach in this new way."
	Support the concentration	2 (5.8%)	"It is not something you do every day, and it encourages you to focus more on what you want to do and achieve it."
	Innovative	2 (5.8%)	“I surpass him in terms of originality and the constant feedback he provides.”
	Practice in first person	1 (2.9%)	“Finding yourself in practice in the first person”
	Realistic	1 (2.9%)	“It’s very realistic and you feel like you’re really learning.”
	Comfortable	1 (2.9%)	“It surpassed comfort and fatigue, you don’t get tired at all”
	Image focus	1 (2.9%)	“When focusing the image”
	Good experience	1 (2.9%)	“It exceeded my expectations since I had never tried it before and I enjoyed the experience.”
	Interactive	1 (2.9%)	“It was better because it was more interactive than a theoretical class.”
Expectations not exceeded		10 (29.4%)	
	Unrealistic	7 (20.5%)	“He failed in tact and sensitivity with real patients.”
	Confusing	1 (2.9%)	“It may be a little confusing because it’s not something we’re used to using in our daily lives.”
	Uncomfortable	1 (2.9%)	“Failed in comfort”
	Sceptical with VR	1 (2.9%)	“It didn’t answer my questions about virtual reality.”

Table 5 The results of the learning experience were evaluated with a rubric from 1 (unacceptable) to 4 (excellent)

	Weight	CG M (SD)	EG M (SD)	−2LL	F	p	Cohen's d
Patient and therapist placement	10%	2.9 (0.2)	3.0 (0.0)	*Not enough variance to model*	1.1	.30	*Not enough variance to calculate*
Position of the therapist's hands	10%	2.3 (0.6)	2.0 (0.5)	79.2	3.2	.078	0.91
Position of the patient's lower limb	10%	2.9 (0.3)	2.8 (0.3)	24.0	0.1	.676	0.40
Height of the stretcher	10%	2.1 (0.5)	2.3 (0.6)	73.5	0.3	.610	0.35
Quantity of angulation movement	20%	2.0 (0.8)	2.2 (0.6)	100.1	0.9	.342	0.36
Angulation and translation synchrony	20%	1.6 (0.9)	2.6 (0.4)	95.9	20.3	**< .001***	1.88
Cadence of repetitions	20%	2.1 (0.8)	2.5 (0.6)	96.7	3.8	.056	0.81
Final evaluation score	100%	7.2 (1.5)	8.3 (1.0)	142.5	7.33	**.010***	0.65

CG Control group, *EG* experimental group, *M* mean, *SD* standard deviation, *−2LL* −2 log likelihood

feedback (Kovanur Sampath et al., 2023). Within the specific skills of the execution of the technique, as examined in RQ2, EG outstood better synchronization between angulation and translation movements. This finding is particularly relevant, as the assimilation of both movements, which must be synchronized precisely, is one of the most challenging aspects of correctly performing the joint mobilization technique (Wholohan et al., 2021). This synchronization is computed through quantified kinematic analysis derived from the embedded sensors of the controllers and headset. These data provide real-time feedback to learners, enabling them to adjust their performance and master the technique more effectively. Similarly, manual therapy instructors could benefit from this quantitative feedback to assess and score learning outcomes, which are currently evaluated primarily through visual observation and are therefore less precise (Petersen et al., 2020).

As this is a novel educational approach in manual therapy, literature is scarce to contrast our results with similar studies, and thus, we draw on research in other areas of health professional learning with VR interventions. For instance, our results are consistent with the learning outcomes in anatomy through interactive iVR experiences where students manipulated 3D models, which supports the understanding of spatial relationships between the different body structures (Lucena-Anton et al., 2022). Similar results have been reported with iVR experiences in nursing education, improving students' preparedness for complex clinical situations (Mørk et al., 2024). On the other hand, concerning decision-making, an essential aspect of a physical therapist's role when interacting with patients, a study showed that learning outcomes with the iVR methodology were slightly worse than traditional methods (Bonnin et al., 2023; Hartstein et al., 2022). This latter used 360° videos to immerse the participants within different clinical situations in a system with scarce interaction. Oppositely, another study showed that an interactive iVR experience improved anatomical knowledge and refined participants' decision-making process in cerebrovascular neurosurgery (Sugiyama et al., 2021). The above-mentioned studies where iVR increased learning outcomes share a common aspect: an interactive experience with real-time feedback. This was also described in other fields such as engineering (Spangenberger et al., 2025), which reinforces the positive impact of iVR on learning in classroom settings in addition to traditional cognitive apprenticeship. Overall, the advantage of such a technology is that it guides students step by step through the learning process while providing objective and context-adapted feedback, which is more effective in skill acquisition than the traditional method (Lohre et al., 2020; Villegas-Ch et al., 2024).

While our results demonstrate significant improvements in learning outcomes, it was also essential to assess participants' subjective experiences, as explored in RQ3. In this study, those experiences were characterised by a degree of ambivalence. On the one hand, methodology with iVR experience was better appreciated and described as "inventive", "leading edge", "curious", "helpful", and "motivating". Similar conclusions were found in several studies in the healthcare educational field, as providing more enjoyment and usefulness than the traditional methodology (Bonnin et al., 2023; García-Robles et al., 2024; Lucena-Anton et al., 2022). Additionally, some students reported that this approach motivated them to engage more actively in learning, which can be attributed to the emotional value inherent in iVR techniques (Allcoat & von Mühlenen, 2018; Makransky & Lilleholt, 2018; Makransky et al., 2021). On the other hand, more than 20% of the participants' comments about expectations of using iVR highlighted the lack of realism or interaction, as the physical contact with a joint and the weight of a real limb cannot be fully replicated in the iVR experience. CG felt that the presentation of content was "clearer", "easier to use", and "efficient". Compared to traditional methods, iVR can be challenging to use at first (Allcoat & von Mühlenen, 2018) or require more mental load, which may lead to distraction and, eventually, poorer learning outcomes (Makransky et al., 2019). Therefore, it is primordial to maintain an intuitive interface with a guided experience so that participants can focus on the content more than on the experience itself. Finally, few participants suffered significant discomfort using the iVR experience according to the SSQ score, reinforcing the idea of using iVR as a complement to traditional teaching.

Limitations

The main limitation of this study was that the iVR experience was not allocated a distinct time slot but was instead delivered concurrently with traditional learning methods within the same session, where the students rotated from practising with their peers under the supervision of the teacher to a different room using iVR headset. This procedure may have introduced bias by disrupting the continuity of the learning experience, potentially causing cognitive load or confusion. A technological limitation lies in the gap between the virtual and real environments, primarily due to the absence of haptic feedback, which can reduce the sense of immersion and may consequently hinder the overall learning experience (Grassini et al., 2020). Furthermore, this study is limited by its small sample size and by participants' exposure to the iVR experience on a single occasion. Regarding qualitative analysis, as the study was not designed to generate or validate theory, inductive qualitative content analysis was considered appropriate; however, future evaluations could adopt grounded theory methods to provide a deeper, theory-generating analysis of open-ended questionnaire responses.

Conclusions

While VR experiences have been increasingly used in education in the last decade, manual therapy education keeps following the traditional approach. We propose the first study that evaluates the impact of an iVR experience on learning outcomes in manual therapy for the joint mobilization technique. To ensure that this study provides the highest quality of evidence, we followed a randomized controlled trial with a mixed-methods approach, integrating both qualitative and quantitative dimensions.

The iVR experience was used as a complementary tool to traditional teaching methods, and the results showed an overall improvement in the final performance score. Specifically, participants in EG demonstrated better synchronization of translational and rotational movements, which are fundamental to the effective execution of joint mobilization techniques. Furthermore, regarding usability, participants revealed that the iVR experience promoted engagement and motivation in learning manual therapy.

However, iVR may not be adapted to everyone since it can generate significant discomfort, and several participants felt confused by the experience, which can be due to the lack of haptic feedback and specific sessions dedicated to iVR training. Further studies should consider these limitations while developing more experiences to learn other manual therapy techniques.

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Author contributions MTF contributed to the conceptualization of the idea, data interpretation, study supervision, and manuscript writing. BB contributed to the development of the virtual reality application, data analysis, data interpretation, and manuscript writing. IJFA worked on data interpretation and manuscript supervision. CGC contributed to data acquisition and manuscript supervision. DMV contributed to data acquisition, data analysis, and manuscript supervision. EDB contributed to data acquisition. ACV contributed to the conceptualization of the idea and study supervision.

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Data availability The datasets generated and/or analysed during the current study is available in an open repository: https://riuma.uma.es/xmlui/handle/10630/38919.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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