Implicit Learning of Professional Skills through Immersive Virtual Reality: a Media Comparison Study

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Abstract

This study investigates the effectiveness of Immersive Virtual Reality (IVR) compared to traditional slideshow lessons in teaching implicit knowledge. For this purpose, the research focuses on professional decision-making skills in viticulture. Most existing research on immersive learning concentrates on explicit learning strategies. In contrast, this study explores the potential of IVR to foster the transfer of implicit knowledge to real-world situations.

Forty third-year engineering students were randomly assigned to an IVR or a traditional slideshow group. They learned to assess vine vigour through an implicit learning phase, followed by a real-world evaluation in an actual vineyard. Learning outcomes were measured by decision-making accuracy, response time, and intrinsic motivation.

The findings show that the IVR group did not significantly outperform the slideshow group in decision-making accuracy. However, the IVR group took more time to make decisions. This observation suggests an impact of immersion during the transfer to real-world situations. Additionally, the IVR group showed a higher level of intrinsic motivation than the slideshow group.

These results suggest that although the immersion effect does not directly enhance learning outcomes for this cognitive objective, it does affect how knowledge is transferred to the real world. They also confirm that the positive impact of immersion is difficult to generalize and may depend on the nature of the knowledge. Still, the immersion effect significantly improves learner motivation. This consistent finding could be a key factor in long-term educational success. Further research exploring the nuanced effects of immersion on different learning strategies and educational objectives could offer new practical perspectives for the future of educational technologies.

Keywords: Immersive Virtual Reality; Immersive Learning; Implicit Learning; Professional Skills Acquisition; Educational Technology

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Index terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—Interaction design—Empirical studies in interaction design

1 Introduction

The rise of educational technologies offers new opportunities for experiential learning approaches by engaging learners in more immersive experiences [32]. These approaches are grounded in old theories with the widely accepted idea that learners progress by actively participating in tasks, often called “learning by doing” [11]. By engaging in these activities, learners gain insights that help them understand and apply their experiences to real-world contexts. This process reflects the natural way human development occurs, where experience plays a crucial role in children's growth [41]. Despite the potential of these constructivist approaches, further empirical validation is needed in the context of educational technology [32]. Therefore, while immersive technologies bring forward fresh perspectives on experiential learning theories, they also offer a valuable chance to demonstrate the benefits of these methods and enhance teaching practices.

1.1 Implicit learning in immersive environments

Among the various pedagogical strategies supported by immersive technologies, implicit learning stands out for its alignment with experiential approaches and world-centred information processing. Implicit knowledge, or complex procedural knowledge, is the ability to turn information into a general rule without being able to explain its complexity [26, 46]. This phenomenon can be observed in many daily situations. For example, recognizing an emotion on someone's face or making decisions while driving happens unconsciously and quickly without being able to detail all the factors involved. Implicit knowledge is constructed through repeated exposure and feedback [46]. This strategy mirrors how humans naturally acquire knowledge through experience [41]. Foundational research has shown that people can learn to identify if a grammatical sequence is correct or incorrect after repeatedly seeing sequences of letters created by an artificial grammar [45]. Another early study has shown that individuals can unconsciously predict the location of a target after repeated exposure to a sequence of stimuli in a complex task without being aware of the underlying pattern [26]. Unlike explicit learning, implicit learning does not rely on deliberate instruction or conscious reasoning. It enables the acquisition of complex skills without requiring verbal explanations or structured steps. Feedback plays a central role in reinforcing internal patterns and supporting the integration of knowledge at an unconscious level. Repetition also plays an essential role in this process. Combined with feedback, it strengthens the recognition of patterns over time. While feedback and repetition form the structural foundation of implicit learning, motivation helps sustain these processes. A high level of motivation in learners supports the repetitive nature of the learning task by maintaining engagement throughout the process [16]. Implicit learning strategy also offers a natural fit to environments designed to engage learners through action and immersion. A theoretical approach has been proposed to use virtual environments as an experiential component in implicit learning strategies [8]. Through implicit learning, individuals can strengthen the capabilities needed for intuitive decision-making, particularly in dynamic and time-constrained scenarios [8]. This connection is supported by findings showing that implicit learning and intuitive decision-making share common neural and cognitive processes [27]. However, this approach has not been explored in other learning domains unrelated to high-stakes environments like military operations and emergency response. Therefore, investigating this strategy using IVR in STEM education seems relevant for developing intuitive skills in performing professional tasks.

1.2 Objectives and rationale

IVR learning research faces the challenge of empirically assessing learning theories while considering the diversity of knowledge types and levels. At this stage, most studies focus on information retention rather than higher-level cognitive processes, such as applying knowledge in new situations [21]. Furthermore, most studies explore a form of learning where learners are passively engaged through explicit learning strategies that rely on written or verbal narration [9].

However, implicit learning strategies, which focus on learning through engaging activities, seem particularly well-suited to the potential of IVR [48]. This study introduces an experimental approach to evaluate the transfer of a professional skill learned through implicit learning into real-world situations.

Participants in this study were divided into two groups. One group received an immersive lesson (IVR group), and the other received a traditional slideshow lesson (Slideshow group). Their performance in a real-world decision-making task was measured by success rate and decision-making time. Additionally, we explored whether the immersive experience fostered greater intrinsic motivation in the learning activity. These investigations were guided by the following research questions:

RQ1: Does the immersion provided by virtual reality allow for better real-world transfer than a non-immersive medium in the case of an implicit learning activity?

RQ2: Is the immersion provided by virtual reality more motivating than a non-immersive medium in the case of an implicit learning activity?

2 THEORY

2.1 Virtual reality in comparative media studies

Research on virtual reality learning has faced criticism due to methodological weaknesses, especially the need for a control group and inferential statistics [12, 17, 21]. A research method has been suggested to address this issue by comparing virtual reality with other learning media. It aims to elucidate how knowledge acquisition in virtual reality differs from traditional formats like slideshow or non-immersive environments. A requirement for this method is to ensure that the content is equivalent when comparing different media [39]. Therefore, studies comparing virtual reality focus on the immersion effect with the same educational content.

Regarding the learning experience, the literature strongly agrees that immersion significantly promotes learner intrinsic motivation and engagement compared to less immersive media [12, 34]. Intrinsic motivation refers to engaging in an activity for its inherent interest and enjoyment [10]. A meta-analysis of 15 recent studies found a large effect size ($g=0.85$) of immersion on engagement [6]. Additionally, a study using a structural modeling approach found that presence and embodiment positively impact motivation, which in turn increases cognitive engagement [20]. The structural modeling approach also shows that motivation does not gradually decline over time due to familiarity [20]. These results suggest that the increased motivation frequently observed in IVR learning is not linked to a novelty effect.

Although a meta-analysis found a small positive effect of immersion on learning, the results revealed a heterogeneity in outcomes [52]. This is evidenced by the wide range of reported effect sizes, from −0.94 to 1.936. These findings highlight that the impact of immersion on knowledge acquisition is still unclear. For instance, a study on a virtual tour of the Sistine Chapel showed that learners in IVR felt more spatially present but did not learn better than those in the non-immersive condition [19]. Similarly, a study on a virtual biology lab lesson showed that learners in IVR had a higher sense of presence but worse learning outcomes [31]. Two studies on cellular biology lessons found that learners in IVR felt more positive than the learners in a slideshow setting, but their learning outcomes differed [15, 40]. One study reported better recall performance [15], while the other found worse recall performance [40]. These mixed results suggest that the relationship between immersion and learning is not direct and may depend on the educational design and the learning strategy. In some cases, immersion may enhance learning through increased motivation and cognitive engagement [30]. In other cases, it may result in cognitive overload, where too much information overwhelms learners [34].

2.2 Explicit learning and cognitive load

Cognitive overload occurs when the amount of information to be processed exceeds the learner's working memory capacity [51]. This issue has been observed in 5 out of 26 studies on IVR that focus on cognitive load [44]. Cognitive load theory identifies three types of cognitive load during explicit learning: intrinsic, extraneous, and germane.

The intrinsic cognitive load of a task depends on its complexity and the level of interactivity between its components [51]. More complex tasks have a higher intrinsic cognitive load. Extraneous cognitive load is caused by poor instructional design, which includes unnecessary elements that do not need to be processed [51]. Finally, germane cognitive load is the internal cognitive process to organize information into a clear and coherent structure [51].

Sensory stimulation is much higher in IVR than in non-immersive media. However, not all the information provided may be relevant to the educational objective. Thus, irrelevant information can distract learners and interfere with processing essential content. This increase in irrelevant information can overload working memory, challenging learning in IVR [34].

One promising solution to this obstacle is to use multimedia learning techniques to reduce extraneous cognitive load [37]. Multimedia learning combines verbal content as narration with visual content as animation following specific principles of instructional design [33]. For example, a IVR lesson on the human body showed that segmenting narrative content into four parts enhanced learners' ability to apply their learning to new situations compared to a control group [23]. Another study revealed that using textual signaling at strategic points to direct learners' attention improved recall performance [1].

It is worth noting that multimedia learning theory is based on an explicit learning strategy. Displaying narration is by nature a form of learning activity that necessarily adds more information to be processed. Contrastingly, the present study introduces an unexplored alternative using implicit learning strategies. These strategies eliminate narrative elements from the lesson. Instead, the learner performs a repetitive decision-making task without being aware of acquiring knowledge. This incidental learning differs drastically from explicit learning and addresses the cognitive load issue by enabling knowledge acquisition without conscious effort [46].

2.3 The case of implicit learning through immersive virtual reality

Immersive virtual reality (IVR) offers unique conditions for implicit learning by combining sensory immersion, embodiment, and real-time interactions with virtual environments [48]. By enabling self-centred and world-centred information processing, being in IVR influences perception and cognition [4]. A good example supporting embodied cognition in IVR is the literature on the Proteus effect [53]. A study showed that Caucasian participants embodying dark-skinned avatars demonstrated reduced racial bias [3]. This illustrates how avatar embodiment can significantly influence user attitudes and perceptions.

Several concepts related to IVR highlight the relevance of this medium for employing implicit learning strategies [48]. First, the sense of presence occurs when a person in IVR reacts to stimuli as if they were real [49]. Even though users are aware of the virtual reality setting, the ability to act spontaneously in the environment and the environment's responses make the scene credible to users. When a sense of presence occurs, the place illusion and plausibility illusion ensure that learners process perceptual events with authenticity as real-world experiences [47]. The sense of presence is fundamental for the virtual environment to play the role of "exposure of the event" during the training phase of implicit learning [8]. Second, the sense of embodiment is defined by virtual reality's unique ability to let individuals experience events from a first-person viewpoint through a simulated body [22]. The embodiment of a simulated body engages the motor system, proprioception, and, in some cases, the sense of touch. This notion is also essential for implicit learning, as it guarantees the fidelity of information processing during the training phase, in the same way it will occur during subsequent exposure to reality.

Based on these considerations, using implicit learning strategies in IVR seems relevant under certain conditions. The knowledge output should result from an intuitive decision-making in a situation requiring the articulation of complex information. This complexity may arise from the intrinsic difficulty of an algorithm, as observed in studies on artificial grammar [45]. Complexity can also stem from time constraints, as seen in military scenarios [8]. In addition, the situation to assess must rely on a multi-sensory scenario involving body position and spatial perception. For example, training in IVR to determine whether a sentence is grammatically correct would be less relevant than training to identify the greatest source of risk in an emergency situation. In military and first-responder training, IVR has been effectively used to improve intuitive decision-making in dynamic and time-constrained environments. Research shows that IVR offers a training environment closer to real-world conditions than 2D video simulations. In a shoot/don't-shoot judgmental task, VR performance was similar to live fire exercises. In contrast, the stationary nature of the 2D task limited decision-making challenges. In IVR, participants had to actively scan their surroundings and respond to changing cues, which created a more realistic and demanding decision-making environment [18]. Another study on aerial firefighting training revealed that IVR simulations successfully replicate the stress and decision-making challenges encountered in real-world operations [7]. Participants demonstrated comparable physiological stress responses in both IVR and live training scenarios. They reported that these simulations provided an adequate space to practice decision-making under pressure while reducing risks and logistical constraints. Another study investigating IVR use to train first responder squad leaders highlighted the role of natural navigation as a key factor for improving training outcomes [36]. The platform allowed participants to move freely within the virtual environment. This feature replicated physical stress and exhaustion similar to real-life conditions. Participants reported that the natural movement system increased their engagement and provided better preparation for real-world emergency responses. While military and emergency training highlights the role of multi-sensory information and intuitive decision-making, these skills are also important in other professional contexts where precise gestures require situational assessments.

2.4 Current study

Professional skills or professional competences result from a dynamic interaction of knowledge coming from the motor, social, and cognitive domains [13]. Beyond this multidimensional perspective, experts often struggle to articulate their work step by step. This difficulty aligns with Polanyi's notion of "knowing more than we can tell" [43]. Professional skill represents a form of communication where words give way to body movement [50], highlighting professional skills that are difficult to verbalize and transfer effectively [24]. This challenge relates directly to incorporated and tacit knowledge [25], comparable to implicit knowledge [46].

The professional skill involved in vine pruning has general characteristics, such as its repetitive nature and execution speed. This skill can be broken down into three stages. Stage one involves diagnosis, where the pruner assesses the plant's vigor, typically categorized into three levels (low, moderate, and high) [5]. Stage two corresponds to the preparation for motor action, guided by the concept of balance [5]. Here, the pruner evaluates sap flow to position the pruning tool accurately, adjusting the angle of the tool to prevent damage to the vine. Finally, stage three is the actual pruning of the plant [5].

This study focuses on the cognitive aspect corresponding to the first stage of this professional skill. Diagnosing vine vigor is typically a complex form of procedural knowledge that relies on intuitive decision-making without the need to analyze the vine's parameters in detail. We hypothesize that immersive learning will positively affect both the accuracy of the vigor assessment (Hypothesis 1.1) and the speed of this diagnosis (Hypothesis 1.2). Additionally, we hypothesize that immersion in the lesson will positively impact intrinsic motivation for the educational activity (Hypothesis 2).

3 Research Methodology

3.1 Participants and design

Forty participants (25 women and 15 men), aged 19-23 ($M = 20.6$, $SD = 1.0$), volunteered for recruitment over a period of self-directed time. All participants were third-year engineering students at an agricultural and food sciences school in France. The sample size was determined based on the quality of sample representativeness rather than a priori power analysis. This choice was motivated by the difficulty in projecting an effect size for the study, given the wide range of effect sizes reported in similar studies, ranging from −0.94 to 1.936 [52]. In a 2x1 between-subjects design, 18 participants were randomly assigned to the immersive virtual reality condition (IVR group), and 22 were randomly assigned to the slideshow condition (slideshow group). The unequal group sizes resulted from practical constraints associated with the IVR setup, including the time required for tutorials, equipment calibration, and ensuring participant comfort during the experience. These factors limited the number of participants who could be reasonably accommodated in the IVR condition within the available timeframe. Volunteers were randomly assigned to these predefined slots to ensure unbiased group allocation.

3.2 Materials

3.2.1 Pre-test Measures

The pre-test measures involved collecting socio-demographic information from the participants and assessing their prior knowledge of the lesson topic. These questions were administered through a paper questionnaire containing two demographic questions (gender, age) and five binary questions about their prior knowledge (e.g., “Do you know one or more cutting techniques?”). Table 1 provides the list of questions used to evaluate prior knowledge. Self-reported measures were chosen instead of objective pre-assessment to minimize the risk of a pre-training effect, which could bias participants during the training phase and reduce the intervention’s impact [35]. This method is commonly used in media comparison studies to assess prior knowledge without disrupting subsequent learning [23, 40].

Table 1 : Questions used to assess participants' prior knowledge

Prior knowledge	Item – English	Item – French
Q1	Have you ever taken a course on winegrowing?	Avez-vous déjà suivi des cours sur la viticulture ?
Q2	Have you ever taken a course in vine pruning?	Avez-vous déjà suivi des cours sur la taille de vigne ?
Q3	Have you ever visited a vineyard?	Avez-vous déjà visité un vignoble ?
Q4	Have you ever taken part in a project involving vine pruning?	Avez-vous déjà participé à un projet impliquant la taille de vigne ?
Q5	Do you know one or more cutting techniques?	Connaissez-vous une ou plusieurs techniques de taille ?

3.2.2 Learning Content

Figure 1 : Screenshot of the immersive virtual reality (IVR) lesson : training phase

The learning content was divided into two parts. The first part was a training session to teach participants how to determine the vigour of a vine. This training was derived from a specific lesson section named “Determining the potential of a strain”. The educational material was initially designed for an immersive virtual environment (Figure 1) and was replicated as a clickable slideshow for the slideshow group. The lesson began with a brief explanation of the various factors that can influence the vigour of a vine strain. This guided participants on where to focus their attention. The central part of the lesson involved a practice session in which participants assessed the potential of 30 strains, receiving feedback after each attempt. The number of attempts was chosen to match the methodology used in a foundational study on implicit learning that involved a similar number of trials [45]. The vigour of each vine strain could be categorized as low, medium, or high. To ensure content equity, it is important to note that only immersion differed between the conditions. Participants in the IVR condition could not manipulate the vine but were able to move around it and observe it from multiple angles. In contrast, participants in the slideshow condition had access to a fixed-point image offering a single perspective. The second part involved an actual vineyard with 30 identified vines, which served as the evaluation material for the participants (Figure 2).

Figure 2: Participants assessing the vigour of a vine strain during the evaluation phase

3.2.3 Post-test Measures

Intrinsic motivation was assessed using a self-report questionnaire on a 7-point Likert scale ranging from “not at all true” to “very true”. The seven items from the validated Interest/Enjoyment subscale of the Intrinsic Motivation Inventory were used to measure motivation (e.g., “I enjoyed doing this activity very much”). According to its authors, this scale reflects intrinsic motivation for an activity [10]. Table 2 shows the list of items and their French translations. Learning outcomes were evaluated based on the results of the evaluation phase in terms of correct responses and the time taken to determine the vigour of all the vine strains. Time was selected as a performance metric alongside accuracy to provide a complementary perspective on learning outcomes. While accuracy captures the correctness of responses, time reflects the efficiency and fluency of decision-making processes [8]. Cognitive models such as ACT-R highlight the importance of timing as an indicator of the automation and integration of learned patterns [2]. Participants had 30 vines to evaluate, categorizing each as having low, medium, or high vigor. The total time taken for the task was measured in minutes from start to finish.

Table 2: Interest and enjoyment questions from the Intrinsic Motivation Inventory

Interest/Enjoyment	Item – English	Item – French
Q1	I enjoyed doing this activity very much.	J'ai beaucoup aimé faire cette activité.
Q2	This activity was fun to do.	Cette activité était amusante à réaliser.
Q3	I thought this was a boring activity. (R)	J'ai trouvé que c'était une activité ennuyeuse. (I)
Q4	This activity did not hold my attention at all. (R)	Cette activité n'a pas du tout retenu mon attention. (I)
Q5	I would describe this activity as very interesting.	Je décrirais cette activité comme étant très intéressante.
Q6	I thought this activity was quite enjoyable.	J'ai trouvé cette activité tout à fait plaisante.
Q7	While I was doing this activity, I was thinking about how much I enjoyed it.	En faisant cette activité, je me suis dit que cela me plaisait beaucoup.

3.3 Procedure

Initially, volunteers were invited to read the information letter and provide written consent. Participants were then randomly assigned to either the IVR or slideshow group and given an identification code to use on all questionnaires. They completed the pre-lesson questionnaire before starting the training phase individually. An experimenter assisted participants in the IVR group with the equipment, which included a Meta Quest 2 headset connected to a computer and two controllers. Participants proceeded with the lesson after completing a tutorial on using the Head-Mounted Display (HMD). Participants in the slideshow group started the lesson directly on a laptop. At the end of the training phase, all participants completed a motivation questionnaire regarding the activity. The following week, all participants were taken to the vineyard for the evaluation phase. One by one, participants were given a timed sheet to report the vigour of 30 labelled vines (numbered 1 to 30). Participants were instructed not to communicate with each other during this task. After completing the evaluation, each participant returned their completed and timed sheet. This procedure was conducted with the protection of human research subjects' rights and IRB approval from the Research Ethics Committee of the University of Toulouse.

4 Results

Assumption checks were conducted on all dependent variables to ensure data normality and equality of variances. The Shapiro-Wilk normality test revealed deviations from normality for most distributions. Consequently, non-parametric tests were used to evaluate the impact of the learning media on all variables. All data analyses were performed using JASP version 0.18.3.0. The detailed results of all analyses are presented in Table 3.

Table 3: Overview of the dependent variables

	IVR Group (N=18)	Slideshow Group (N=22)	
Pre-test	M (SD)	M (SD)	p-value
Age	20.7 (1.2)	20.5 (0.7)	0.89
Gender (M/F)	7/11	8/14	0.88
Prior Knowledge (out of 5)	2.8 (1.3)	2.5 (1.3)	0.46
Score			
Intrinsic Motivation (out of 7)	6.2 (0.9)	5.5(1.0)	0.005**
Transfer Test (out of 30)	17.2 (3.1)	16.5 (3.2)	0.70
Time (minutes)	8.6 (3.2)	6.5 (2.6)	0.013*

*p<.05; **p<.01

The first set of analyses aimed to ensure the groups' comparability at the outset. The results of the Mann-Whitney test showed no significant group differences in age (U=193, p=0.89), gender (U=193, p=0.88), or prior knowledge (U=172, p=0.46). This absence of difference established the groups' comparability without the need for covariation.

The first prediction was based on the learning potential of IVR for implicit knowledge, assuming that the IVR group would show better decision-making performance in terms of accuracy and time response compared to the slideshow group. This prediction was based on the affordances of immersive media for experiential learning, potentially facilitating transfer to reality compared to non-immersive media. For performance scores, the IVR group (M=17.2, SD=3.1) had a higher mean score than the slideshow group (M=16.5, SD=3.2). However, the Mann-Whitney test (U=183.5, p=0.7) showed no significant difference between the IVR and slideshow groups. These results do not support the hypothesis of IVR efficacy for acquiring implicit knowledge regarding decision-making accuracy (H1.1). For time performance, the IVR group (M=8.6, SD=3.24) had a higher mean total time than the slideshow group (M=6.5, SD=2.6). The Mann-Whitney test results (U=106.5, p=0.013) indicated a significant difference between the IVR and slideshow groups. These results do not support the hypothesis of IVR efficacy for acquiring implicit knowledge regarding decision-making time (H1.2). Moreover, these results contradict our prediction.

The second prediction was based on the IVR's motivational capacity, assuming that the IVR group would show higher levels of interest and enjoyment in the activity compared to the slideshow group. Descriptive statistics indicated that the IVR group (M=6.2, SD=0.88) had a higher intrinsic motivation score than the slideshow group (M=5.5, SD=0.95). The Mann-Whitney test (U=94.5, p=0.005) indicated a significant difference between the IVR and slideshow groups. These results support the motivation hypothesis (H2).

5 Discussion

5.1 Contributions

This study aimed to provide empirical data on immersive learning by employing an experimental method to compare learning performance between immersive media (IVR) and traditional media (Slideshow). This study focused on using implicit learning in the professional task of vine pruning. Implicit learning as a learning strategy remains underrepresented in current research on immersive learning. The overall results in Table 3 show that immersive learning positively affects learners' motivation but does not improve their learning performance compared to non-immersive learning. These findings align with other studies exploring the potential of immersion through media comparison methods [28, 40].

Learning outcomes in this study were assessed by measuring the accuracy and decision-making time involved in evaluating the potential of a vine strain. This study represents the first known attempt to investigate the knowledge transfer capabilities of an immersive medium to a real-world scenario using an implicit learning strategy. The IVR group showed significantly higher accuracy (M=17.2) than the theoretical probability level of 10. However, a comparative analysis with the slideshow group (M=16.5) showed no significant difference between groups. This lack of difference suggests that immersive learning may not offer the advantage we hypothesized in this educational context (H1.1). These findings add to the body of research in media comparison, showing that immersive learning can have diverse effects, ranging from positive [15] to negative [39] or neutral [19]. Research explains this lack of effectiveness due to cognitive overload present in IVR [34]. This factor has been identified during immersive learning compared to non-immersive learning [44]. However, the present study employed an implicit learning strategy that does not rely on conscious cognitive processes [46], yet still led to an absence of significant results. It seems that the impact of immersion depends not only on instructional design but also on the relevance of immersion regarding the nature of the targeted knowledge. It also appears that the effectiveness of the immersion effect is more nuanced for cognitive domain knowledge than for knowledge in motor or social domains [21].

A second learning outcome considered was the response time in decision-making, evaluated by the total time taken during the transfer test. This metric is not commonly used to assess learning outcomes but is central to implicit knowledge, which involves rapid decision-making. Notably, no time constraints were given to the participants during the transfer test. This choice aimed to observe participants' natural behaviour without the effects of time pressure that could alter their performance. Where we anticipated a faster response time for the IVR group (H1.2), the data instead showed a significantly longer response time for the IVR group (M=8.6) compared to the slideshow group (M=6.5). Although these results were contrary to our expectations, this trend indicates an impact of immersion on behaviour during the transfer to real-world situations. One possible explanation for these results is that the richer sensory knowledge construction in the IVR group requires more time to process when transitioning to real-life applications, as participants try to translate all aspects perceived during immersive learning. Another factor might be the impact of immersion on learner motivation. Increased motivation, which correlates with sustained cognitive engagement during IVR lessons [6], could extend beyond the IVR experience into the real-world transfer phase. These speculations require further investigation to be supported but offer potential insights into how virtual reality devices could be effectively used in education.

Intrinsic motivation during the learning activity was significantly higher for the IVR group than the slideshow group. These results support our predictions (H2) and align with studies examining the motivational processes involved in immersive learning [44]. These findings appear consistent regardless of the metrics and constructs used to evaluate motivational states. One possible explanation is that learners experience a greater sense of control over the lesson and perceive its greater value in IVR [29]. These results should be regarded as meaningful in themselves, given the importance of intrinsic motivation for learners' well-being and academic success [38]. Affective processes may also support knowledge acquisition by sustaining cognitive engagement during learning [16]. In the same way, a positive affective state towards lesson content is linked to improved information processing and enhanced higher-level cognitive activities [42]. Thus, these findings support the use of IVR in classrooms to promote cognitive engagement and learners' well-being.

5.2 Limitations

First, a limiting factor could be related to the pedagogical material, specifically the possibly insufficient number of training sessions. The educational goal of learning to determine the vigour of a vine strain was chosen because it is the first step in the professional practice of pruning vines. This skill of judgment represents tacit knowledge, as decision-making becomes intuitive for experts without them being able to consistently explain the reasons. The significant variability in vine growth, influenced by factors like previous years' pruning, suggests that achieving expertise in this domain demands extensive training. In our study, participants were exposed to thirty different vine strains during the training phase, receiving feedback after each attempt. However, this training did not enable participants to achieve more than 23 correct responses out of 30 during the evaluation phase. It is possible that the number of trials during training was insufficient to master the complexity of the vine strains. More extensive training with a greater number of sessions might have allowed participants to surpass this performance ceiling and produce more discriminative results. The fixed number of trials was chosen to replicate the original study on artificial grammar [45]. It might have been valuable to allow participants control over the number of training sessions, to take advantage of the engaging nature of IVR lesson. Additionally, relying on intuition-based decision-making might be an unfamiliar approach for novices. It could have been valuable to interview participants after the testing phase to gain deeper insight into how they approached the vine assessment task.

Another limitation that should be noted is the choice of metrics used in this study during the evaluation phase. The response time measured during the evaluation was initially chosen to observe the extent to which the task was performed instinctively. The unexpected results offer an interesting perspective for interpreting behaviour during the transfer from virtual to real environments. Although the time spent in an activity represents a relevant metric for evaluating engagement, further research could more thoroughly investigate the robustness of these findings by using complementary metrics, such as systematic observation.

A final limitation concerns the study's statistical power, assessed through a post-hoc analysis using G*Power [14]. For H1.1 (decision-making accuracy), the power was 0.10 with a small effect size ($d = 0.23$). For H1.2 (decision-making time), the power reached 0.58 with a medium-to-large effect size ($d = 0.72$). For H2 (intrinsic motivation), the power was 0.68 with a large effect size ($d = 0.82$). These values indicate a limited ability to detect small effects, while medium-to-large effects were captured with moderate confidence. The low power for H1.1 suggests that a potential effect on decision-making accuracy if it exists, might require a larger sample to become evident. In contrast, the statistical power was sufficient for the significant results, supporting confidence in the observed effects. Larger sample sizes in future studies could provide clearer insights across all outcomes.

6 Conclusion

This study compared immersive learning using IVR with non-immersive learning using a slideshow. The results did not indicate that immersive media is superior for implicit learning strategies (RQ1). Given the practical challenges of using HMD in lessons, it is advisable to selectively apply them in contexts where immersive features directly enhance learning outcomes. However, the study found that the immersive lesson led to higher motivation than the non-immersive one (RQ2). These results align partially with the theoretical model of immersive learning [30]. Therefore, while IVR should be used strategically based on its relevance for specific learning goals, its potential to enhance motivation and engagement remains valuable and should be considered when designing educational interventions.

Research on immersive learning with HMDs is still in its early stages and offers valuable opportunities to better understand the field of experiential learning. Future experimental research should use media comparisons to clarify the current variety of results [52]. It would be beneficial for future studies to specify the learning strategy used and the types of knowledge targeted to create a detailed picture of effective approaches. Additionally, it is worthwhile to continue exploring existing learning strategies whose theoretical foundations take advantage of the potential of immersion, such as those based on interactive affordances [15], generative activities [23], or implicit learning [48].

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