Exploring the Use of Virtual Reality with Struggling Students: Perceptions and Teaching Practices of Life and Earth Sciences Teachers

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***Abstract*—Despite growing interest in Virtual Reality (VR) in education, little research has examined how teachers' professional profiles influence its adoption for supporting struggling learners in Life and Earth Sciences (L&E). The objective of this study is to analyze the viewpoints, perceived benefits, and challenges associated with incorporating VR as an educational instrument in L&E instruction, with a specific focus on its potential for supporting struggling learners. A quantitative cross-sectional survey was administered to 82 secondary school teachers using a validated structured questionnaire assessing digital competencies, professional seniority, work environment, VR familiarity, and perceived pedagogical value. Data were analyzed using descriptive statistics and chi-square tests of independence, with Cramér's V reported as effect size. Results show that most teachers recognize the pedagogical potential of VR-particularly for simplifying abstract scientific concepts and enhancing engagement among struggling students-yet actual implementation remains limited. Significant associations were found between teachers' VR perceptions and seniority ($\chi^2 = 45.344$, df = 6, $p < 0.001$, V = 0.74), digital skills ($\chi^2 = 39.291$, df = 4, $p < 0.001$, $V = 0.69$), and work environment ($\chi^2 = 18.768$, df = 2, $p < 0.001$, $V = 0.48$). These findings highlight several persistent challenges hindering the integration of VR in science education, including inadequate technological infrastructure, limited access to appropriate digital tools, and insufficient development of teachers' digital competencies. These constraints continue to restrict the effective and equitable use of VR in classroom practice, particularly in inclusive educational contexts.**

***Keywords*—virtual reality, life and earth sciences teaching, struggling learners, educational innovation, school inclusion**

I. Introduction

Over the past two decades, digital innovations have advanced rapidly, becoming a major driver of transformation in educational systems [1]. Although the COVID-19 pandemic accelerated the adoption of digital solutions to ensure pedagogical continuity [2], it also revealed significant structural limitations and pedagogical challenges, particularly in addressing the needs of students with diverse learning profiles [3]. In Morocco, despite more than a decade of initiatives aimed at modernizing the educational system, a gap remains between the deployment of technological tools and their effective integration to enhance learning outcomes in complex subjects such as Life and Earth Sciences (L&E).

One of the most persistent challenges in science education concerns the cognitive barriers students encounter when engaging with abstract or microscopic phenomena. Learners experiencing academic difficulties, in particular, often struggle to visualize complex biological and geological processes through traditional Two-Dimensional (2D) representations. In this context, Virtual Reality (VR) emerges as a transformative pedagogical tool. Unlike conventional digital resources, VR offers immersive and interactive environments that can reduce cognitive load and enhance spatial understanding [4]. By enabling students to "experience" scientific concepts rather than merely read about them, VR holds considerable potential for fostering inclusive education, particularly by providing tailored support to learners facing academic challenges.

However, despite these evident advantages, the integration of VR in Moroccan classrooms remains limited. This situation cannot be attributed solely to infrastructural constraints; rather, it is closely linked to teachers' perceptions, professional seniority, and levels of digital competence [5]. Moreover, there is a notable lack of research examining how educators perceive the role of VR specifically as a tool for remediation and support for learners experiencing academic difficulties.

In light of these considerations, the primary objective of this study is to analyze teachers' perspectives, as well as the perceived benefits and challenges associated with integrating VR as a pedagogical tool in Life and Earth Sciences (L&E) instruction, with particular emphasis on its potential to support struggling learners. The study also seeks to identify key factors—such as professional seniority and digital competence—that influence the adoption of these technologies by Moroccan teachers in order to promote a more inclusive learning environment.

The paper begins by outlining the fundamental characteristics of VR in educational contexts. It then presents an empirical investigation based on a survey of 82 L&E educators, analyzing their perspectives to propose contextually relevant and inclusive approaches to implementation within the Moroccan educational system.

II. Literature Review

The rapid development of immersive technologies has generated increasing interest in their potential to transform educational practices, particularly in science education. Among these technologies, Virtual Reality (VR) and Augmented Reality (AR) are increasingly regarded as promising pedagogical tools capable of enhancing visualization, interactivity, and learner engagement. These features are particularly relevant for students experiencing

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learning difficulties, who often struggle to comprehend abstract scientific concepts that are not directly observable.

Despite the growing body of research highlighting the pedagogical potential of immersive technologies, several limitations persist in the existing literature. First, most studies have primarily focused on student learning outcomes, while comparatively little attention has been paid to teachers' perceptions and pedagogical practices, which play a decisive role in the successful adoption of educational technologies. Second, the majority of existing studies have been conducted in well-equipped educational settings or in higher education contexts, resulting in a limited understanding of how these technologies are perceived and implemented in environments where infrastructure and digital competencies vary considerably.

Moreover, only a limited number of studies have examined the use of Virtual Reality specifically within Life and Earth Sciences (L&E) education, a discipline characterized by complex and often abstract phenomena that are difficult for struggling learners to conceptualize through traditional instructional methods. Consequently, the question of how teachers evaluate the potential of VR to support these learners remains insufficiently explored.

In addition, previous research has rarely examined how teachers' professional characteristics—such as digital competence, teaching experience, and work environment—influence their perceptions of Virtual Reality and their willingness to integrate it into classroom practice. Understanding these factors is essential for designing effective strategies to promote inclusive and technology-enhanced science education.

The present study addresses these gaps by examining secondary school Life and Earth Sciences teachers' perceptions of Virtual Reality and by analyzing how professional variables including seniority, digital skills, and institutional context influence the perceived usefulness of VR and its integration in supporting struggling students.

A. VR: Core Concepts: Definitions, Types, and Fundamentals

1) Conceptual definitions of virtual reality

Academic sources do not provide a single standardized definition of Virtual Reality (VR), but instead offer multiple conceptual frameworks that vary across technological, technocentric, and human-centered perspectives, depending on the analytical approaches and objectives pursued [6]. This conceptual plurality is not merely terminological; rather, it reflects deeper divergences regarding whether VR should be understood as a technical system, a perceptual phenomenon, or a cognitive and experiential state.

Since the early 2000s, scholars have increasingly focused on the field of Virtual Reality, proposing comprehensive conceptualizations that have gained considerable traction within academic research [7]. In its most inclusive sense, Virtual Reality can be defined as "a research and technical field that employs computational methods and user interfaces to model, within a simulated environment, the dynamics of three-dimensional elements that interact in real time with one another and with one or more participants who are organically integrated through sensory and physical channels." Rather than being limited to purely material features, Virtual Reality is characterized by the user's deep immersion in an artificial environment, in which they continuously perceive and interact through sensory and motor processes within a coherent virtual space [6]. While this definition usefully highlights the experiential and interactive dimensions of VR, it remains primarily descriptive and does not account for variations in levels of immersion across different VR systems a distinction that has important implications for learning design, as discussed in the following sections.

From a technological perspective, Virtual Reality can be described as a digitally created, three-dimensional simulated environment delivered to the user in an interactive and responsive manner, thereby fostering an immersive and active experience [8]. VR is an evolving technology situated at the intersection of multiple domains, including visual computing, computer-aided engineering, experiential modeling, remote control systems, media technologies, and collaborative computing. The system integrates various types of hardware with bespoke software solutions, carefully designed to address specific use cases.

At present, Virtual Reality is referred to using a range of terms in both academic and industry literature, including "artificial environment", "cyberspace", "simulated world", and "digital reality". Each of these labels carries specific conceptual implications, the meaning of which varies across disciplinary contexts, leading to substantial differences in interpretation between fields. This diversity of terminology reflects the complex and inherently interdisciplinary nature of Virtual Reality [9].

However, this terminological fragmentation also poses a methodological challenge for researchers attempting to synthesize findings across studies, as differences in the type of VR system used are often underreported or insufficiently described, thereby limiting the comparability of outcomes. Accordingly, the present study clearly specifies the type of VR/AR medium employed and its technical characteristics in order to ensure reproducibility and facilitate comparison with future research.

2) Types of virtual reality

Virtual Reality systems can be classified into three main categories: non-immersive, semi-immersive, and fully immersive. These categories are distinguished by the degree of immersion they provide, as well as by the configuration of their integrated technological components [10].

Non-immersive Virtual Reality (VR) uses a computer screen as a window into a virtual environment, providing a limited yet useful experience in fields such as Computer-Aided Design (CAD) and modeling systems. Its applications are diverse, including virtual meetings, online classrooms, museum simulations, and educational games. A key advantage of this approach is that the required equipment—such as computers, keyboards, mice, or tablets—is often already available in most educational settings [11]. This form of VR is based on Two-Dimensional (2D) software displayed on a screen and is characterized by a relatively low level of immersion [12].

Semi-immersive Virtual Reality (VR) refers to a system in which the user is placed in a room equipped with projection surfaces (walls and floor), spatially distributed loudspeakers, motion sensors integrated into the environment, and audio devices. The user, wearing dedicated stereoscopic glasses, perceives the virtual environment in three dimensions. However, because users retain visual awareness of their own physical body within the real environment, this type of system does not produce full immersion. The Cave Automatic Virtual Environment (CAVE) system is a representative example of this approach [13]. Semi-immersive Virtual Reality has been defined as a technology that places users in a three-dimensional digital environment without fully immersing them.

Fully immersive Virtual Reality (VR) refers to a system in which the user's sensory experience is mediated through a head-mounted display that integrates the user into the virtual environment by fully occupying the field of vision. In this digital context, the distinction between online and offline interactions becomes increasingly blurred. Such environments can generate a strong sense of presence and sensory isolation, thereby producing experiences characterized by a high degree of realism. This level of immersion is achieved through the use of VR headsets [14].

3) Fundamentals of virtual reality

Grigore Burdea, a faculty member at Rutgers University and head of the Human–Computer Interface Research Division, situates Virtual Reality within a triangular framework in which the letter "I" is placed at each vertex (Fig. 1). This model highlights the three core pillars of Virtual Reality, namely immersion, interaction, and imagination [15].

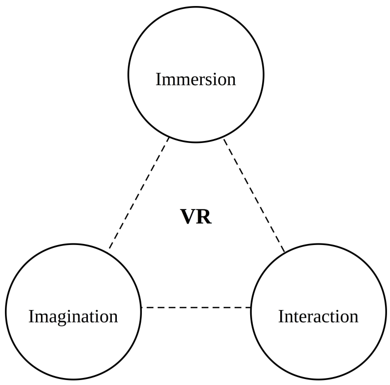

Fig. 1. Virtual reality triangle [15].

Immersion: The immersive experience in Virtual Reality (VR) is influenced by factors such as perceived control, ease of use, and ergonomic design. This level of immersion has been shown to facilitate the emergence of a psychological flow state. Consequently, high levels of immersion in VR, in conjunction with the flow state, generate a range of beneficial effects, including increased motivation, enhanced curiosity, perceived cognitive benefits, greater cognitive engagement, and a more positive evaluation of the experience. The dotted line labeled "Moderating Effect" indicates that some of these relationships may be influenced by unspecified external variables. In summary, a positive initial experience with VR has been shown to foster greater engagement and more favorable perceptions of its outcomes [16]. However, a critical limitation of this line of research is that immersion is typically operationalized and measured inconsistently across studies, ranging from self-reported presence scales to physiological measures, which complicate cross-study comparisons. Furthermore, the relationship between immersion and learning outcomes is not always linear; in some cases, excessively high levels of immersion have been associated with cognitive overload, particularly among novice users a finding that can be directly interpreted through Cognitive Load Theory, which posits that poorly calibrated instructional environments may increase, rather than reduce, extraneous cognitive load [17]. This nuance is directly relevant to the present study, which examines how Moroccan Life and Earth Sciences teachers perceive the level of immersive engagement afforded by VR, and whether their digital competence profiles and institutional contexts influence their ability to deploy VR in ways that support, rather than hinder, learning among struggling students.

Imagination: In the domain of virtual environment design, creative freedom enables developers to define the foundational principles governing their digital worlds. In accordance with project requirements, designers may construct environments and elements that closely replicate real-world physics and behaviours for simulation purposes. Alternatively, they may choose to relax or bypass certain natural laws in order to enhance user engagement, improve navigability, or facilitate the understanding of complex concepts [18]. This design flexibility is particularly relevant in Life and Earth Sciences education, where certain phenomena—such as geological processes unfolding over millions of years or molecular-scale interactions—are inherently inaccessible to direct observation and therefore benefit from environments that prioritize conceptual clarity over strict physical fidelity.

Interaction: Since the emergence of Virtual Reality (VR) technologies, scholars have devoted considerable attention to user interaction, recognising it as a central component underpinning the functionality of interactive computing systems. User interaction can be defined as a communicative framework that enables dialogue between humans and computer systems. This framework involves the bidirectional exchange of inputs and outputs between users and digital environments through various interface mechanisms, including sensory feedback systems, motor control devices, and specific interaction techniques [19]. Despite the central role of interaction in the pedagogical potential of VR, much of the existing literature conceptualises it as a binary variable—either present or absent—rather than as a continuum comprising qualitatively distinct modes. The question of which types of interaction (e.g., manipulative, navigational, communicative) are most conducive to specific learning outcomes remains insufficiently explored, constituting a gap that the present study seeks to address.

B. VR in Science Education: Pedagogical Applications

1) Virtual environments for teaching abstract concepts

It is widely acknowledged that the sciences frequently address abstract concepts and phenomena that are difficult to observe directly in the real world. Virtual Reality has been shown to provide visual representations of such otherwise invisible elements, thereby facilitating the understanding of concepts such as physical forces, chemical reactions, and planetary motion [20]. VR can also recreate realistic simulations of natural habitats, including forests, oceans, and deserts, offering students opportunities to explore and study these ecosystems in an immersive manner. This approach supports the comprehension of complex interactions between species and their environments. For example, students can observe food chains in virtual settings, analyze the effects of climate change, and track ecosystem evolution within simulated environments [21].

In this field, researchers are increasingly designing Virtual Reality (VR) environments specifically intended to support the learning of complex or abstract knowledge. A notable example dates back to 2003, when researchers at the Korea Institute of Educational Sciences [22] developed a VR platform specifically designed for biology instruction for students aged 15 to 16. This system enabled learners to interactively explore the anatomy and function of the human eye, notably by allowing them to modify their viewpoint within the virtual environment. The findings of this study suggest that learning about the anatomy and functioning of the eye is significantly more effective when conducted within an immersive environment. VR has also been shown to be highly engaging for young learners and to play an important role in motivation by providing novel and stimulating learning experiences [23].

2) Virtual environments for practical teaching in the field

Virtual reality has had a profound impact on educational practices by offering experiences that are both immersive and captivating [24]. The integration of technology-based learning aids has been demonstrated to facilitate the comprehension of abstract concepts, simplify the completion of complex experimental tasks, and enhance learner motivation and performance. Furthermore, the creation of virtual spaces conducive to group work is conducive to facilitating collaboration between students and teachers [25, 26].

3) Virtual environments for teaching "simulation of scientific experiments" practical exercises

In disciplines such as chemistry and biology, Virtual Reality offers students the opportunity to conduct scientific experiments without the need for expensive or potentially hazardous equipment. By simulating chemical and biological reactions within a virtual environment, VR provides a safe and accessible alternative, which is particularly valuable for institutions with limited resources [27].

The design and implementation of a virtual laboratory environment that replicates real-world scientific practical sessions, including experiments in chemistry and physics, enable students to engage with a range of scientific instruments and conduct experiments within a safe, controlled, and reproducible environment [28].

4) Virtual environments for teaching special needs students

Virtual Environments (VEs) have been proposed as a means of providing effective support for students with learning difficulties, offering educational experiences that are both interactive and immersive. Such pedagogical approaches are particularly beneficial for learners with specific needs, such as attention disorders or difficulties in understanding abstract concepts. These environments enable students to progress at their own pace while exploring scientific or mathematical concepts in a more concrete and engaging manner. By replicating real-life experiences in a virtual setting, these tools facilitate the visualization and comprehension of complex ideas, representing a significant asset for individuals who experience difficulties with conventional teaching methods [29].

Moreover, the importance of timely feedback in such contexts has been emphasized, highlighting its central role in supporting learners experiencing learning difficulties [30]. Interactive simulations provide immediate feedback, enabling learners to promptly identify and correct errors while improving their understanding and skill acquisition. This approach is particularly beneficial for individuals with social interaction difficulties in daily life, such as those diagnosed with autism spectrum disorder, as it offers opportunities to practise and develop confidence within a controlled environment [31].

A growing body of literature has examined the specific potential of immersive technologies for learners with academic difficulties or special educational needs. Virtual environments have been shown to provide interactive and self-paced learning experiences that are particularly well suited to students with attention disorders, difficulties in understanding abstract concepts, or challenges in participating in conventional classroom settings [32].

By providing immediate, individualized feedback and allowing learners to progress at their own pace, VR environments address several of the key barriers faced by struggling students in traditional instructional contexts. For learners with social interaction difficulties including those diagnosed with autism spectrum conditions VR environments offer a controlled setting in which they can practise social and academic skills without the anxiety associated with real-world performance situations [33]. These affordances position VR not merely as a tool for enrichment, but as a means of fostering genuine educational inclusion.

5) Augmented reality environment in science education

A closely related body of research has also emerged on Augmented Reality (AR), which overlays digital content onto the real world and offers an accessible alternative that requires less costly infrastructure a particularly relevant consideration for resource-constrained contexts such as the Moroccan secondary school system examined in this study. In vocational education, Dewi *et al.* [34] reported strong validity and practicality of an AR-based learning tool, demonstrating its effectiveness in enhancing students' conceptual understanding. Similarly, Yanto *et al.* [35] evaluated AR-enhanced electronic worksheets with 97 students and found a very high level of practicality across four usability dimensions. Furthermore, Dewi *et al.* [36] showed that AR technology features, task value, and usage intention positively predicted academic self-efficacy outcomes.

These findings converge in suggesting that the pedagogical value of both VR and AR lies in their capacity to render abstract content more tangible across different learning modalities. However, most studies have been conducted in technical and vocational disciplines, with few examining these technologies in the context of Life and Earth Sciences, and even fewer adopting teachers' perspectives rather than students' a gap that the present study specifically addresses.

C. Theoretical Framework: Teacher Adoption Models

The preceding literature review establishes the empirical landscape of VR and AR in education but does not, in itself, explain why some teachers adopt VR while others do not, why seniority and digital skills should predict adoption attitudes, or why institutional context should moderate behavioural intentions. These explanatory questions require a clear theoretical grounding. The present study is anchored in three complementary theoretical frameworks—the Technology Acceptance Model (TAM), the Unified Theory of Acceptance and Use of Technology (UTAUT), and Cognitive Load Theory (CLT) which together provide a coherent and testable account of teachers' adoption of VR within a complex educational system.

The Technology Acceptance Model (TAM) [37], grounded in Ajzen and Fishbein's Theory of Reasoned Action, posits that technology adoption is primarily determined by two cognitive appraisals: Perceived Usefulness (PU), defined as the extent to which an individual believes that using a technology will enhance performance, and Perceived Ease of Use (PEOU), defined as the extent to which the technology is perceived as requiring minimal effort. In the present study, TAM provides a framework for analysing teachers' perceptions of the pedagogical value of VR. When teachers report that VR facilitates the understanding of complex biological or geological concepts, they are expressing perceived usefulness, whereas reluctance among teachers with limited digital literacy reflects low perceived ease of use a barrier consistently identified in educational technology research [38]. Importantly, perceived ease of use is not an inherent property of the technology but a subjective evaluation that varies according to user experience. This helps explain the significant association observed between digital competence and VR perceptions.

UTAUT [39] extends the Technology Acceptance Model (TAM) by incorporating social and organisational dimensions of technology adoption. It identifies four core determinants of behavioural intention performance expectancy, effort expectancy, social influence, and facilitating conditions and introduces experience and contextual factors as moderating variables. In the present study, professional seniority is operationalised as a proxy for experience. UTAUT suggests that more experienced teachers, having developed established pedagogical routines, may be less receptive to new technological affordances, a pattern consistent with the significant association observed. Similarly, work environment is operationalised as a proxy for facilitating conditions. Teachers working in better-equipped institutions report stronger perceptions of institutional support, which directly influences adoption attitudes.

CLT [40], posits that learning is constrained by the limited processing capacity of working memory and distinguishes three types of cognitive load: intrinsic load, determined by the complexity of the material; extraneous load, generated by the instructional format without contributing to learning; and germane load, which is devoted to schema construction. For struggling students in Life and Earth Sciences, abstract phenomena-such as cellular organelles, tectonic dynamics, and molecular interactions-generate high intrinsic load because they cannot be directly observed and must be mentally reconstructed from two-dimensional representations. This dual demand may exceed working memory capacity, thereby hindering learning [41]. Virtual Reality (VR) mitigates this constraint by externalizing three-dimensional representations. Rather than mentally constructing a spatial model of a biological cell, learners can navigate within it, thereby reducing extraneous load and freeing cognitive resources for meaningful conceptual processing and long-term understanding. CLT therefore provides a precise theoretical mechanism through which VR can support struggling learners - a mechanism that teachers in this study appear to intuit, given that most identify "simplifying complex scientific concepts" as the principal advantage of VR.

These three frameworks are not additive but mutually reinforcing, as summarized in Table 1 below.

Table 1. Theoretical frameworks, variables operationalized, and corresponding research questions

Ref.	Theory	What it explains	Variables operationalized	Research question
[37]	TAM	Why teachers accept or reject VR based on perceived usefulness and ease of use	Digital skills; perceived pedagogical value of VR	RQ2: Current teaching practices
[39]	UTAUT	How seniority and institutional context moderate adoption intentions	Seniority (experience); work environment (facilitating conditions)	RQ3: Barriers to VR integration
[40]	Cognitive Load Theory	Why VR reduces cognitive barriers for struggling L&E students	Perceived VR utility for abstract concepts; struggling student difficulties	RQ1: Student difficulties in L&E

CLT explains why VR is pedagogically effective for struggling L&E students (RQ1); TAM explains how teachers evaluate that effectiveness and form adoption intentions (RQ2); UTAUT explains what contextual factors moderate those intentions and their translation into actual practice (RQ3). The three independent variables examined in the chi-square analyses seniority, digital competencies, and work environment are thus not arbitrary demographic covariates but theoretical constructs derived from TAM and UTAUT, operationalized through survey items. This grounding transforms the study's quantitative findings from descriptive statistical associations into theoretically interpretable and externally generalizable results.

III. Materials and Methods

This study investigates how Life and Earth Sciences (L&E) teachers integrate Virtual Reality (VR) into their pedagogical practices, while examining their level of digital competence and the perceived barriers to VR adoption. A quantitative, cross-sectional, questionnaire-based design was employed. This design enables the collection of standardized data from a sufficiently large sample, ensuring reliability and facilitating replication in similar educational contexts.

A. Research Design

Fig. 2 presents the research design adopted for this study, entitled "The Integration of Virtual Reality in Life and Earth Sciences Education: Supporting Struggling Learners". The investigation employed a quantitative research approach to collect and analyze measurable data on teachers' perceptions and the direct impact of Virtual Reality (VR) on students with learning difficulties. The target population consisted of 82 Moroccan secondary school L&E teachers, selected due to their central role in implementing innovative pedagogical approaches and their direct experience with students' learning challenges. The findings are structured around three main dimensions identified in the study design:

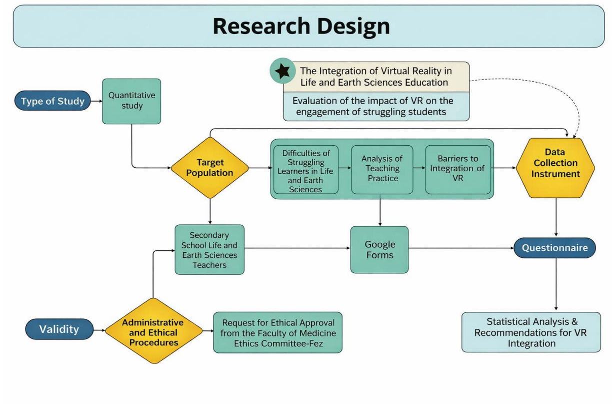

Fig. 2. General design of the study.

- Learner difficulties: Teachers reported challenges in understanding abstract concepts, performing practical tasks, and maintaining engagement, especially among struggling students.
- Teaching practices: Most use traditional lectures and occasional digital resources. Younger teachers and those with higher digital skills are more likely to integrate interactive tools, including VR.
- Barriers to VR integration: Major obstacles include high equipment costs, limited training, and insufficient institutional support. Statistical analysis showed significant associations between teachers' perceptions of VR and their age, digital skills, and work environment ($p < 0.001$).

For data collection, a structured questionnaire was developed and administered online via Google Forms. Invitations were distributed through professional mailing lists and institutional contact networks, enabling broad participation among secondary school teachers of Life and Earth Sciences. Participation was voluntary and anonymous, requiring approximately 10 min completing. Data collection was conducted over a four-month period, allowing extensive dissemination among teachers with diverse professional backgrounds. A total of 82 teachers participated in the study. The sample size aligns with methodological recommendations for correlational studies (minimum $N \geq 50$ +8 m form predictors), ensuring sufficient statistical power.

B. Conceptual Model and Hypotheses

To better structure our approach, the table below presents the variables studied, the associated hypotheses, and the indicators chosen to measure them. This framework clearly illustrates the relationships envisaged in our conceptual model (Table 2).

This hypothetical model (Fig. 3) explores the factors influencing teachers' integration of Virtual Reality (VR) in pedagogy and its effect on struggling students' academic performance. The main research question focuses on the impact of VR integration on students experiencing learning difficulties.

H1: Integration of VR enhances the academic performance of struggling learners, measured through school results, tests, and pedagogical observations.

Table 2. Research variables, hypotheses, and measurement indicators

Variable Type	Variable	Hypothesis	Indicators /Measures
Main dependent variable	VR Integration / Student Performance	**H1:** The integration of virtual reality improves the performance of struggling learners.	Teacher-reported academic improvement
Independent variable	Work Environment	**H1.1:** The use of VR is more widespread among teachers in urban areas than in rural areas.	Geographic location (urban vs. rural) and frequency of VR use reported by teachers.
	Teaching Seniority	**H1.2:** Younger teachers are more favourable to VR integration than experienced teachers.	Years of teaching experience and attitude towards VR
	Digital Competence	**H1.3:** Digital skills influence willingness to integrate VR into teaching practice.	Level of digital skills self-assessment, Frequency of VR use.

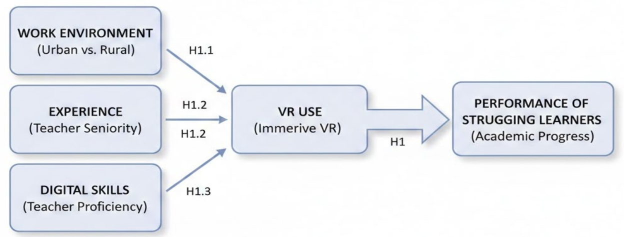

Fig. 3. Hypothetical model: factors influencing the pedagogical use of virtual reality.

The model also investigates several independent and mediating variables that may influence VR adoption by teachers:

- Work Environment (Urban vs. Rural)—H1.1: Does the school context affect VR use? It is hypothesized that teachers in urban schools may adopt VR more frequently than those in rural areas. Measurement includes teachers' geographic location and reported VR usage frequency.
- Teaching Seniority (Experience)—H1.2: Does professional experience affect teachers' attitudes toward VR? It is hypothesized that younger teachers or those with fewer years of seniority are more favorable toward VR integration. Measurement includes years of teaching experience and attitudes toward VR.
- Digital Skill Digital Skills (Teacher Proficiency)—H1.3: Does teachers' digital competence affect VR adoption? Teachers with higher digital skills are expected to integrate VR more effectively. Measurement can include self-assessment, digital skills tests, or certifications. (Teacher Proficiency)—H1.3: Does teachers' digital competence affect VR adoption? Teachers with higher digital skills are expected to integrate VR more effectively. Measurement can include self-assessment, digital skills tests, or certifications.

C. Instrument Development and Validation

1) Description of the questionnaire

The questionnaire consists of four main sections, each designed to explore a specific aspect of the integration of new technologies into life and earth sciences teaching (Table 3).

Table 3 outlines the structural framework of the research instrument, categorized into four strategic thematic axes.

This progression moves from contextualizing the participant profiles (Axis 1) to diagnosing subject-specific pedagogical challenges (Axis 2). It further examines the operational integration of Virtual Reality (VR) (Axis 3) and concludes by evaluating the perceived value and systemic barriers (Axis 4). Together, these axes provide a holistic view of the factors influencing the digital transformation of Life and Earth Sciences education.

Table 3. Thematic axes and educational goals

Thematic Axis	Constructs Measured	Objective
Axis 1: Demographic Information	Gender, workplace, seniority	Collect key demographic data to contextualize teachers' background and allow for cross-analyses based on professional characteristics.
Axis 2: Learning Difficulties	Student challenges in L&E Sciences	Identify the main difficulties students face in Life and Earth Sciences, in order to tailor pedagogical strategies.
Axis 3: Teaching Practices	VR integration frequency, methods	Assess how teachers incorporate VR into their teaching and the methods used to enhance student engagement and learning outcomes.
Axis 4: Barriers and Benefits	Perceived obstacles, advantages	Explore teachers' perceived benefits and challenges of using VR, providing insight into potential facilitators and hindrances for technology integration.

2) Validation process

Content Validity: The questionnaire was reviewed by three experts in educational technology and science didactics to ensure content validity-that is, the degree to which the items accurately measure the intended constructs, including teachers' perceptions, teaching practices, and perceived barriers related to VR integration in Life and Earth Sciences. The experts assessed the clarity, relevance, alignment with research objectives, and cultural appropriateness of all items. Their feedback led to refinement of several questions, particularly those addressing perceived VR barriers and frequency of use, enhancing the instrument's practicality (usability and applicability for teachers). Practicality here refers to the ease with which participants could understand, interpret, and respond to each item.

Pilot Testing: A pilot study was conducted with 10 secondary school teachers to evaluate comprehension, response time, and potential ambiguities. This phase was critical to ensure that teachers could easily understand and respond to the items, particularly those measuring digital competence and VR usage, which are key variables for the study. Minor adjustments were made to improve clarity and reduce potential misunderstandings, thereby increasing the reliability of responses in the main survey.

Ethical Considerations: The study received approval from the Ethics Committee of the Faculty of Medicine in Fez, ensuring compliance with ethical standards, including confidentiality and voluntary participation. These measures were necessary to protect participants' rights and encourage honest reporting, which is particularly important when exploring teachers' perceived barriers and self-assessed digital skills. Participants were informed that they could withdraw at any time without consequences, supporting ethical and unbiased data collection.

3) Instrument reliability

Before presenting the substantive findings, the reliability of the questionnaire was assessed using Cronbach's alpha coefficient. This test assesses the extent to which the questionnaire questions are inter-correlated, and whether they consistently measure different aspects of teachers' pedagogical practices, particularly with regard to the use of new technologies and virtual reality (Table 4).

Table 4. Item total statistics

Item	Scale mean	Scale variance	Full correlation of corrected items	Cronbach's Alpha
Where do you work?	32.20	42.360	0.379	0.767
To which educational sector do you belong?	32.25	44.713	−0.056	0.785
What level of teaching do you provide?	31.86	43,519	0.125	0.777
How long have you been teaching?	31.78	40,050	0.369	0.763
What would you say is your estimated level of digital skills acquisition?	31.51	48.328	−0.545	0.805
What types of difficulties do you most frequently encounter with struggling learners?	31.56	43.900	0.050	0.781
Which subject area (Life and Earth Sciences) represents the greatest challenge for your struggling learners?	31.77	43.932	0.069	0.779
In your opinion, what are the main difficulties encountered by these learners in the chosen area?	30.75	41.488	0.104	0.794
In your opinion, is the Life and Earth Sciences program for learners with difficulties:	31.04	42.386	0.168	0.777
What pedagogical practices do you use to improve learning for learners with difficulties in Life and Earth Sciences?	30.73	33.650	0.528	0.752
Have you ever heard of virtual reality?	32.19	40.478	0.726	0.754
What is your perception of the technical features of virtual reality?	31.32	32.496	0.788	0.719
Virtual reality as a pedagogical tool can :	31.28	32.806	0.752	0.723
Would you like to use virtual reality in your Life and Earth Sciences teaching?	32.06	38.109	0.830	0.739
What media would you consider appropriate for learners with learning difficulties?	31.33	42.875	0.092	0.783
What materials do you consider possible to use?	31.74	43.719	0.058	0.781
How often do you think virtual reality could be integrated into your	32.05	38.198	0.813	0.740

curriculum?				
What measures do you think are needed to help you integrate virtual reality into your teaching practice?	32.07	38.494	0.811	0.742
In your opinion, what are the obstacles to the use of virtual reality in Life and Earth Sciences teaching?	32.07	38.494	0.811	0.742
Total				**0.775**

Cronbach's alpha for all 19 items was 0.775, indicating good internal consistency of the scale. This result suggests that the items consistently measure the same underlying construct. Consequently, the instrument can be considered reliable for data analysis, particularly for interpreting the overall score (Fig. 4).

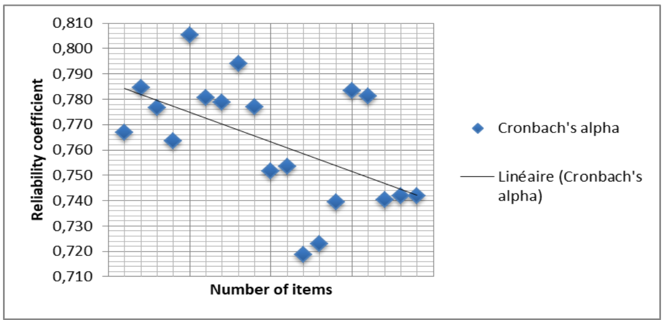

Fig. 4. Cronbach's Alpha results for the model variables.

As illustrated in Fig. 4, the individual reliability coefficients for the different variables remain consistently above the 0.70 threshold, ranging specifically between 0.720 and 0.805. Although the linear trend shows slight fluctuations depending on the number of items, the concentration of data points in the upper quadrant reinforces the robustness of the instrument. This stability ensures that the survey provides a dependable basis for evaluating teacher perceptions and the integration of Virtual Reality in the classroom.

D. Data Analysis

Data analysis was conducted to provide a comprehensive understanding of teachers' practices, perceptions, and the factors influencing the integration of Virtual Reality (VR) in Life and Earth Sciences education. The analyses aimed to: (1) describe the sample characteristics and key variables; (2) evaluate the reliability of the measurement instruments; and (3) explore associations between variables to test the proposed hypotheses. All analyses were performed using IBM SPSS Statistics, a robust software widely employed in educational research, chosen for its ability to conduct both descriptive and inferential analyses and to enhance the reproducibility of the study.

Descriptive Analysis: Descriptive statistics were calculated to summarize the demographic characteristics of teachers, the difficulties encountered by students, and teachers' familiarity with and usage of VR. Indicators included means, standard deviations, frequencies, and percentages. Specifically, descriptive analysis addressed:

- Teachers' demographic variables (age, gender, seniority, school environment)
- Students' learning difficulties as perceived by teachers
- Teachers' familiarity with, frequency of use, and perceived usefulness of VR

This step provided a comprehensive overview of the sample and the primary variables, serving as a foundation for further inferential analyses.

Reliability Analysis: The internal consistency of each section of the questionnaire was assessed using Cronbach's Alpha, with $\alpha \geq 0.70$ considered acceptable, indicating adequate reliability. Items with low item-total correlations were reviewed to determine whether their removal could improve overall consistency. This analysis ensures that the measurement instruments are reliable, and that subsequent statistical results are valid and interpretable.

Bivariate (Correlational) Analysis: Pearson correlation coefficients were computed to examine relationships between continuous variables, including perceived digital competence, frequency of VR use, perceived usefulness of VR, and teacher seniority. A two-tailed significance level of $p < 0.05$ was applied. The resulting correlation matrix provided a comprehensive view of inter-variable associations, allowing identification of meaningful patterns and potential predictors of VR integration in classroom practice.

Chi-Square Tests of Independence: Chi-square tests of independence were conducted to examine associations between categorical variables (teacher characteristics including seniority, digital skills, and school setting) and their perceptions or reported use of VR. Prior to analysis, the assumption of adequate expected cell frequencies (≥5) was verified for each test; any cells with expected frequencies below this threshold are reported explicitly in the results. A p-value < 0.05 was adopted as the threshold for statistical significance. Effect sizes were calculated using Cramér's V ($V < 0.10$ = negligible; 0.10–0.30 = small; 0.30–0.50 = moderate; >0.50 = large), and are reported alongside chi-square statistics to allow evaluation of practical as well as statistical significance.

Pearson correlation coefficients were computed to examine relationships between variables including perceived digital competence, frequency of VR use, perceived usefulness, and seniority. A two-tailed significance level of $p < 0.05$ was applied. It is acknowledged that several variables are operationalized at the ordinal level (e.g., seniority categories, self-rated digital skills); Pearson r values should therefore be interpreted as approximate association measures.

IV. Result

Results are presented in four successive subsections, following the logical sequence of the research questions: (A) sample characteristics and instrument reliability; (B) learning difficulties observed by teachers; (C) perceptions of VR and its pedagogical potential; and (D) factors associated with VR adoption. This structure enables a progressive reading, from description to analysis and interpretation.

A. Sample Characteristics

The sample consists of 82 teachers with the following demographic characteristics (Table 5):

The demographic landscape of the study is defined by a high concentration of female educators (70%) and a strong representation of the urban-public sector (78% and 89%, respectively). With over two-thirds of the sample identifying as having intermediate digital competencies, the profile suggests a workforce positioned at a transitional stage of technological adoption (see Table 5).

Table 5. Sample demographic characteristics

Variable	Category	Frequency (n)	Percentage (%)	Cumulative %
Gender	Female	57	69.5%	69.5%
	Male	25	30.5%	100%
Work Environment	Urban	64	78.0%	78.0%
	Rural	18	22.0%	100%
Work Sector	Public	73	89.0%	89.0%
	Private	4	4.9%	93.9%
	Both	5	6.1%	100%
Education Level Taught	Middle School	37	45.1%	45.1%
	High School	45	54.9%	100%
Seniority	1–5 years	42	51.2%	51.2%
	6–15 years	31	37.8%	89.0%
	16–25 years	4	4.9%	93.9%
	Over 26 years	5	6.1%	100%
Digital Skills	Beginner	15	18.3%	18.3%
	Intermediate	58	70.7%	89.0%
	Advanced	9	11.0%	100%

B. Teachers' Perceptions: Learning Difficulties and the Use of Virtual Reality

1) Learning difficulties observed among struggling learners

A significant proportion (83%) of the teachers surveyed is involved in supporting learners with academic difficulties, while a smaller proportion (17%) is not. This majority indicates that supporting struggling students is a widespread and essential practice in the studied context, reflecting a strong awareness of the specific needs of these learners. The minority who do not work with this group likely correspond to contexts in which such interventions are less required (Fig. 5).

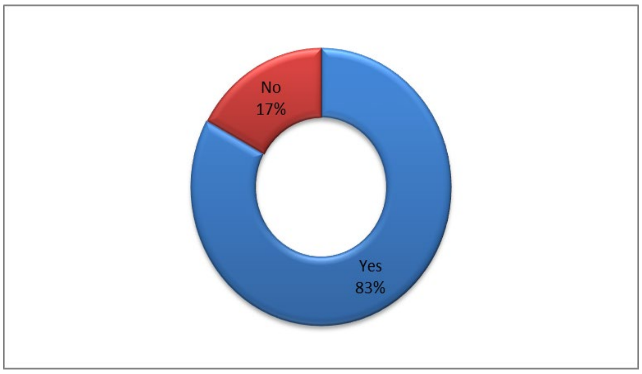

Fig. 5. Frequency of attendance in classes with struggling students.

Among teachers reporting that they work with learners experiencing learning difficulties (83% of the sample), the majority (66%) identify difficulties not formally recognized as disabilities, such as lack of concentration, memory problems, or disruptive behaviour. Approximately 23% report difficulties associated with recognized disabilities, including motor, sensory, or specific learning disorders (e.g., dyslexia, dyspraxia). Finally, 11% mention social or emotional difficulties, such as anxiety or social isolation.

These data indicate that the difficulties encountered are mainly cognitive and behavioural in nature, but may also relate to neurodevelopmental conditions or emotional vulnerabilities, reinforcing the importance of adaptive teaching approaches (Fig. 6).

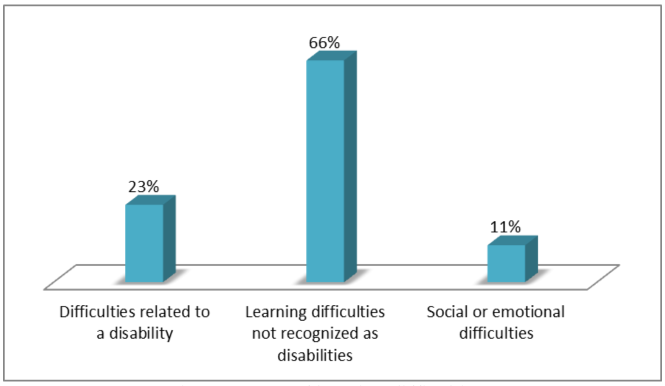

Fig. 6. Nature of learning difficulties.

When comparing perceptions of learning difficulty in Life and Earth Sciences between learners with and without learning difficulties, notable differences emerge. Among learners with difficulties, 12% of teachers rate the content as "very difficult", compared with none in the group without difficulties. Furthermore, 44% of teachers consider the content "difficult" for learners with difficulties, compared with 43% for those without difficulties. The "moderately difficult" category concerns 40% of learners with difficulties and 50% of those without difficulties. Finally, only 4% of learners with difficulties are perceived as finding Life and Earth Sciences easy, compared with 7% of learners without difficulties.

These results highlight a more pronounced perception of difficulty among learners with learning difficulties, with a higher concentration in the upper difficulty levels. This suggests a potential disparity in access to learning, which may justify the use of differentiated pedagogical tools (Fig. 7).

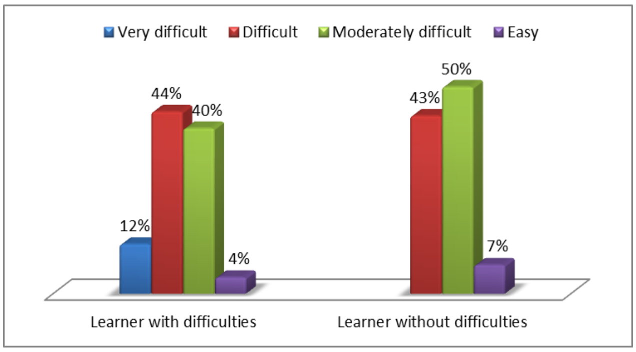

Fig. 7. Perceived level of difficulty of the Life and Earth Sciences program.

With regard to the specific difficulties encountered by learners with learning difficulties in the Life and Earth Sciences subject area identified as most problematic (mainly geology), teachers primarily highlight the language of instruction, cited by 40% of respondents. This is followed by the presence of abstract concepts (22%) and a curriculum considered too demanding (18%). Finally, difficulties related to lack of motivation (10%) and insufficient teaching resources (10%) are also reported.

These findings indicate that barriers to learning are not solely related to scientific content but also involve linguistic, structural, and pedagogical factors, highlighting the need for accessible and multimodal instructional approaches, particularly for learners with special educational needs (Fig. 8).

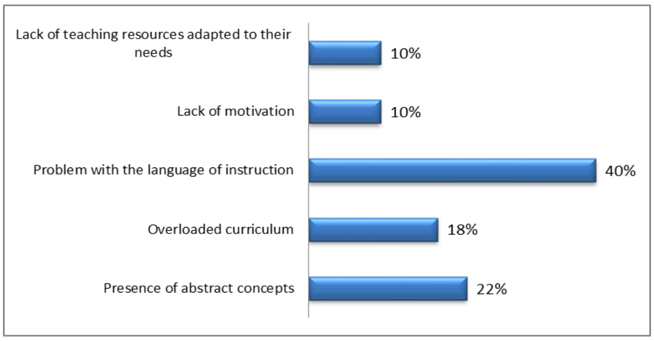

Fig. 8. Barriers to learning in life and earth sciences.

2) Teachers' perceptions of virtual reality

As part of the study, participants were asked about their familiarity with Virtual Reality (VR). The results show that 77% of respondents ($n = 63$) reported having heard of Virtual Reality, while 23% ($n = 19$) reported having no prior awareness of it.

This predominance indicates a certain level of dissemination of the concept within the educational context, although nearly a quarter of teachers remain unfamiliar with it. These findings reflect a partial but substantive level of awareness of VR, which constitutes a relevant starting point for considering its integration into educational systems, provided that teachers are adequately supported in understanding and effectively implementing these immersive technologies (Fig. 9).

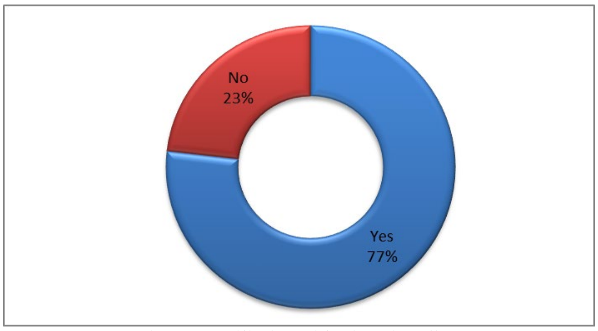

Fig. 9. Familiarity with virtual reality.

When asked to characterise their perceptions of the technical functionalities of Virtual Reality, 40% of teachers identified it as a learning tool based on the simulation of real-life situations, highlighting its immersive and experiential potential. A further 31% viewed it primarily as a tool for visualising complex concepts, emphasising its value for teaching abstract or difficult-to-represent notions, particularly in science education. Only 6% of respondents expressed reservations of a technical or financial nature, considering VR to be a costly or difficult-to-implement approach in current educational contexts. Finally, 23% of teachers reported having no specific perception of its functionalities, indicating a need for awareness-raising or training among a substantial proportion of the sample (Fig. 10).

Teachers were asked to comment on the most appropriate and accessible media for integrating Virtual Reality into their teaching practices. VR headsets were perceived as the most appropriate medium (40%), although they were considered of limited practical use (9%), highlighting a gap between the perceived pedagogical ideal and material constraints in practice. Conversely, 3D computer simulations were reported as easier to use (50%), although they were less frequently perceived as the most pedagogically appropriate option (29%). Similarly, VR applications on smartphones or tablets were considered both appropriate (31%) and relatively accessible (41%), making them a pragmatic compromise between accessibility and pedagogical relevance (Fig. 11).

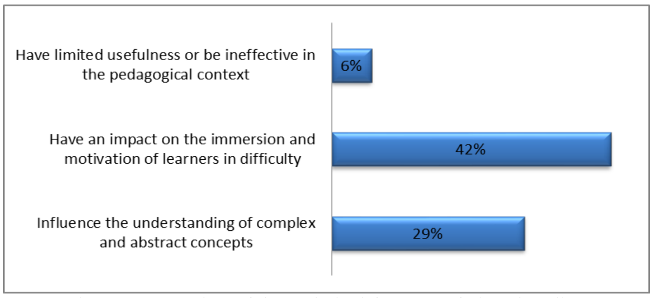

Fig. 10. Perception of the technical features of virtual reality.

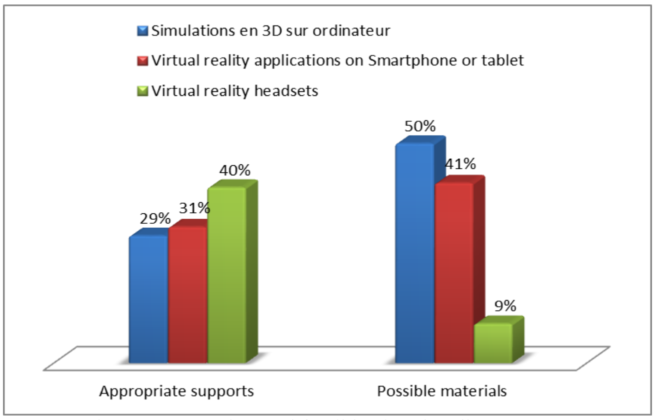

Fig. 11. Appropriate and feasible virtual reality supports.

To promote the integration of Virtual Reality into their teaching practices, participants identified several key needs. The majority (70%) stressed the importance of access to adequate technological resources and equipment, such as VR headsets and high-performance computers. In addition, 24% considered that specific training in the pedagogical use of Virtual Reality is essential for its effective appropriation. Finally, 6% mentioned the need to establish partnerships with VR specialists, demonstrating a willingness to engage in external collaboration to support this approach.

These results indicate that the main obstacles are related to equipment and training, highlighting the importance of dual support both technical and professional to ensure the sustainable and successful adoption of Virtual Reality in educational settings (Fig. 12).

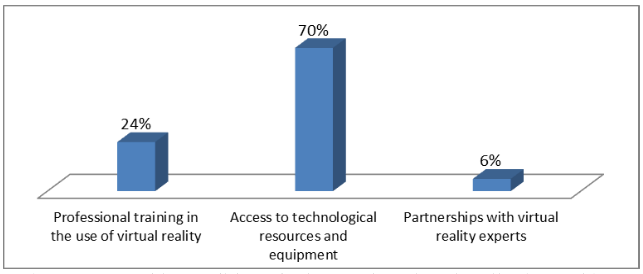

Fig. 12. Favorable conditions for integrating virtual reality in teaching.

Virtual Reality (VR) is perceived by a majority of teachers as a pedagogical tool with significant benefits. Indeed, 42% believe that VR can positively influence the immersion and motivation of struggling learners, highlighting its potential to capture attention and foster engagement. Furthermore, 29% of teachers recognise that VR can facilitate the understanding of complex and abstract concepts, which is particularly relevant in disciplines such as Life and Earth Sciences. However, a minority of respondents (6%) consider VR to be of limited pedagogical value, or even ineffective in certain contexts, reflecting a degree of scepticism regarding its relevance. In addition, 23% of teachers reported having no clear understanding of the advantages that VR can offer, underlining a substantial need for information and training to enable more effective use of this tool (Fig. 13).

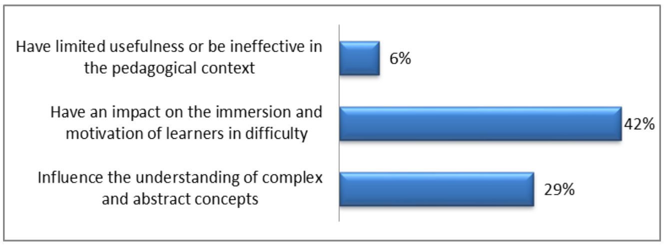

Fig. 13. Pedagogical role of virtual reality.

Teachers identified several major obstacles to integrating Virtual Reality into Life and Earth Sciences teaching. The cost of equipment was the most frequently reported concern, with 70% of respondents citing it as the main barrier. This economic constraint limits access to essential equipment, such as VR headsets and computers capable of running immersive environments.

Another major obstacle, reported by 24% of teachers, is the lack of training. This highlights the need for both pedagogical and technical support to ensure the safe and effective use of these tools in classroom practice.

In contrast, curriculum integration does not appear to constitute a major difficulty, with only 1% of teachers identifying it as an obstacle. Similarly, technical issues such as breakdowns or incompatibilities are rarely reported, with only 5% of participants mentioning them. This low proportion may reflect either a positive perception of hardware reliability or a limited level of hands-on experience with these technologies (Fig. 14).

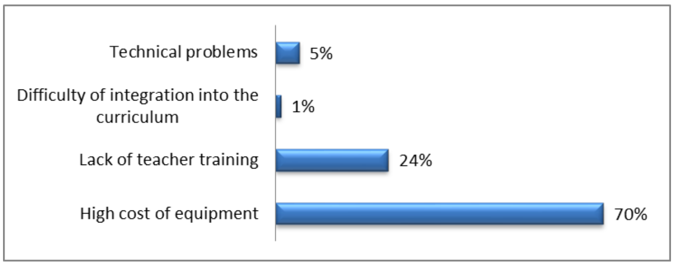

Fig. 14. Barriers to the use of virtual reality.

C. *Inferential Analyses: Correlations and Chi-Square Tests (Hypothesis Testing)*

An analysis of teaching practices according to teachers' levels of digital competence reveals several notable trends. Teachers with advanced digital competence are characterised by a greater use of innovative technologies (7 occurrences) and occasional use of visual and interactive media (2 occurrences), reflecting their increased ease in integrating complex digital tools into their teaching practices. In contrast, beginner teachers primarily report the use of lectures (6 occurrences), with moderate use of collaborative activities, differentiated instruction, visual supports, and hands-on experimentation, suggesting a more traditional and less diversified pedagogical practice.

Teachers with a medium level of digital competence, who represent the majority, show a clear preference for visual and interactive supports (42 occurrences), while remaining relatively less engaged in the use of innovative technologies (2 occurrences) and differentiated instructional practices (1 occurrence). A notable use of practical experimentation is also observed among this group (8 occurrences) (Fig. 15).

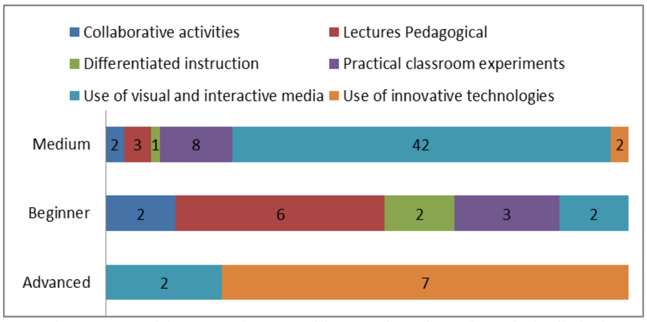

Fig. 15. Teaching practices used by teachers based on their digital competency level.

The analysis of responses according to working environment reveals notable differences between urban and rural teachers. A majority of urban teachers expressed a willingness to integrate Virtual Reality into their teaching practices, with 51 respondents selecting "Yes, I would like to integrate it". In contrast, only six rural teachers reported the same intention. A relatively higher number of rural teachers (11) selected "Maybe, with more information", compared with eight urban teachers, suggesting a stronger need for training and support in rural contexts. Finally, a small proportion of teachers indicated a preference for alternative methods (five urban teachers and one rural teacher).

These findings are consistent with the statistical analysis, which reveals a significant association between working environment and teachers' attitudes toward the integration of Virtual Reality in teaching practices (Fig. 16).

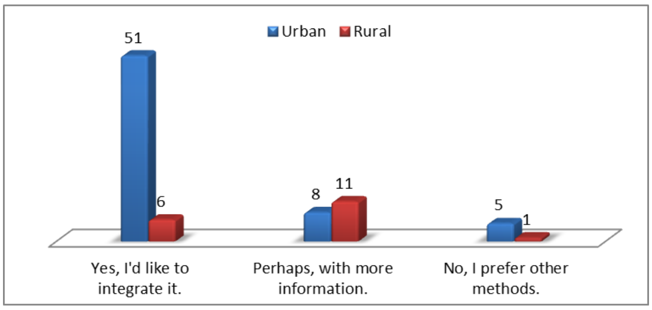

Fig. 16. Virtual reality usage.

The analysis of teachers' opinions according to their professional experience reveals notable variations. Teachers with between one and 15 years of experience show strong support for the integration of Virtual Reality in Life and Earth Sciences teaching, with more than three-quarters expressing a willingness to adopt this technology. In contrast, teachers with more than 16 years of experience appear more reserved, and none of those with more than 26 years of seniority expressed a clear intention to integrate Virtual Reality into their teaching practices.

These results suggest that teaching experience may be associated with teachers' perceptions of immersive technologies. This trend highlights the potential importance of targeted training initiatives aimed at supporting more experienced teachers in adopting innovative pedagogical tools such as Virtual Reality (Fig. 17).

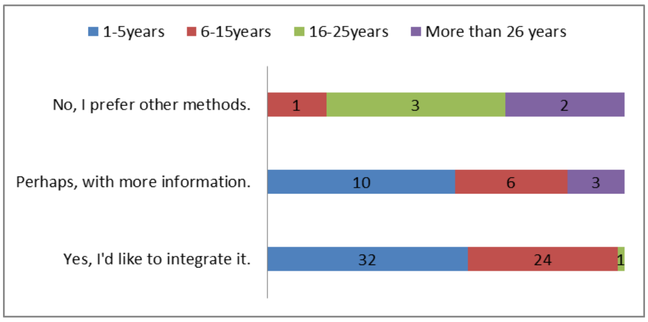

Fig. 17. Opinions on the Integration of virtual reality by teaching experience.

An examination of Fig. 16 reveals a clear disparity in the adoption rates of Virtual Reality (VR) according to self-assessed levels of digital competence. A structural shift in usage patterns is observed as technical expertise increases: "Beginner" profiles exhibit predominantly episodic use, whereas "Medium" and "Advanced" profiles are mainly characterised by weekly usage. This distribution suggests that the frequency of interaction with the tool is closely associated with users' technical proficiency.

Furthermore, the data highlight a significant entry barrier for novice users. While the transition from "Beginner" to "Medium" status is accompanied by a marked shift toward regular integration, the "Advanced" group demonstrates the highest level of consistency, with nearly 89% of its members maintaining a weekly usage pattern. This progression indicates that a certain threshold of digital literacy is not merely advantageous but may constitute a prerequisite for the sustained and frequent use of immersive technologies such as VR in educational contexts (Fig. 18).

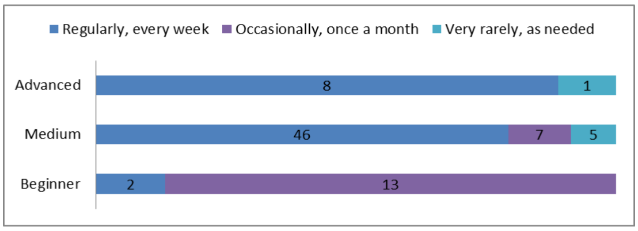

Fig. 18. Degree of virtual reality use according to digital competency level.

The three variables analyzed seniority, digital competence, and work environment all showed highly significant associations ($p < 0.001$) with teachers' perceptions and use of virtual reality. Effect sizes, calculated using Cramér's V, indicate that seniority had a large effect ($V = 0.74$), digital skills also a large effect ($V = 0.69$), and work environment a moderate effect ($V = 0.48$). Prior to each chi-square test, the assumption of adequate expected cell frequencies was verified: all expected cell frequencies were ≥5 for the digital skills test (df = 4) and the work environment test (df = 2). For the seniority test (df = 6), two cells in the categories "16–25 years" and "Over 26 years" had expected frequencies below 5, owing to the small subgroup sizes ($n = 4$ and $n = 5$, respectively). This constitutes a limitation that should be interpreted with caution; results for this test remain indicative but may not fully satisfy chi-square assumptions. These findings justify their consideration in the analysis and recommendations (Table 6).

To examine the relationships between the study variables, a Pearson correlation analysis was conducted. The results are presented in Table 7.

Table 6. Chi-Square test between variables of the correlation matrix

Test		Value	df (degrees of freedom)	Asymptotic significance (p-value)	Cramér's V (Effect Size)
Seniority	Pearson chi-square	45,344a	6	0.000	
	Likelihood ratio	32,211	6	0.000	0.74
	N of valid observations	82	6		
Digital skills	Pearson chi-square	39,291a	4	0.000	
	Likelihood ratio	37,034	4	0.000	0.69
	N of valid observations	82	4		
Work environment	Pearson chi-square	18,768a	2	0.000	
Seniority	Likelihood ratio	16,680	2	0.000	0.48
	N of valid observations	82			

Table 7. Pearson correlation matrix

Variables Compared	Correlation (r)	Significance (p)	Interpretation
Workplace ↔ VR usage	0.296	0.007 (**$p < 0.01$**)	A moderate positive correlation is observed, indicating that certain work environments are more favorable to the integration of virtual reality. This may reflect variations in institutional support, access to technological resources, and digital culture.
Seniority ↔ VR usage	−0.490	< 0.001 (**$p < 0.01$**)	A moderate to strong negative correlation is found, suggesting that teachers with lower seniority (early-career teachers) are more likely to adopt virtual reality compared to more experienced teachers.
Digital skills ↔ VR usage	0.318	0.004 (**$p < 0.01$**)	A moderate positive correlation indicates that higher levels of digital competence are associated with increased use of virtual reality in teaching practices.

As shown in Table 7, three variables are significantly correlated with VR usage. First, workplace shows a moderate positive correlation with VR usage ($r = 0.296$, $p = 0.007$), suggesting that the professional environment in which teachers work is associated with the likelihood of VR integration. Second, seniority exhibits a moderate to strong negative correlation with VR usage ($r = -0.490$, $p < 0.001$), indicating that early-career teachers tend to report higher levels of VR adoption than their more experienced counterparts. Third, self-perceived digital skills are moderately and positively correlated with VR usage ($r = 0.318$, $p = 0.004$), suggesting that teachers who consider themselves more digitally competent are more likely to use VR in their teaching practice. All three correlations are statistically significant at the 0.01 level.

V. Discussion

This study provides a detailed overview of teachers' perceptions and the integration of Virtual Reality (VR) in education, particularly for students with learning difficulties. The descriptive analysis indicates that the sample is predominantly female (70%, $n = 57$) and mainly based in urban areas (78%, $n = 64$). These teachers generally have between one and five years of professional experience and report an average level of digital competence, suggesting openness to educational innovation but also a need for further technological support to fully exploit the potential of VR.

Correlational analyses reveal significant relationships between certain teacher characteristics and the use of VR. Seniority shows a moderate-to-strong negative correlation with VR use ($r = -0.490$, $p < 0.001$), indicating that less experienced teachers - particularly those with one to 15 years of professional experience - tend to integrate this technology more frequently into their teaching practices. In contrast, teachers with higher seniority (16 years and above) appear considerably more reluctant to adopt VR, a finding consistent with UTAUT predictions that established pedagogical routines developed over years of practice may act as a barrier to technology adoption. This result directly supports Hypothesis H1.2 and aligns with the patterns observed in Fig. 15, where no teacher with more than 26 years of experience expressed a clear intention to integrate VR.

These findings are also supported by recent literature. Gupta and Bhaskar [42] demonstrate that teachers' personal characteristics, such as computer proficiency, technological self-efficacy, and age, significantly influence their intention to adopt VR, thereby confirming the importance of individual factors in the integration of immersive technologies. Research focusing specifically on algorithmic and programming courses also confirms the positive impact of VR on student learning outcomes [43].

However, a deeper analysis of inclusion needs suggests that the successful integration of these technologies requires broadening the discussion to include Augmented Reality (AR) as a complementary approach to Virtual Reality (VR). While VR enables full immersion in complex environments—which, as this study demonstrates, significantly facilitates the understanding of complex concepts and enhances learner motivation—AR offers a different yet equally important pedagogical contribution. By overlaying scaffolding tools such as 3D models and audio instructions directly onto the real-world environment, AR maintains continuity between the virtual and physical contexts. This feature reduces cognitive load and is particularly effective for students with dyspraxia or Attention-Deficit/Hyperactivity Disorder (ADHD), as it enables intuitive interaction and provides immediate multisensory feedback [44].

Consequently, the results of this study confirm that both VR and AR are effective educational tools capable of enhancing the quality of learning and the emotional engagement of students experiencing academic difficulties, particularly in scientific disciplines, as noted in [24, 45]. By integrating AR features alongside VR, teachers can design more supportive and flexible learning pathways, facilitating the transition from immersive virtual exploration to concrete classroom application [46].

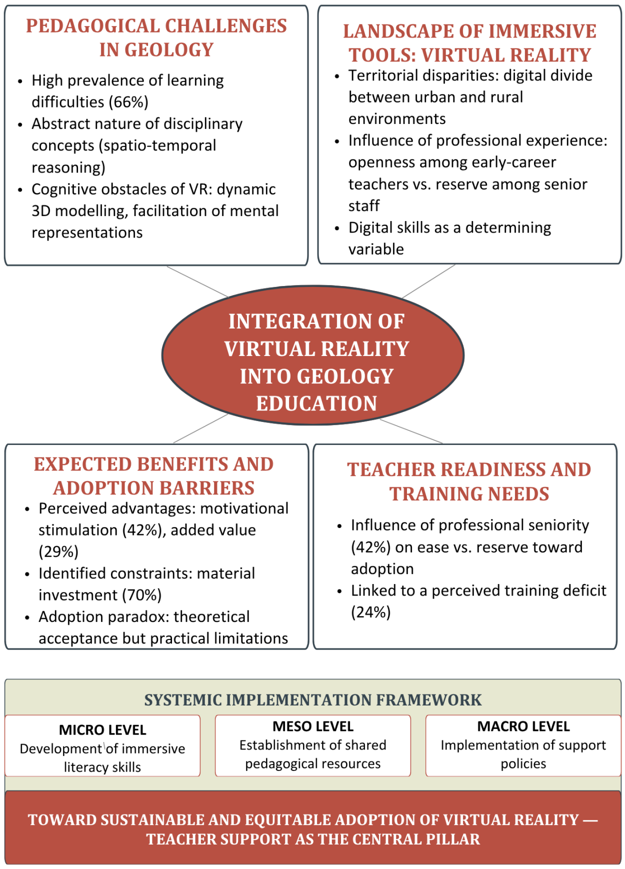

Fig. 19. Conceptual model of virtual reality integration in education.

Despite this positive perception of the benefits for inclusive education, adoption remains moderate. The main obstacles identified high equipment costs and insufficient specific training are consistent with the findings of Ref. [21]. The relatively low frequency of references to pedagogical resistance suggests that the primary barrier is not teacher rejection, but rather limited access to resources and the need to further develop digital skills in order to effectively bridge the gap between VR immersion and AR-based support.

This study has several limitations. The relatively small sample size and its predominantly urban composition may limit the generalisability of the findings. In addition, the use of self-administered questionnaires may introduce response bias regarding teachers' digital competence and their actual use of VR. Finally, the absence of direct classroom observations limits a more comprehensive understanding of how this technology is implemented in practice.

Despite these limitations, the results highlight the critical importance of developing teachers' digital competence, a key factor in ensuring the sustainable and effective adoption of VR in education. At the micro level, developing VR literacy combining technological proficiency with pedagogical design appears essential. At the meso level, the creation of shared immersive ecosystems through resource exchange could help reduce territorial inequalities. At the macro level, establishing an enabling policy framework that includes continuous professional development and integration into curricular standards would serve as a key lever for large-scale adoption (see Fig. 19).

Ultimately, this research outlines a roadmap for the thoughtful integration of Virtual Reality that moves beyond mere intention toward genuine appropriation. In line with Refs. [24, 45], the findings demonstrate that VR holds substantial transformative potential for the most vulnerable learners; however, its effective realization depends on a proactive educational policy that places teacher support particularly in terms of equipment provision, professional training, and institutional recognition at the core of its strategy, thereby reinforcing the relevance of the recommendations made in [21, 47].

VI. Conclusion

This study investigated the integration of Virtual Reality (VR) into the teaching of Life and Earth Sciences, with particular attention to students with learning difficulties. Overall, science teachers reported a positive perception of this technology, recognizing its potential to render abstract concepts more concrete and to enhance student motivation and engagement. These findings are consistent with prior research highlighting the positive effects of immersive technologies on cognitive and emotional engagement.

However, despite this favourable perception, several barriers were identified that limit the effective use of VR in teaching practices. Teachers reported insufficient training, limited access to appropriate equipment, and a lack of pedagogical resources specifically designed for immersive environments. Addressing these challenges requires investment in both technological infrastructure and teacher professional development.

The study also revealed that teacher characteristics, including seniority, work environment, and perceived digital competence, were significantly associated with VR use, in line with previously reported patterns. These results underscore the importance of providing targeted support, particularly for teachers working in under-resourced or rural contexts.

Overall, the findings shed light on the conditions necessary for the successful integration of VR into the Moroccan education system and highlight the need for further research into its pedagogical, social, and emotional impacts, especially within inclusive learning contexts. For VR to function as a genuine driver of educational innovation and a tool for supporting learners with difficulties, effective enabling conditions are essential, including in-service training, accessible teaching resources, and strengthened technological infrastructure.

Finally, this study raises an important question for future research: how can educational policies mobilize resources and foster technological innovation to ensure that VR becomes a meaningful driver of success and equal opportunity for all learners?

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

A.B. conceptualized the study, designed the virtual reality scenarios, conducted the field research, and wrote the original draft of the manuscript. S.B.F. contributed to the study design, supervised data collection, and reviewed and edited the manuscript. K.E.K. provided guidance on methodology, statistical analyses, and critically revised the manuscript. All authors have read and approved the final version of the manuscript.

References

[1] S. Mantouzi, "Artificial intelligence and the performance of the Moroccan higher education sector: Issues and interactions," *Rev. Fr. Écon. Gest.*, vol. 4, no. 11, pp. 21–42, 2023.

[2] T. Martineaud, "Self-training and digital technologies: Teachers' practices during and after the COVID-19 crisis in France," *Distances Médiations Savoirs*, vol. 48, 2024. doi: 10.4000/12xom

[3] H. D. E. Bouffy, "The integration of ICT in teacher training in Morocco," *International Journal of Accounting, Finance, Auditing, Management and Economics*, 2022. doi: 10.5281/ZENODO.7158416

[4] S. Grégoire, "The use of virtual reality in education," *Rev. Int. d'Éduc. Sèvres*, no. 96, pp. 11–15, Sep. 2024. doi: 10.4000/12fsj

[5] E. Forsans. (2020). The main obstacles and challenges identified by VR developers. [Online]. Available: https://afjv.com/news/10301_les-plus-grands-obstacles-et-defis-de-la-realite-virtuelle.htm?utm_source=chatgpt.com (in French)

[6] M.-L. Weber, F. Rodhain, and A. Chollet, "Use of virtual reality in higher education: From posture to competence—A reflection through professional didactics," presented at the Conf. Digital Uses in Higher Education, 2018.

[7] L. Perot. (2022). Virtual and augmented reality in education. M.S. thesis. [Online]. Available: https://dumas.ccsd.cnrs.fr/dumas-03899723 (in French)

[8] A. B. Saga and N. E. Mqaddem, "Use of virtual reality and augmented reality in higher education: From experimentation to effective integration into training curricula," *J. Inf. Sci.*, vol. 21, pp. 194–202, 2023. doi: 10.34874/IMIST.PRSM/JIS-V21I2.36539

[9] N. Ouramdane, S. Otmane, and M. Mallem, "3D interaction in virtual reality: State of the art," *Tech. Sci. Inform.*, vol. 28, no. 8, pp. 1017–1049, 2009. doi: 10.3166/tsi.28.1017-1049

[10] T. S. Mujber, T. Szecsi, and M. S. J. Hashmi, "Virtual reality applications in manufacturing process simulation," *J. Mater. Process. Technol.*, vol. 155–156, pp. 1834–1838, Nov. 2004. doi: 10.1016/j.jmatprotec.2004.04.401

[11] I. Dubovi, S. T. Levy, and E. Dagan, "Now I know how! The learning process of medication administration among nursing students with non-immersive desktop virtual reality simulation," *Comput. Educ.*, vol. 113, pp. 16–27, 2017. doi: 10.1016/j.compedu.2017.05.009

[12] C. Marquis, C. Saint-Jérôme, and B. Poellhuber, "Virtual reality for better science learning: Educational scenarios that promote motivation, engagement, and flow," *Spectre*, vol. 52, no. 1, 2022. (in French)

[13] K. Ponto, J. Kohlmann, and R. Tredinnick, "DSCVR: Designing a commodity hybrid virtual reality system," *Virtual Real.*, vol. 19, no. 1, pp. 57–70, 2015. doi: 10.1007/s10055-014-0254-0

[14] M. Musa, P. Rahman, and D. Buhalis, "Virtual Reality (VR) types," in *Encyclopedia of Tourism Management and Marketing*, D. Buhalis, Ed. Cheltenham, U.K.: Edward Elgar Publishing, 2022, pp. 679–683. doi: 10.4337/9781800377486.virtual.reality

[15] G. Burdea and N. A. Langrana, "Virtual force feedback: Lessons, challenges, future applications," *J. Robot. Mechatron.*, vol. 5, no. 2, pp. 178–182, 1993. doi: 10.20965/jrm.1993.p0178

[16] C. R. Guerra-Tamez, "The impact of immersion through virtual reality in the learning experiences of art and design students: The mediating effect of the flow experience," *Educ. Sci.*, vol. 13, no. 2, 185, Feb. 2023. doi: 10.3390/educsci13020185

[17] A.-B. Stănescu, S. Travadel, R.-V. Rughiniș, and R. Bucea-Manea-Țoniș, "Modeling learning outcomes in virtual reality through cognitive factors: A case study on underwater engineering," *Electronics*, vol. 14, no. 17, 3369, 2025. doi: 10.3390/electronics14173369

[18] F. Landragin, "Multimodal interaction in a virtual environment," Ph.D. dissertation, Univ. de Caen, France, 1998. (in French)

[19] L. Sternberger, "Interaction in virtual reality," Louis, Pasteur University of Strasbourg 1, France, 2006.

[20] T. A. Mikropoulos and A. Natsis, "Educational virtual environments: A ten-year review of empirical research (1999–2009)," *Comput. Educ.*,

vol. 56, no. 3, pp. 769–780, 2011. doi: 10.1016/j.compedu.2010.10.020
[21] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," *Comput. Educ.*, vol. 147, 103778, 2020. doi: 10.1016/j.compedu.2019.103778
[22] K. C. Shim, J.-S. Park, H.-S. Kim, J.-H. Kim, Y.-C. Park, and H.-I. Ryu, "Application of virtual reality technology in biology education," *J. Biol. Educ.*, vol. 37, no. 2, pp. 71–74, 2003. doi: 10.1080/00219266.2003.9655854
[23] F. Marchi *et al.*, "Learning by doing in nanosciences and nanotechnologies by means of virtual realities and multisensory interaction with haptic systems at CIME Nanotech Grenoble," *J3eA*, vol. 21, 1009, 2022. doi: 10.1051/j3ea/20221009
[24] C. Marquis, C. de Saint-Jérôme, and B. Poellhuber, "Virtual reality for better science learning," *Spectre*, vol. 52, no. 1, 2022. (in French)
[25] E. Raymer, Á. MacDermott, and A. Akinbi, "Virtual reality forensics: Forensic analysis of Meta Quest 2," *Forensic Sci. Int. Digit. Investig.*, vol. 47, 301658, Dec. 2023. doi: 10.1016/j.fsidi.2023.301658
[26] M. Masalkhi *et al.*, "Apple Vision Pro for ophthalmology and medicine," *Ann. Biomed. Eng.*, vol. 51, no. 12, pp. 2643–2646, 2023. doi: 10.1007/s10439-023-03283-1
[27] J. Bailenson, *Experience on Demand: What Virtual Reality Is, How It Works, and What It Can Do*, New York, NY: W. W. Norton & Co., 2018.
[28] C. Baudouin, M. Beney, P. Chevaillier, and A. Le Pallec, "Collection of traces for monitoring the activity of learners in practical work in a virtual reality environment," *STICEF*, vol. 14, pp. 389–418, 2008. (in French)
[29] H. Yougsassen, "Virtual communities as a catalyst for the academic and socioeconomic development of students in Morocco," *Rev. Repères Littéraires Lang. Artistiques*, no. 3, pp. 242–258, 2023. (in French)
[30] J. Hattie and H. Timperley, "The power of feedback," *Rev. Educ. Res.*, vol. 77, no. 1, pp. 81–112, Mar. 2007. doi: 10.3102/003465430298487
[31] S. Greener, *Learning and Teaching in a Virtual Environment: A Review of Current Thinking*, Brighton Business School, University of Brighton, UK, 2007.
[32] J. Parong and R. E. Mayer, "Learning science in immersive virtual reality," *J. Educ. Psychol.*, vol. 110, no. 6, pp. 785–797, 2018. doi: 10.1037/edu0000241
[33] F. Ke and T. Im, "Virtual-reality-based social interaction training for children with high-functioning autism," *J. Educ. Res.*, vol. 106, no. 6, pp. 441–461, 2013. doi: 10.1080/00220671.2012.692462
[34] I. P. Dewi, L. Asnur, R. Marta, D. T. P. Yanto, M. Dhanil, E. M. Saari, and S. K. Ali, "How effective is immersive AR continental food course for vocational education? Analyzing knowledge gains and learning outcome effects," *Int. J. Inf. Educ. Technol.*, vol. 15, no. 1, pp. 127–136, 2025. doi: 10.18178/ijiet.2025.15.1.2225
[35] D. T. P. Yanto, G. Ganefri, S. Sukardi, J. P. Yanto, A. D. Samala, I. P. Dewi, R. Kurani, H. Setiawan, and M. Kabatiah, "Innovative laboratory learning: A study evaluating the practicality of integrated e-worksheets with augmented reality in electrical machines course," *Int. J. Inf. Educ. Technol.*, vol. 14, no. 7, pp. 996–1005, 2024. doi: 10.18178/ijiet.2024.14.7.2127
[36] I. P. Dewi, H. Hidayat, D. Irfan, A. Asrifan, M. Dhanil, S. A. Bakar, and A. Bengueddach, "Augmented reality in computer network learning: How to improve students' self-efficacy?" *Int. J. Inf. Educ. Technol.*, vol. 16, no. 1, pp. 91–101, 2026. doi: 10.18178/ijiet.2026.16.1.2486
[37] F. D. Davis, "Perceived usefulness, perceived ease of use, and user acceptance of information technology," *MIS Q.*, vol. 13, no. 3, pp. 319–340, Sep. 1989. doi: 10.2307/249008
[38] R. Scherer, F. Siddiq, and J. Tondeur, "The Technology Acceptance Model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education," *Comput. Educ.*, vol. 128, pp. 13–35, 2019. doi: 10.1016/j.compedu.2018.09.009
[39] V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis, "User acceptance of information technology: Toward a unified view," *MIS Q.*, vol. 27, no. 3, pp. 425–478, 2003. doi: 10.2307/30036540
[40] J. Sweller, "Cognitive load during problem solving: Effects on learning," *Cogn. Sci.*, vol. 12, no. 2, pp. 257–285, 1988. doi: 10.1207/s15516709cog1202_4
[41] R. E. Mayer and R. Moreno, "Nine ways to reduce cognitive load in multimedia learning," *Educ. Psychol.*, vol. 38, no. 1, pp. 43–52, Jan. 2003. doi: 10.1207/S15326985EP3801_6
[42] K. P. Gupta and P. Bhaskar, "Teachers' intention to adopt virtual reality technology in management education," *Int. J. Learn. Change*, vol. 15, no. 1, pp. 28–50, 2023. doi: 10.1504/IJLC.2023.127719
[43] I. P. Dewi, A. Ambiyar, H. Effendi, M. Giatman, H. F. Hanafi, and S. K. Ali, "The impact of virtual reality on programming algorithm courses on student learning outcomes," *Int. J. Learn. Teach. Educ. Res.*, vol. 23, no. 10, pp. 45–61, Oct. 2024. doi: 10.26803/ijlter.23.10.3
[44] W. B. Latif, I. Yasin, A. Rahaman, S. Forid, N. Islam, and M. Z. Hossain, "Impact of Augmented Reality (AR) and Virtual Reality (VR) on interactive learning systems," *Pac. J. Adv. Eng. Innov.*, 2024. doi: 10.70818/pjaei.2024.v01i01.016
[45] R. Canopé. (2025). Virtual reality for teaching abstract knowledge or requiring field practice. *Réseau Canopé* [Online]. Available: https://www.reseau-canope.fr/agence-des-usages/realite-virtuelle.html
[46] H. T. Crogman, V. D. Cano, E. Pacheco, R. B. Sonawane, and R. Boroon, "Virtual reality, augmented reality, and mixed reality in experiential learning: Transforming educational paradigms," *Educ. Sci.*, vol. 15, no. 3, 303, Feb. 2025. doi: 10.3390/educsci15030303
[47] J. Tondeur, N. P. Roblin, J. V. Braak, J. Voogt, and S. Prestridge, "Preparing beginning teachers for technology integration in education: Ready for take-off?" *Technol. Pedagogy Educ.*, vol. 26, no. 2, pp. 157–177, Mar. 2017. doi: 10.1080/1475939X.2016.1193556