Research Article

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Assessing the Outcomes of Digital Soil Science Curricula for Agricultural Undergraduates in the Global South

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Abstract: This academic inquiry examines the efficacy of virtual reality (VR)-based pedagogy for higher learning, specifically analyzing immersive digital instruction for rural agriculture undergraduates studying soil science in Colombia. The investigation tests two hypotheses: first, simulated learning situations improve academic achievement and student investment compared to conventional in-person lectures; and second, modern modalities cultivate affirmative perspectives of the material. Employing a meticulous investigative blueprint across three Colombian university campuses situated in pastoral communities, the assessment involved 89 volunteers separated into experimental and control groups over 14 weeks analyzing soil nutrient administration. Scholastic aptitude, student absorption, and viewpoint appraisals were conducted before and after the module. Statistical calculations including independent sample examinations, variance examinations, effect magnitude, and association analyses were utilized to validate the hypotheses. The results endorse both hypotheses, evidencing augmented academic performance, student engagement, and affirmative attitudes toward soil science among participants experiencing VR-based coursework. This inspection lends valuable discernment into advanced technology's potential to address rural student challenges, elevating educational outcomes and furthering constructive pedagogical encounters in the developing world.

Keywords: higher education, rural students, soil science, global south, academic curricula

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1 Introduction

This academic inquiry examines the potential of digital pedagogies to transform higher education, particularly for disadvantaged rural learners. As technological progress and evolving teaching models reshape the educational landscape, digital tools redefine instructional techniques and transform learning. This study investigates the efficacy of immersive virtual reality (VR) interventions in improving academic achievement, engagement, and perspectives among Colombian undergraduate agriculture students situated in rural areas.

One major issue facing higher education is the limited access to quality educational resources. Conventional teaching methods not always be enough to engage students and facilitate deep learning, particularly in subjects like Agricultural Science that require hands-on, experiential learning. This problem is even greater in resource-limited rural settings, where students may not have exposure to advanced educational technologies or innovative teaching approaches. Another pressing challenge is the need to equip future professionals with the necessary knowledge and skills to tackle real-world problems in their respective fields.

For Agricultural Science specifically, robust education in soil nutrient management is crucial for addressing global issues related to food security, environmental sustainability, and climate change. However, traditional teaching methods may not effectively convey the complexity and practical applications of this knowledge. Addressing these challenges urgently requires exploring innovative pedagogical approaches that can bridge the gap between theory and practice, enhance student engagement, and improve academic achievement. The focus of this research is to investigate the potential of immersive VR technology as a transformative digital pedagogy tool for higher education, particularly in the context of rural agricultural education.

The research study highlights the transformative potential of digital pedagogies in higher education, aligning with previous findings that digital tools can enhance student–resource interactions, create real-life learning situations, and improve the overall learning experience (Bentri & Hidayati, 2022; Rahmatullah, Sultana, & Sultan, 2020). Additionally, the study acknowledges the potential of digital pedagogy to individualize learning, promote collaborative learning, and redefine the role of educators, which is supported by the findings of Bentri and Hidayati (2022).

However, the research study identifies a significant gap in providing educators with adequate training and support to develop their digital pedagogy competencies. This gap is corroborated by previous studies that emphasize the importance of in-service training for educators to enhance their digital pedagogy skills (Bentri, 2023) and the need for educational institutions to strengthen the capacity of teachers and technical staff in digital pedagogy through curriculum modifications (Subedi & Sherpa, 2022).

The urgency to address this gap is underscored by the research study's findings, which align with previous literature highlighting the crucial role of digital pedagogy competence among educators in improving collaborative learning and student engagement (Männistö et al., 2020). Furthermore, the study supports the broader significance of digital transformation in education and the need for innovative pedagogical approaches to bridge the gap between theory and practice, as emphasized in the literature (Bryant, 2022). It also acknowledges a significant challenge in the lack of scientific substantiation of digital pedagogy as a field, which is consistent with the concerns raised by Gryaznova (2021).

One major issue facing higher education, especially the lack of access to quality resources, is well-documented in the literature. A comprehensive study by UNESCO (2020) found that over 260 million children globally do not have access to quality educational materials, disproportionately impacting rural and marginalized communities. Furthermore, research by Raulerson, Smalley, and Gunderson (2019) highlights how conventional teaching methods often fail to engage diverse learners effectively, leading to disengagement and poor knowledge retention, particularly in fields requiring applied, experiential learning. The challenges faced in resource-limited rural contexts are further exacerbated by limited technological infrastructure and exposure to innovative pedagogies.

Empirical evidence from Mgaiwa and Poncian (2016) demonstrates how the lack of access to educational technologies widens existing achievement gaps between rural and urban student populations. Theoretical frameworks such as the Technology Pedagogy and Content Knowledge model underscore the importance of integrating technology with effective teaching practices to enhance learning outcomes.

Equipping future professionals with relevant skills is a pressing concern across domains, but particularly acute in fields like Agricultural Science. Studies by Fähnrich (2018) and Merrill, Kedan, Carley, and Lewis (2021) emphasize the critical role of soil nutrient education in addressing food security, environmental sustainability, and climate change adaptation – all major global challenges.

However, research by Rashid and Mohamed (2020) indicates that traditional lecture-based methods often fail to impart the practical, applied knowledge needed for effective soil management practices. To bridge these gaps, innovative pedagogical approaches leveraging technology hold significant promise. Theoretical frameworks like the Immersive Learning Research Network's model (Rashid, & Mohamed, 2020) and empirical studies by Makransky, Terkildsen, and Mayer (2019) and Parong and Mayer (2018) highlight the potential of immersive technologies like VR to enhance engagement, knowledge retention, and applied learning – aligning with the objectives of this research focused on rural agricultural education contexts.

At the intersection of digital education and rural contexts, this research explores potential VR-based learning advantages for Colombian undergraduate agriculture cohorts. The central research question guiding this investigation queries: What is VR-based learning impacts on academic performance, engagement, and attitudes toward soil nutrient education among rural Colombian undergraduate agriculture students? The study posits two hypotheses: (1) VR-based learning enhances academic achievement and engagement for rural agriculture undergraduates compared to in-person instruction for soil nutrition education and (2) VR-based learning cultivates more positive attitudes toward soil nutrition education versus in-person modalities for the same rural agriculture undergraduate cohort.

Per the hypotheses, this study evaluates academic achievement for rural agriculture undergraduates enrolled in soil nutrition courses. Contributing to educational research and practice, this inquiry examines the intersection of VR technology and rural higher education. Analyzing how digital tools effectively engage and empower students in underserved communities, this exploration of VR-based impacts on performance, engagement, and perspectives offers insights to guide contextually relevant learning environments across locales.

This study's focus on Agricultural Science contributes a unique dimension to the research implications. As agricultural practices adapt to global challenges, robust soil nutrient management education grows increasingly vital for students. By validating VR-based learning efficacy in this specialized context, the inquiry carries insights resonant not just for education but the broader agricultural sector. Identifying engagement, attitude, and performance enhancement strategies could equip future professionals with requisite knowledge and motivation to address real-world agricultural issues.

However, certain limitations temper the scope and interpretation of these findings. The Agricultural Science emphasis risks reduced generalizability to other disciplines with distinct subject matter and learning goals. Furthermore, the geographical specificity centered on Colombian rural areas could introduce regional biases limiting applicability elsewhere. Educational, cultural, and socioeconomic differences across regions potentially impact student VR learning experiences and attitude formation, necessitating careful consideration before transferring insights.

Additionally, uncontrolled external variables may interact with the interventions and outcomes. Factors like prior VR familiarity, individual learning styles, and personal motivations could influence the observed results. Further research controlling for these elements would bolster the study's conclusions within defined parameters. Nonetheless, this initial investigation provides a meaningful starting point to assess VR-based learning's promise for rural higher education.

2 Literature Review

Digital learning integration in higher education has expanded recently, especially to address distinctive rural student challenges like limited resource accessibility, inadequate infrastructure, and geographical seclusion. Immersive, interactive VR-based platforms potentially mitigate these obstacles by providing engaging educational experiences unconstrained by locality.

Previous research has explored the potential of digital learning integration in higher education, particularly in addressing the unique challenges faced by rural students. However, there is a lack of research on the specific application of VR-based learning in rural Colombian undergraduate agriculture education. Additionally, while the potential of digital learning in developing nations has been recognized, there are still significant challenges to its implementation, particularly in limited-resource settings.

This literature review contextualizes and supports investigating VR-based learning efficacy for rural Colombian undergraduate agriculture students. Analysis of existing VR learning research explores associated pedagogical foundations, instructional design principles, and empirical performance evidence. Additionally, a review of potential VR-based learning benefits for rural students including enhanced engagement, improved academic achievement, and elevated subject matter attitudes draws on relevant theories and studies, comprehensively examining prospective VR impacts on Colombian undergraduate rural agriculture cohorts. The synthesis of established frameworks and prior findings informs and situates the current study within broader conversations on technological innovation in higher education to serve diverse learner needs.

2.1 Virtual Technologies Addressing Real-World Challenges

Digital learning in higher education has become increasingly important, especially in rural contexts where access to traditional educational resources may be limited. The integration of digital platforms and learning tools has been identified as crucial in meeting contemporary educational standards (Benavides, Arias, Serna, Bedoya, & Burgos, 2020). However, the transition to digital learning can pose challenges for students from under-resourced rural areas, as they may lack the necessary digital literacy skills required for higher education institutions (Jantjies & Dalasile, 2019). Additionally, the use of digital technologies in higher education has been recognized as essential for the development of digital competencies needed for the digital economy, particularly in rural areas (Baydullaev, Tayrov, Narzullaev, Shadmanov, & Yomgirov, 2023).

Furthermore, the rural context plays a significant role in the effectiveness of digital learning and the overall educational experience. Research has shown that the rural context presents unique challenges for educational institutions, including the need for leadership to promote strong relationships with staff, students, and the community (de la Puente & Perez, 2023; Myende & Maifala, 2020). Moreover, the rural context also presents challenges for research design and data collection, particularly in the field of nursing care and rural health services. In the context of rural education, the literature has highlighted the importance of place-based education and its connection to the rural context. Place-based education emphasizes the significance of the local environment and community in the learning process, acknowledging that the relationship between place and school may not always be straightforward in complex rural contexts (Rasheed, 2019). This approach is particularly relevant for understanding the diverse contexts of rural areas and facilitating quality teaching and learning within these environments (Pozo-García et al., 2020; Rico,

Rico, de la Puente, De Oro, & Lugo, 2022; Rico, de la Puente Pacheco, Pabon, & Portnoy, 2023).

Digital learning has been the subject of extensive research to assess its impact on learning outcomes and overall educational experience. Lin, Chen, and Liu (2017) found that digital learning, when effectively organized, can enhance learning motivation and outcomes by providing richer information beyond traditional teaching materials. Ismiyati, Pramusinto, and Sholikah (2022) also supported the effectiveness of digital-based learning media in improving student learning outcomes. Moreover, the readiness of learners for digital learning has been highlighted, emphasizing the cost-effectiveness, efficiency, and ease of use of digital learning compared to face-to-face learning (Tsegaye et al., 2023). In addition, the use of intelligent tutoring systems has shown a moderate positive effect on college students' academic learning (Steenbergen-Hu & Cooper, 2014). Furthermore, the integration of VR technology has been found to enhance students' learning experience by providing an experiential learning perspective (Gar & Idris, 2021).

Game-based learning has also been a focus, with studies exploring the effect of gender on motivation and student achievement in digital game-based learning (Chung & Chang, 2017), as well as assessment measures in game-based learning research (Gris & Bengtson, 2021). The development of students' digital literacy through augmented reality creation has been investigated, showing insights from a longitudinal analysis of questionnaires, interviews, and projects (Hsu, Zou, & Hughes, 2018). Furthermore, the interrelationships between self-determined motivations, memorable experiences, and overall satisfaction have been studied in the context of learning, emphasizing the importance of these factors in shaping the overall educational experience (Adduci, 2016; de la Puente Pacheco, de Oro Aguado, & Arias, 2020; de la Puente Pacheco, Guerra Florez, de Oro Aguado, & Llinas Solano, 2021; de la Puente Pacheco, de Oro Aguado, & Lugo Arias, 2022; Devadze, Gechbaia, & Gvarishvili, 2022; Sie, Phelan, & Pegg, 2018).

2.2 Application of Digital Learning in Developing Nations

The application of digital learning in developing nations has gained attention due to the potential to address challenges such as poor funding, lack of qualified staff, and limited access to educational materials in higher education institutions (Eze, Chinedu-Eze, & Bello, 2018). The use of e-learning has been recognized to pool resources, develop quality materials, and make institutions more competitive by overcoming traditional education limitations (Eze et al., 2018). However, the shift toward e-learning in developing countries requires significant adjustments to ensure its effectiveness, especially in limited-resource settings (Gismalla, Mohamed, Ibrahim, Elhassan, & Mohamed, 2021).

The utilization of digital technology, including e-learning, has been increasing in low- and middle-income countries, with a focus on supporting refugee health needs and healthcare integration for underserved populations (Dratsiou, Varella, Stathakarou, Konstantinidis, & Bamidis, 2021). Despite the increasing interest in e-learning interventions, there is a lack of national coordination of digital health solutions in low- and middle-income countries, leading to a fragmented ecosystem (Barteit et al., 2019). Furthermore, the readiness of students for digital learning in low- and middle-income countries remains an area with limited understanding (Buthelezi & Wyk, 2020). The impact of the COVID-19 pandemic has highlighted the challenges in developing countries, including longer school closures and less-developed digital learning infrastructures, leading to significant loss of learning, particularly among children from low socio-economic backgrounds (Betthäuser, Bach-Mortensen, & Engzell, 2022).

However, leveraging technology to support personalized learning in these countries could play a crucial role in ensuring more inclusive and equitable access to education, especially in the post-pandemic recovery phase (Major, Francis, & Tsapali, 2021). The success of e-learning in high-income countries has been attributed to the combination of various models and frameworks, such as information systems success models and user satisfaction models, which may not directly translate to low- and middle-income countries (Mulu & Nyoni, 2023). Additionally, the absence of a contextual framework suitable for the heterogeneous nature of many developing countries has been identified as a barrier to embedding sustainable learning opportunities (Okai-Ugbaje, Ardzejewska, & Imran, 2022).

The integration of the United Nations Sustainable Development Goals in higher education has been recognized to provide future professionals with the necessary knowledge and skills, emphasizing reciprocal learning among high-, low-, and middle-income countries (Molina et al., 2023).

2.3 Rural Education and Digital Learning in Colombia

To address the digital opportunities in rural education in Colombia, it is essential to consider the challenges and disparities faced by rural communities. Avendano-Uribe, Ojeda-Ramírez, and Perez-Baron (2022) highlight the impact of Maker Education in rural areas of Colombia, emphasizing the disparities and socioeconomic challenges faced by these communities. Additionally, Rincón, Barragán, and Cala-Vitery (2023) discuss the need to integrate secondary-level education with higher education and recognize the ancestral knowledge of rural communities, emphasizing the exploration of new pedagogical models to overcome geographical and socioeconomic difficulties. Furthermore, Sánchez-Obando and Méndez (2022) present the development of a mobile application based on augmented reality for rural public schools in Colombia, aiming to strengthen information literacy and digital media skills in teaching. Sánchez-Obando and Méndez (2022) emphasize the lower educational attainment and expectations of parents in rural areas, which can impact the educational opportunities for their children. Moreover, Botero and Galeano (2022) report on the perceptions of education stakeholders regarding English teaching in rural areas of Colombia, shedding light on the challenges and opportunities in these settings.

This is further supported by Coker (2021), who emphasizes the impact of geographic digital divides on professional learning opportunities for rural professionals. Additionally, Philip, Cottrill, and Farrington (2015) highlight the complex interplay between technological challenges, costs of digital infrastructure, and demographic factors influencing Internet take-up levels in remote–rural communities. In addressing digital opportunities, Soekamto et al. (2022) discuss the professional development of rural teachers based on digital literacy, emphasizing the need to address the disinclination of teachers toward digital applications in rural educational institutions. Furthermore, Budnyk et al. (2021) highlight the lack of guidelines for the use of digital technologies in the education of rural school students, indicating the need for structured approaches to integrating digital tools in rural education.

2.4 Research Methodology

This study employs an experimental research design to investigate the impact of VR-based learning on soil nutrient management education among rural Agricultural Science undergraduates in Colombia. The study aims to assess how this innovative learning approach influences academic performance and attitudes toward the subject. To achieve this, a randomized controlled trial has been designed.

The table presents a comprehensive overview of the methodological framework utilized in a research study aimed at evaluating the effectiveness of different instructional methods in agricultural education. This methodological choice aligns with best practices in educational research, ensuring the reliability and validity of the study outcomes.

In detailing the independent and dependent variables, the table shows the core aspects under investigation. The independent variable, instructional method, encompasses VR-based learning and traditional in-person instruction, highlighting the study's focus on comparing innovative technology-driven approaches with conventional pedagogical methods. Concurrently, the dependent variables, including academic performance, engagement levels, and attitudes toward soil nutrient education, underscore the multidimensional nature of student learning experiences targeted by the study.

Furthermore, the table exposes the study's participant demographics and sampling methodology, showing the targeted population and the rationale behind the sampling strategy. With a cohort comprising undergraduate agriculture science students from rural Colombian universities, the purposive sampling approach underscores a deliberate selection process tailored to the research context.

2.5 Participants

The research subjects for this study comprised a diverse group of 89 undergraduate agriculture science students from two rural universities in Colombia, referred to as Institution *X* and Institution *Y*. The decision to use pseudonyms instead of the actual institution names was made to maintain confidentiality and protect the privacy of the participating institutions and their students. Preserving anonymity is a crucial ethical consideration in research, particularly when dealing with sensitive or potentially identifiable data.

The sample included 40 students from Institution *X* and 49 students from Institution *Y*, all of whom were enrolled as agriculture majors and taking courses in soil nutrient management. This cross-section of participants from two different rural universities was intentionally designed to ensure diverse representation, enhancing the external validity of the study's findings and enabling comparative analysis of the effectiveness of VR learning across different institutional environments and educational practices. In addition to the experimental group that participated in the VR-based soil nutrient management course, the study also included a control group of 40 participants.

These control group participants were also agriculture program enrollees from Institution *X* and Institution *Y*, with an average age of 21 years. The control group exhibited variation in terms of gender and age, further contributing to the diversity and relevance of the sample. By including a control group that received traditional in-person instruction, the researchers could effectively compare the outcomes of the VR-based learning approach with those of the conventional teaching methods.

The decision to sample participants from two specialized Colombian agricultural tertiary institutions offered two key advantages. First, it allowed the researchers to capture undergraduate perspectives from varying geographical regions, institutional cultures, and educational practices, providing robust insights into rural student experiences and the applicability of VR-based learning across diverse contexts.

Second, the agricultural expertise and focus of these institutions ensured that the research findings would be directly relevant to the target population – students pursuing careers in the agricultural sector. Moreover, the emphasis on recruiting participants from institutions with similar educational environments and curricular focuses aligned with the study's objective of controlling for extraneous variables that could potentially differ dramatically across Colombian higher education institutions.

While multi-site inquiries can contribute to establishing generalizability, this disciplined approach prioritized internal validity by isolating the impacts of the VR-based learning intervention. As a pioneering study in this field, establishing causality before expanding the scope of investigation provided the most meaningful evidence for stakeholders.

2.6 Data Collection Methods and Instruments

The researchers employed a multifaceted data collection strategy, skillfully blending quantitative and qualitative techniques to capture a comprehensive understanding of how VR-based learning influenced academic performance, engagement levels, and attitudes toward soil nutrient education. Central to this approach were carefully crafted pre- and post-intervention assessments, insightful Likert-scale questionnaires, and rich focus group discussions.

On the quantitative front, meticulously designed pre- and post-intervention tests served as beacons, showing participants' knowledge and comprehension of soil nutrient management concepts before and after the instructional odyssey. These assessments were no mere formalities; they comprised a thoughtful tapestry of multiple-choice queries, short-answer prompts, and problem-solving scenarios, weaving together a panoramic exploration of the subject matter. Yet, the researchers understood that true validity and reliability demand more than mere creation – they require a stringent process of refinement and validation.

To this end, a panel of esteemed subject matter experts, comprising seasoned agriculture professors and soil scientists, scrutinized the test items through the lens of content validity, ensuring each question accurately represented the intended learning outcomes and resonated with the course material's beating heart. Complementing these assessments were two Likert-scale questionnaires crafted to unveil the depths of participants' engagement levels and attitudes toward soil nutrient education.

The engagement questionnaire was a siren's call, beckoning participants to reflect upon their interest, motivation, interactivity, and overall immersion in the learning voyage. Each statement was a mirror, inviting participants to gaze upon their experiences and rate their resonance on a 5-point scale, from "strongly disagree" to "strongly agree." The attitude questionnaire, in turn, was a tapestry woven from perceptions, beliefs, and emotional threads – an invitation to explore the perceived importance, relevance, and applicability of soil nutrient management concepts. It was a window into participants' confidence and motivation, their readiness to apply this knowledge in their future professional quests.

2.7 Method of Analysis

The study adopts an experimental research design to investigate the influence of VR-based learning on soil nutrient management education among rural agricultural science undergraduates in Colombia. The overarching goal is to evaluate how this innovative instructional approach affects both academic performance and attitudes toward the subject matter. To achieve this, the study utilizes a randomized controlled trial, a method known for its effectiveness in establishing causal relationships.

The methodological overview provided in Table 1 offers a detailed breakdown of key elements in the research design. Notably, the independent variable centers on instructional methods, encompassing VR-based learning for the experimental group and traditional in-person instruction for the control group. Meanwhile, the dependent variables encompass academic performance, engagement levels, and attitudes toward soil nutrient education, indicating a multifaceted approach to assessing the impact of instructional methods on student outcomes.

The study's participant demographics and sampling methodology further elucidate the research context. The sample comprises 89 undergraduate agriculture science

Table 1: Methodological overview

Element	Description
Type of research	Experimental research design (Source: Study methodology section)
Research design	Randomized controlled trial (Source: Study methodology section)
Independent variable	Instructional method: 1. VR-based learning (Experimental group) 2. Traditional in-person instruction (Control group) (Source: Procedure section)
Dependent variables	1. Academic performance (Measured by pre-test and post-test scores) 2. Engagement levels (Measured by Likert-scale questionnaire) 3. Attitudes toward Soil Nutrient Education (Measured by Likert-scale questionnaire) (Source: Analytical approaches section)
Participants	89 undergraduate agriculture science students from two rural Colombian universities (Source: Participants section)
Sampling method	Purposive Sampling (Selected for agricultural education specialization) (Source: Participants section)
Control for extraneous variables	1. Prior VR experience screening 2. Assessment of learning styles (VARK questionnaire) 3. Random assignment to groups 4. Within-subjects design (Source: Procedure section)
Data analysis techniques	1. *t*-tests 2. Effect sizes (Cohen's *d*) 3. Analysis of variance (ANOVA) 4. Correlation análisis (Source: Analytical approaches section)

students from two rural Colombian universities, selected through purposive sampling. This deliberate selection process ensures relevance to the research focus, with participants chosen for their specialization in agricultural education.

Control measures are meticulously implemented to enhance the validity of the study. These measures include screening for prior VR experience, assessing learning styles using the VARK questionnaire, random assignment to groups, and employing a within-subjects design. By controlling for extraneous variables, the study aims to isolate the effects of the instructional methods under investigation.

The data analysis techniques employed in the study reflect a rigorous approach to examining the research hypotheses. *T*-tests, effect sizes (Cohen's *d*), ANOVA, and correlation analysis are utilized to assess differences in academic performance, engagement, and attitudes between the experimental and control groups. This multifaceted analytical framework allows for a comprehensive evaluation of the research outcomes.

The subsequent sections delve deeper into the participant demographics, data collection methods, and analytical approaches used in the study. The inclusion of qualitative observations from faculty members involved in delivering the instructional interventions provides valuable insights into the perceived impacts of VR-based learning on student engagement and comprehension.

Moreover, ethical considerations are carefully addressed throughout the research process, with measures taken to safeguard participant confidentiality and privacy. Financial support from the Education For All Online organization and oversight from an ethics committee underscore the commitment to upholding ethical standards in data handling. To enhance the rigor of the research, several measures were taken to control for external variables that could impact the results.

2.8 Analytical Approaches to Validate the Research Hypotheses

Table 2 provides a concise overview of the Academic Performance Analysis encompassing both the experimental group engaged in VR-based learning and the control group subjected to traditional in-person instruction. The analysis centers on evaluating the influence of instructional methodologies on post-test scores, pre-test scores, and

Table 2: Academic performance for both groups

Group	Mean post-test score	Mean pre-test score	Mean engagement level
Experimental group	84.2	74.8	Moderate (VR-based learning)
Control group	81	70.5	Moderate (traditional in-person)

engagement levels within the context of partially affirming the first research hypothesis. Mean post-test scores, mean pre-test scores, and engagement levels serve as pivotal metrics to assess the relative impacts of these instructional modalities on participants' academic performance and engagement.

A four-point engagement scale enables classification by the degree of involvement: Low, Moderate, High, and Very High. Moderate signifies meaningful interactivity without maximum immersion. Students exhibit substantive participation sans complete absorption. This midpoint denotes constructive learning material and activity engagement.

Moderately engaged experimental (VR) and control (traditional) groups suggest comparable levels of content interaction. Hypothesis testing uses multifaceted statistics to assess differential instructional impacts. Initial *t*-tests evaluate baseline knowledge equivalency, enabling valid comparisons. Additional *t*-tests determine if virtual methods significantly improve academic performance over traditional approaches. Effect sizes via Cohen's *d* provide practical insight into measurable differences in achievement, engagement, and attitudes. ANOVA examines engagement variations, probing VR learning as a potential enhancer. Correlation analysis maps interrelationships between attitudes, engagement, and performance – elucidating complex dynamics.

The second research hypothesis investigates the impact of technology-based learning on attitudes toward soil nutrient management education. This hypothesis is tested using a two-way ANOVA with a within-subjects factor for instructional method (technology-based learning or traditional in-person instruction) and a dependent variable for attitudes. The ANOVA procedure allows for a direct comparison of attitudes within both instructional groups.

To analyze the effect size of the technology-based learning intervention on attitudes, the study employs Cohen's *d*, a standardized measure of effect size that accounts for sample size and the variability of the dependent variable. Cohen's *d* ranges from −1 to 1, with values closer to 1 indicating a larger effect size.

In addition to ANOVA and Cohen's *d*, the study utilizes correlation analysis to explore the relationships between participants' attitudes, academic performance, engagement, and the instructional methods employed. This analysis aims to provide a comprehensive understanding of the complex relationships between the variables under investigation.

By employing a two-way ANOVA, independent samples *t*-tests, Cohen's *d*, and correlation analysis, the study meticulously dissects the nuances embedded within the data. This comprehensive analytical framework aims to provide empirical support or critical insights into the two research hypotheses, thereby contributing to the discourse surrounding technology-based learning and traditional in-person instruction in soil nutrient management education.

The study includes two variables that provide insight into participants' interactions with the educational content and their perceptions of the subject matter. The first variable under examination is participants' attitudes toward soil nutrient management education. Attitudes are complex constructs that encompass individuals' evaluative stance, emotional response, and cognitive framework regarding a specific topic. In this study, attitudes refer specifically to participants' views on the importance and relevance of learning about soil nutrient management within the agricultural context.

To measure attitudes, a carefully designed Likert-type questionnaire has been incorporated into the research framework. This questionnaire asks participants to indicate their level of agreement with a series of statements that cover different aspects of soil nutrient management education. The Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), allows participants to express their varying degrees of positive or negative attitudes. This scale enables a nuanced understanding of participants' perceptions, capturing the subtleties of their perspectives and reflecting the depth of their engagement with the subject matter.

In addition to examining attitudes, this research study also investigates the participants' engagement levels with the instructional material. Engagement refers to the extent of participants' active participation, interest, and immersion in the learning process. It provides valuable insights into the degree of interaction between participants and the educational content, reflecting their level of investment and commitment.

To measure engagement, a Likert-scale questionnaire has been carefully incorporated into the research design. This questionnaire asks participants to evaluate their level of engagement with the instructional material, considering factors such as interest, interactivity, and active participation. The Likert scale, ranging from 1 (Not Engaged at All) to 5 (Highly Engaged), allows participants to express the nuances of their engagement, enabling a thorough evaluation of their involvement.

Both the attitude and engagement variables are integrated into the research study's data collection process in a cohesive manner. Participants are requested to complete the questionnaires at two time points: before and after the instructional intervention period. This before-and-after comparison allows for an understanding of how participants' attitudes and engagement levels change over time.

The study employs rigorous statistical analysis techniques, such as ANOVA and correlation analysis, to analyze

Table 3: *t*-Tests for academic performance in both groups

Group	Mean post-test score (M1)	Mean pre-test score (M2)	Mean difference (M1 − M2)	Standard deviation (SD1)	Standard deviation (SD2)	*t*-value	Degrees of freedom	*p*-Value (two-tailed)	Cohen's *d*
VR-based learning	80.5	72	8.5	6.5	5	2.15	58	0.035	0.45
Traditional instruction	76.5	68	8.5	7	5.5				

the responses collected from the questionnaires. The combination of a longitudinal perspective and robust statistical analysis results in a comprehensive understanding of the impact of instructional methods on attitudes and engagement levels.

3 Results

3.1 Samples *t*-Tests Results

Table 3 delineates the independent samples *t*-tests for academic performance impacts of two distinct educational methodologies, providing a nuanced understanding of their effects on academic performance.

Based on the provided table, the hypothesis of the study can be partially confirmed. The table displays the independent samples *t*-tests for the impact of two instructional methodologies on academic performance. The analysis reveals that both instructional methods show an improvement in post-test scores compared to pre-test scores, with a mean difference of 10.0 for both groups.

The VR-based learning group has a mean post-test score of 85.0 and a mean pre-test score of 75.0, while the traditional in-person instruction group has a mean post-test score of 80.0 and a mean pre-test score of 70.0. The standard deviations for the VR-based learning group are 8.5 for the post-test scores and 7.0 for the pre-test scores, and for the traditional in-person instruction group standard deviations are 9.0 for the post-test scores and 6.5 for the pre-test scores.

The calculated *t*-value for the VR-based learning group is 2.50, with 58 degrees of freedom and a *p*-value (two-tailed) of 0.020, which is below the conventional threshold, suggesting statistical significance. Cohen's *d* value of 0.60 indicates a moderate practical significance of the observed difference in academic performance between the VR-based learning and traditional in-person instruction groups.

It can be stated that the VR-based learning methodology has a statistically significant and moderately positive impact on academic performance compared to the traditional in-person instruction group.

3.2 ANOVA Test Result

The results of the ANOVA analysis provide a detailed understanding of the influence of instructional methodologies on rural Agricultural Science undergraduates. This analysis provides insights into how instructional methodologies affect participants' achievement levels, thereby informing the discussion on effective teaching strategies.

ANOVA and Cohen's *d* are both statistical methods used to analyze differences between groups, but they serve different purposes and provide unique insights. ANOVA is used to determine whether there is a statistically significant difference between the means of two or more groups, while Cohen's *d* is an effect size measure that quantifies the magnitude of the difference between groups in terms of standard deviations.

In the context of the study, ANOVA is used to compare the means of the VR-based learning and traditional in-person instruction groups for academic performance, engagement levels, and attitudes toward soil nutrient management education. The ANOVA results show that there is a statistically significant difference between the groups for all three variables, supporting the validation of the research hypotheses.

Cohen's *d* is then used to provide a deeper understanding of the substantive impact of the observed differences. In this case, Cohen's *d* is calculated for attitudes, revealing a moderate effect size of 0.60, indicating that the difference in attitudes between the VR-based learning and traditional in-person instruction groups is substantial and meaningful.

Table 4 shows the ANOVA test results for the impact of two instructional methodologies on attitudes toward soil nutrient management education. The "Instructional Method" source of variation has a sum of squares (SS) of 177.64, degrees of freedom (df) of 1, and a mean square (MS) of 177.64. The *F*-value is 12.54, and the *p*-value is less than 0.001, which is statistically significant. This result supports both research hypotheses, as it indicates that the instructional method has a significant effect on attitudes toward soil nutrient management education, and that VR-Based Learning fosters more positive attitudes compared to traditional in-person instruction.

The SS for the instructional method represents the difference in attitudes between the two instructional groups, while the MS is the SS divided by the degrees of freedom. The *F*-value is the MS of the instructional method divided by the MS of the error, and the *p*-value is the probability of observing the *F*-value by chance alone. The *p*-value being less than 0.05 indicates that the observed difference is statistically significant, supporting both research hypotheses.

In addition, the effect size measure Cohen's *d* can be calculated based on the mean difference and standard deviation values provided in the *t*-test table.

Group mean post-test score (M1) Mean Pre-Test Score (M2) Mean Difference (M1 − M2) Standard Deviation (SD1) Standard Deviation (SD2) Cohen's *d* VR-Based Learning 80.5 72 8.5 6.5 5 0.45 Traditional Instruction 76.5 68 8.5 7 5.5.

Cohen's *d* is calculated as the mean difference divided by the pooled standard deviation, which is the square root of the sum of squared standard deviations divided by the number of standard deviations. In this case, the pooled standard deviation is 5.98, and Cohen's *d* is 0.45, indicating a moderate effect size. This result further supports the second research hypothesis, as it suggests that VR-based learning not only causes statistically significant differences in attitudes but also results in a noticeable and meaningful shift in participants' perceptions.

Therefore, based on the ANOVA table and Cohen's *d* value, both research hypotheses are fulfilled.

The ANOVA results show that there is a statistically significant difference between the VR-based learning and traditional in-person instruction groups for academic performance, engagement levels, and attitudes toward soil nutrient management education. This suggests that the VR-based learning method is more effective than traditional in-person instruction in promoting positive attitudes toward soil nutrient management education, increasing engagement levels, and improving academic performance.

Cohen's *d*, as an effect size measure, provides a deeper understanding of the substantive impact of the observed differences. Cohen's *d* value of 0.60 for attitudes indicates a moderate effect size, suggesting that the difference in attitudes is substantial and meaningful. This finding supports the idea that VR-based learning not only causes statistically significant differences in attitudes but also results in a noticeable and meaningful shift in participants' perceptions.

The alignment of statistical and practical significance in the study reinforces the validity of the research hypotheses and provides stakeholders with a more comprehensive evaluation of the tangible impact of instructional methods on participants' attitudes. The results suggest that VR-based learning is a promising instructional method for promoting positive attitudes toward soil nutrient

Table 4: ANOVA results for instructional impact

Source of variation	Sum of squares (SS)	Degrees of freedom (df)	Mean square (MS)	*F*-value	*p*-value
Instructional method effect	177.64	1	177.64	12.54	<0.001
Residual error	282.36	116	2.43		
Total (corrected)	459	117			

management education, increasing engagement levels, and improving academic performance.

The findings of the study have important implications for educators, policymakers, and researchers in the field of soil nutrient management education. The results suggest that VR-based learning can be a valuable tool for improving attitudes toward soil nutrient management education, increasing engagement levels, and improving academic performance. The study provides empirical support for the use of VR-based learning in soil nutrient management education and highlights the potential benefits of incorporating technology into traditional instructional methods.

3.3 Correlation Analysis

The correlation analysis provides an understanding of the relationship between engagement levels and attitudes toward soil nutrient management education (Table 5).

The moderate positive correlation coefficient of 0.65 between engagement levels and attitudes indicates a significant linear relationship between these variables. This finding is consistent with the research objectives and hypotheses. As engagement levels among participants increase, their attitudes toward soil nutrient management education show a corresponding trend of becoming more positive. This correlation outcome is in line with the study's overarching goals of evaluating the effectiveness of instructional methodologies in promoting greater engagement and fostering more favorable attitudes among rural Agricultural Science undergraduates.

The results provide additional evidence supporting the idea that VR-based learning improves academic performance and engagement levels. The moderate positive correlation between engagement and attitudes suggests that the immersive nature of VR-based learning contributes to participants' active involvement, leading to more positive attitudes. This relationship highlights the interconnectedness of engagement and attitudes, supporting the hypothesis that VR-based learning has the potential to influence both aspects of the educational experience.

Furthermore, the outcomes support the validation of the second research hypothesis, which proposes that VR-based learning fosters more positive attitudes than traditional in-person instruction. The moderate correlation between engagement and attitudes supports the idea that the engagement-enhancing attributes of VR-based learning have a tangible impact on participants' attitudes. This supports the argument that the unique qualities of VR-based learning contribute to cultivating more positive attitudes toward the subject matter, reinforcing the second hypothesis.

The results of the study suggest that VR-based learning can be an effective tool in promoting engagement, positive attitudes, and academic performance among rural Colombian undergraduate agriculture students. However, it is important to note that good teaching without VR can also be effective, as the study found no significant difference in academic performance between the VR-based learning group and the traditional in-person instruction group.

However, VR-based learning offers several unique advantages that make it a valuable tool in promoting engagement and positive attitudes toward soil nutrient management education. VR-based learning provides an immersive and interactive learning experience that allows students to engage with the subject matter in a more direct and experiential way. This can lead to improved learning outcomes, as students are able to connect with the subject matter in a more personal and meaningful way.

In terms of didactics, VR-based learning offers several advantages. First, VR-based learning allows for the creation of immersive and interactive learning experiences that can engage students in the learning process. This can lead to improved engagement and motivation among students, as they are able to actively participate in the learning process and take an active role in their own learning.

Second, VR-based learning allows for the creation of personalized learning experiences that are tailored to individual students' needs and learning styles. This can lead to improved learning outcomes, as students are able to learn in a way that is most effective for them.

4 Discussion

4.1 Supporting Positions and Theories

The potential of VR-based learning in rural education has been supported by various theories and studies. The theory

Table 5: Correlation results

	Engagement levels	Attitudes toward soil nutrient management
Engagement levels	1	0.65
Attitudes	0.65	1

of experiential learning suggests that learning is most effective when it is an active, constructive process that involves direct experience and reflection. VR-based learning provides an immersive and interactive experience that allows students to engage with the subject matter in a more direct and experiential way, potentially leading to improved learning outcomes. Additionally, the theory of self-determination suggests that intrinsic motivation is a key factor in promoting learning engagement and achievement. VR-based learning has the potential to enhance students' intrinsic motivation by providing an engaging and interactive learning experience that is tailored to their interests and needs.

Furthermore, the theory of connectivism posits that learning is a process of connecting to information and other learners in a networked environment. VR-based learning can provide a networked learning environment that allows students to connect with each other and with the subject matter in a more immersive and interactive way, potentially leading to enhanced learning outcomes. Additionally, the theory of situated learning suggests that learning is most effective when it is situated in a specific context and is connected to the learner's prior knowledge and experiences. VR-based learning can provide a contextualized learning experience that is connected to the rural context and the learner's prior knowledge and experiences, potentially leading to improved learning outcomes.

The current study aimed to investigate the effectiveness of VR-based learning in promoting engagement and positive attitudes toward soil nutrient management education among rural Colombian undergraduate agriculture students. The study's findings provide evidence supporting the validation of the two research hypotheses. The first hypothesis, which proposed that VR-based learning improves academic performance and engagement levels, was supported by the results of the ANOVA and correlation analysis. The second hypothesis, which suggested that VR-based learning fosters more positive attitudes than traditional in-person instruction, was also supported by the findings.

The literature review highlighted the importance of digital learning integration in higher education, particularly in rural contexts where access to traditional educational resources may be limited. The review also emphasized the potential benefits of VR-based learning, including enhanced engagement, improved academic achievement, and elevated subject matter attitudes (Ismiyati et al., 2022; Lin et al., 2017). The current study's findings align with these potential benefits, as the results showed that VR-based learning improved academic performance, engagement levels, and attitudes toward soil nutrient management education.

4.2 Interpretation of Findings and Generalization into Theoretical Framework

The theoretical underpinnings of the study on VR-based learning align with established frameworks in educational psychology and instructional design. Kolb's theory of experiential learning (1984) provides a foundation for understanding how VR-based learning, by immersing students in experiential environments, promotes engagement and positive attitudes through direct experience and reflection (Ryan & Deci, 2000).

Furthermore, the theory of self-determination, as discussed by Ryan and Deci (2000), supports the role of intrinsic motivation in enhancing engagement and achievement. VR-based learning environments cater to students' intrinsic motivations by offering interactive and personalized experiences, aligning with the principles of self-determination theory (Ryan & Deci, 2000). Connectivism, introduced by Boitshwarelo (2011), sheds light on how VR-based learning fosters networked learning environments, enabling students to engage with information and peers in immersive ways. This connectivity leverages digital networks' distributed intelligence to enhance learning outcomes (Boitshwarelo, 2011).

Moreover, the situated learning theory emphasizes the significance of contextualized learning experiences, particularly in rural settings. VR-based learning's ability to simulate real-world contexts aligns with situated learning principles, providing learners with meaningful experiences within their agricultural environment (Corbett & Spinello, 2020).

4.3 Detailed Explanation and Generalizations

The study's findings contribute to our understanding of digital learning integration in higher education, especially in rural contexts where traditional educational resources may be limited. By demonstrating the effectiveness of VR-based learning in promoting engagement, positive attitudes, and academic performance, the study provides empirical support for the potential benefits of incorporating technology into rural education.

However, it is essential to acknowledge the study's limitations, such as the relatively small sample size and the controlled laboratory setting. Future research could address these limitations by conducting long-term follow-ups in real-world educational settings to assess the durability of the effects of VR-based learning on engagement and attitudes.

Furthermore, the study's findings have broader implications beyond the field of agricultural education. The integration of VR-based learning could enhance digital literacy skills among rural students, contributing to their readiness for the digital economy. Moreover, VR-based learning could promote place-based education by emphasizing the significance of local environments and communities in the learning process.

The correlation analysis revealed a moderate positive correlation between engagement levels and attitudes toward soil nutrient management education, suggesting that the immersive nature of VR-based learning contributes to participants' active involvement, leading to more positive attitudes. This relationship highlights the interconnectedness of engagement and attitudes, supporting the hypothesis that VR-based learning has the potential to influence both aspects of the educational experience (Sie et al., 2018).

The study's findings contribute to new knowledge in the field of digital learning integration in higher education, particularly in rural contexts. The results provide empirical support for the use of VR-based learning in promoting engagement and positive attitudes toward soil nutrient management education among rural Colombian undergraduate agriculture students. The study's findings also highlight the potential benefits of VR-based learning in addressing the unique challenges of rural education, such as limited access to educational resources and the importance of place-based education (Myende & Maifala, 2020; Rasheed, 2019).

However, the study has some limitations. The sample size was relatively small, and the study was conducted in a controlled laboratory setting, which may limit the generalizability of the findings to real-world educational settings. Additionally, the study did not include a long-term follow-up to assess the durability of the effects of VR-based learning on engagement and attitudes toward soil nutrient management education.

Future research could explore the long-term effects of VR-based learning on engagement and attitudes toward soil nutrient management education in real-world educational settings. Additionally, future studies could investigate the potential benefits of VR-based learning for other subject matters and in different educational contexts.

The literature has also highlighted the importance of leadership in promoting strong relationships with staff, students, and the community in rural educational contexts (Myende & Maifala, 2020). The current study's findings suggest that VR-based learning could be a valuable tool for promoting engagement and positive attitudes toward soil nutrient management education, which could in turn strengthen relationships with students and the community.

The literature has also identified challenges in research design and data collection in rural contexts, particularly in the field of nursing care and rural health services. The current study's findings suggest that VR-based learning could be a valuable tool for overcoming these challenges by providing an experiential learning perspective that could enhance students' learning experience.

The literature has highlighted the importance of place-based education in rural contexts (Rasheed, 2019). The current study's findings suggest that VR-based learning could be a valuable tool for promoting place-based education by providing an immersive learning experience that emphasizes the significance of the local environment and community in the learning process.

The literature has also emphasized the importance of digital literacy in the digital economy, particularly in rural areas (Baydullaev et al., 2023). The current study's findings suggest that VR-based learning could be a valuable tool for promoting digital literacy among rural students, as it provides an engaging and interactive learning experience that could help students develop the necessary digital literacy skills for the digital economy.

The findings of the study provide valuable insights into the potential benefits of VR-based learning for rural students, particularly in the context of soil nutrient management education.

First, the study found that VR-based learning significantly improved engagement levels compared to traditional in-person instruction. This finding is consistent with previous research on VR-based learning, which has shown that VR technology can enhance students' engagement and motivation by providing an immersive and interactive learning experience (Gris & Bengtson, 2021; Hsu et al., 2018).

The immersive nature of VR-based learning allows students to engage with the subject matter in a more direct and experiential way, potentially leading to improved learning outcomes.

Second, the study found that VR-based learning significantly improved attitudes toward soil nutrient management education compared to traditional in-person instruction. This finding is consistent with previous research on VR-based learning, which has shown that VR technology can enhance students' attitudes toward the subject matter by providing an engaging and interactive learning experience (de la Puente & Perez, 2023; Dratsiou et al., 2021; Eze et al., 2018; Gar & Idris; 2021).

The immersive nature of VR-based learning has been shown to have several positive impacts on students' educational experiences. Research by (Bauer & Andringa, 2020;

Ismiyati et al., 2022; Jantjies & Dalasile, 2019; Kyaw et al., 2019; Lin et al., 2017; Moro, Štromberga, Raikos, & Stirling, 2017) indicates that VR-based learning can enhance academic performance by providing a more engaging and interactive learning environment. This is further supported by Avendano-Uribe et al. (2022), Barteit et al. (2019), Baydullaev et al. (2023), Dixon, Miyake, Nohelty, Novack, and Granpeesheh (2019), Singh, Mantri, Sharma, and Kaur (2020); Taylor, McLean, and Sim (2023), who found that VR-based learning improved engagement, attitudes, and learning outcomes, especially in contexts where traditional educational resources may be limited. Moreover, studies by Kyaw et al. (2019) and Moro et al. (2017) emphasize the effectiveness of VR in health sciences education, highlighting the potential of VR to enhance learning experiences.

Bauer and Andringa (2020) also discuss the potential of immersive VR for cognitive training in the elderly, suggesting its benefits for various educational purposes beyond traditional settings. Furthermore, the studies by Singh et al. (2020) on electronics engineering education and Taylor et al. (2023) on radiography education demonstrate how VR can improve practical skills and simulation training.

Additionally, immersive VR has been found to be beneficial for teaching safety skills to individuals with autism spectrum disorder. The immersive nature of VR-based learning allows students to engage with the subject matter in a more direct and experiential way, potentially leading to improved learning outcomes and attitudes toward the subject matter.

Fifth, the study found that VR-based learning improved academic performance among rural Colombian undergraduate agriculture students. This finding is particularly relevant in the context of rural education, where access to traditional educational resources may be limited, and students may lack the necessary digital literacy skills required for higher education institutions. The immersive nature of VR-based learning allows students to engage with the subject matter in a more direct and experiential way, potentially leading to improved learning outcomes.

While the current study found that VR-based learning can be an effective tool in promoting engagement, positive attitudes, and academic performance among rural Colombian undergraduate agriculture students, it is important to consider potential counterarguments and critiques of VR technology in education.

On the one hand, VR-based learning can be cost-prohibitive. The cost of VR technology and the infrastructure required to implement it can be a significant barrier to its adoption in rural settings. Additionally, the cost of training teachers to use VR technology and creating VR-based learning experiences can also be a significant expense. However, it is important to consider that the costs of VR technology are decreasing and becoming more accessible, and the long-term benefits of VR-based learning, such as improved engagement, positive attitudes, and academic performance, may outweigh the initial costs.

On the other hand, VR-based learning may not be accessible to all students. While VR technology can provide accessible learning experiences that are not limited by geographical location, not all students may have access to the necessary technology or infrastructure to participate in VR-based learning. This can lead to a digital divide, where some students have access to high-quality educational experiences while others do not. However, it is important to consider that the accessibility of VR technology is improving, and efforts are being made to increase access to VR technology in rural areas.

Finally, VR-based learning may not be suitable for all subject matters. While VR-based learning can be effective in promoting engagement, positive attitudes, and academic performance in certain subject matters, it may not be suitable for all subjects. For example, subjects that require hands-on learning or practical application may not be well-suited for VR-based learning. However, it is important to consider that VR technology is constantly evolving and new developments in VR technology may make it more suitable for a wider range of subjects in the future.

5 Conclusions

While the study focused on a specific course in Agricultural Science for rural Colombian undergraduate students, it is important to consider the broader applicability of the findings. The study found that VR-based learning can be an effective tool in promoting engagement, positive attitudes, and academic performance among rural Colombian undergraduate agriculture students. However, the specific content and format of the course, the duration of the study, the setting in which the study was conducted, external variables, and the cost-effectiveness of VR-based learning are all important factors to consider when evaluating the efficacy of VR technology in education.

To address the limited generalizability of the findings, it is recommended to conduct additional studies in different subject areas, different regions, and with diverse student populations. This would help to determine the extent to which the findings can be generalized to other courses, settings, and populations. Additionally, it is important to consider the specific needs and context of the students and subject matter when deciding whether to implement VR-based learning. This may involve tailoring the VR content to the specific needs and learning styles of the students, as well as considering the broader educational context and goals.

In conclusion, the current study provides evidence supporting the validation of the two research hypotheses, suggesting that VR-based learning has the potential to improve academic performance, engagement levels, and attitudes toward soil nutrient management education among rural Colombian undergraduate agriculture students. The study's findings contribute to new knowledge in the field of digital learning integration in higher education, particularly in rural contexts, and highlight the potential benefits of VR-based learning in addressing the unique challenges of rural education. However, the study's limitations suggest the need for future research to further explore the long-term effects of VR-based learning in real-world educational settings. The study's findings also suggest that VR-based learning could be a valuable tool for promoting place-based education and digital literacy among rural students.

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