Assessing the impact of virtual reality on mathematics teaching in rural middle schools: A quasi-experimental approach*

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Abstract

In this study, the impact of using virtual reality in teaching mathematics at a rural secondary school in Antiguo Morelos, Mexico, was evaluated. Two groups of students, one exposed to virtual reality and another following a traditional didactic sequence, were compared in terms of their performance before and after the intervention. The results revealed a significant improvement in the group that used virtual reality, suggesting that this technology can be an effective tool for teaching mathematics in rural environments. Although further research is needed, these findings support the investment in educational technology and proper teacher training in rural communities.

Keywords

Virtual reality, mathematics, rural secondary, technology

1. Introduction

Mathematics education confronts formidable challenges in the digital epoch, necessitating an imperative evolution from conventional pedagogies that often constrict experiential learning and spatial comprehension. Virtual Reality (VR), as delineated by Botella, "a technology that enables the creation of a real-world analog through simulated environments, engendering a sensation of presence via multisensory interaction," [1] heralds a progressive pedagogical paradigm. This treatise scrutinizes the amalgamation of VR in the domain of mathematical education and its ensuing impact on learning outcomes, informed by an empirical investigation and avant-garde practical applications. The study aspires to enrich the incipient scholarly canon, by elucidating the experimental deployment of VR in mathematical tutelage and offering an incisive discourse on its influence on student academic progression.

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VR transcends mere enhancement of spatial knowledge representation and experiential learning; it catalyzes student motivation and scholastic achievement [2]. Its capacity to facilitate mathematical problem-solving, exemplified in the computation of perimeters and areas of geometric entities, signifies a substantial advancement beyond the traditional didactic stratagems [3]. Moreover, VR forges avenues for soft skill cultivation, such as intercultural leadership among STEM graduates, through immersive modules harnessing a spectrum of recording genres [4]. The multifaceted deployment of VR thus accentuates its potential as an integrative educational apparatus.

Conversely, the instruction of sophisticated mathematical constructs, such as multivariable calculus, via VR has yielded heterogeneous results, signifying a disjunction between favorable student perceptions and tangible academic betterment [5]. Contrastingly, VR has demonstrated supremacy in the pedagogy of scientific laboratory techniques over conventional 2D imagery, enhancing both the learning experience and utility [6]. The conception of pedagogic implements, for instance, iFractions, is directed at ameliorating specific challenges inherent in fraction comprehension, evidencing efficacy in preliminary evaluations [7].

The application of VR environments employing the Singaporean pedagogical approach has been shown to ameliorate metacognitive prowess and scholastic outcomes [8]. Innovations such as BRICKxAR/T have underscored the significance of contextualizing mathematical concepts within tangible settings to bolster comprehension [9]. Analogously, Immersive Virtual Environments (IVEs) have been substantiated as effective for the inculcation of essential mathematical operations in foundational education stages [10].

The burgeoning salience of VR in education is illuminated by its deployment in virtual STEM laboratories, epitomizing the confluence with emergent 5G technologies [11]. Augmented Reality (AR) emerges as a pivotal instrument in bridging abstract mathematical notions with the tangibility of quotidian experiences, as showcased in fraction studies among third-grade learners [12]. Moreover, the incorporation of gamification within VR contexts has been observed to enhance mathematical aptitudes vis-à-vis traditional computer-assisted instruction paradigms [13], while the reception of VR among tertiary educators is influenced by their technological expertise and pedagogical acumen [14, 15].

Gamification within VR realms has intimated an affirmative impact on mathematical performance, albeit necessitating broader sample sizes to corroborate its statistical significance [16]. The promulgation of immersive VR-based geometric learning systems has been linked with an uplift in student motivation and performance [3], and platforms such as NeoTrie VR have been instrumental in facilitating geometric task resolution, thereby fostering cooperative and active learner engagement [17].

This research delineates the objective to appraise the efficacy of VR in the pedagogy of volume calculation for prisms and straight cylinders amongst Telesecundaria students in Northern Mexico, specifically within Tamaulipas. Mastery in computing the perimeters and areas of regular polygons and circles, drawing from disparate data, stands as a pivotal educational expectation within the Telesecundaria syllabus [18]. Such knowledge is imperative for the comprehension of further mathematical concepts under the rubric of Magnitudes and Measures and the educational axis of shape, space, and measurement. Notwithstanding, this conceptual grasp can be elusive for some scholars, particularly those grappling with the evolution of logical-mathematical and spatial intelligence, as postulated by psychologist Howard Gardner.

The traditional didactic techniques geared towards area computation often hinge on rote memorization of algorithms and formulas, an approach that may seem abstract and enigmatic to some learners [19]. This quandary has been accentuated in the current milieu, imprinted by the COVID-19 pandemic, which has engendered profound disruptions in global education. As noted by the World Bank Group's manifesto "Act now to protect the human capital of our children," the pandemic has laid bare and intensified the educational access chasm, notably in nations like Mexico [20]. Predominantly in its rural precincts, a significant cohort of students battles with the paucity of technological resources and connectivity, which has engendered substantial educational continuity interruptions, owing to their inability to partake in virtual learning or to tap into digital educational repositories [21].

This dichotomy has precipitated an expanding scholastic chasm between the rural and urban student populace in Mexico, with urbanites potentially enjoying a more effective continuation of their educational pursuits via online resources and technological means, in stark contrast to their rural counterparts' formidable learning impediments, this phenomenon is not unique to Mexico; countries such as Pakistan have also witnessed a widening educational gap between their rural and urban student populations [22]. The inequitable distribution of online educational access and educational technologies has exacerbated pre-existing educational disparities, underscoring the imperative for more inclusive and universally accessible pedagogical methodologies, irrespective of geographical locale or technological accessibility [23]. Consequently, this research endeavors to explore the feasibility of integrating cutting-edge technologies, such as Virtual Reality (VR), alongside innovative pedagogical strategies in communities most adversely affected by technological deprivation. Through this initiative, we aim not only to highlight the educational benefits of such technologies but also to demonstrate that, even in rural communities and those with limited access to advanced technologies, it is feasible to adapt and implement educational content within the classroom setting.

2. Methods

This research employed a quasi-experimental design to compare two non-equivalent groups of second-grade telesecundaria students within the rural municipality of Antiguo Morelos, Tamaulipas, Mexico. Participants were selected based on their enrollment in the second school year, aged between 12 and 13 years, representing a demographic that reflects the typical age range for this grade level in the region. The study's setting is notably rural, located in the Sierra Madre Oriental, characterized by a low socioeconomic status and limited technological resources.

Given the natural educational environment, students were not randomized but instead assigned to the two groups based on existing classroom divisions. The experimental group engaged with the "Shape, Space, Magnitudes and Measurments" unit through an innovative teaching approach utilizing Oculus Quest 2 VR headsets and the Prismath application, aiming to enhance their understanding of calculating the perimeter and area for regular polygons and circles.

Conversely, the control group received instruction on the same mathematical concepts through traditional methods outlined in the standard mathematics curriculum, ensuring that the content remained consistent across both groups. A teacher facilitated the teaching-learning process in both scenarios, ensuring instructional support and consistency.

2.1. Mejoredu test

To assess the impact of our pedagogical intervention, this study utilized the "Mejoredu" test, a standardized diagnostic assessment mandated by Mexico's Secretariat of Public Education [24]. Administered pre- and post-intervention, the test enabled a comparative analysis of student performance across two distinct cohorts, control and experimental, offering insights into the intervention's effectiveness.

The "Mejoredu" assessment, integral to Mexico's basic education evaluation framework, is designed to equip educators with insights into their students' initial learning levels in key areas: Reading, Mathematics, and Civic and Ethical Education. Targeting students entering the 2nd, 3rd, 4th, 5th, and 6th grades of elementary school, as well as the 1st, 2nd, and 3rd grades of middle school, its alignment with the national educational curricula ensures that it accurately reflects current academic standards and objectives.

As a tool to chart academic progress, "Mejoredu" is pivotal in setting initial learning benchmarks and pinpointing areas in need of instructional support. In the context of public health crises, such as the Covid-19 pandemic [25], its role in guiding adaptive educational strategies has become even more crucial, enabling targeted interventions to address emergent learning gaps.

Employing "Mejoredu" to evaluate mathematical understanding, especially within the "Shape, Space, and Measurent" domain, was chosen due to its specific focus on assessing foundational mathematical skills. This choice underpins our effort to refine teaching methods and improve the quality of math education, ensuring students develop essential competencies in this fundamental subject area.

2.2. Experimental procedure

The experimental procedure for this study spanned one week, with daily sessions lasting one hour. Two groups were established: a control group and an experimental group. The focus was on mathematical concepts such as geometric figures, magnitudes, and measurements, scheduled from 8:50 to 9:50 AM, following the academic curriculum. The experimental group engaged with Oculus Quest 2 VR headsets and the Prisms Math app, while the control group adhered to conventional teaching strategies. Pre- and post-tests were conducted using the Mejoredu assessment to evaluate the impact of virtual reality on learning mathematical topics, under a quasi-experimental design. Eighteen participants were divided between the two groups.

In Figures 1 and 2, the experimental group students from the tele-secondary school are depicted engaging in practical activities using virtual reality (VR) headsets. As part of the experimental procedure and to ensure the engagement of all participants, the visuals from the VR headset were projected for the other students to view and indirectly participate in the activities. This approach facilitated a collective learning experience, even for those not directly using the VR equipment.

Figure 1: Student using Oculus Quest 2 virtual reality headsets with the Prisms Math application.

Table 1
Average scores of the thematic axis "Shape, Space, and Measurement" on the "Mejoredu" diagnostic test

Group	Pre-intervention	Post-intervention
Experimental	27.3	70.2
Control	30.4	57.8

3. Results

In this section, we detail the outcomes of our quasi-experimental study, which compared the learning achievements in the "Shape, Space, and Measure" domain using virtual reality (VR) for the experimental group against a traditional didactic sequence for the control group. The findings, outlined in Table 1, are derived from the students' performances on the "Mejoredu" diagnostic test, conducted before and after the intervention. It's important to note that the test's grading scale ranges from 0 to 100, providing a quantitative measure of learning outcomes.

The descriptive statistics for both the experimental and control groups, as presented in Tables 1 and 2, provide a comprehensive overview of the performance changes before and after the tests. In the experimental group (Table 2), there was a significant increase in the average score from the pre-test to the post-test, rising from 27.33 to 70.22. This notable improvement is further emphasized by the increase in both the standard deviation and the range of scores, with the

Figure 2: Telesecondary student performing mathematical calculations using the Prisms Math Math application.

maximum score increasing from 32 in the pre-test to 85 in the post-test. The median score also notably increased from 28 to 67.

In contrast, the control group (Table 3) displayed a more moderate increase in average score, from 30.44 in the pre-test to 57.89 in the post-test. While this improvement is evident, it is less pronounced than that observed in the experimental group. The standard deviation and range of scores also increased, but to a lesser extent, with the maximum score reaching 70 in the post-test compared to 34 in the pre-test. The median score showed a similar trend, increasing from 31 to 59.

These statistics collectively suggest that while both groups showed improvement in scores from the pre-test to the post-test, the experimental group exhibited a more substantial enhancement in performance. This difference is particularly evident in the higher mean, maximum, and median scores observed in the post-test for the experimental group.

In our study, we have taken into account the fundamental assumptions necessary for conducting a Student's t-test. Following the guidelines established in the scientific literature, we have verified the normality of the data and the homogeneity of variances between groups. As indicated in the work of Kim and Park (2019)[26], the conditions required to perform a t-test include values measured on an interval or ratio scale, simple random extraction, homogeneity of variance, an appropriate sample size, and a normal distribution of the data. In our analysis, the normality of the distributions was confirmed through the Shapiro-Wilk test, and the equivalence of variances was validated by the Levene test, thus fulfilling the essential premises for the

Table 2
Descriptive Statistics for the Experimental Group in Pre and Post Tests

Metric	Pre Test	Post Test
Count	9	9
Mean	27.33	70.22
Standard Deviation	3.84	10.79
Minimum	22	52
Maximum	32	85
Median	28	67

Table 3
Descriptive Statistics for the Control Group in Pre and Post Tests

Metric	Pre Test	Post Test
Count	9	9
Mean	30.44	57.89
Standard Deviation	2.65	8.40
Minimum	26	45
Maximum	34	70
Median	31	59

application of parametric tests.

To assess the normality of the score distributions in the tests, the Shapiro-Wilk test was applied to the data from the pre-test and post-test for both the control group (CG) and the experimental group (EG). The results indicated that the score distributions for the pre-test and post-test in the control group did not significantly deviate from a normal distribution (pre-test: $W = 0.951$, $p = 0.705$; post-test: $W = 0.958$, $p = 0.773$). Similarly, the score distributions for the pre-test and post-test in the experimental group also conformed to a normal distribution (pre-test: $W = 0.891$, $p = 0.207$; post-test: $W = 0.953$, $p = 0.728$). In all cases, the p-values were above the conventional threshold of 0.05, suggesting a lack of sufficient evidence to reject the null hypothesis that the samples come from a normally distributed population.

To further substantiate the appropriateness of parametric tests in our analysis, an additional test for the equivalence of variances was conducted. The Levene's test was applied to the pre-test and post-test scores for the control and experimental groups, aiming to verify the homogeneity of variances between the two groups. The results of the Levene's test for the pre-test indicated no significant differences in variances between the groups ($F(1, 16) = 1.339$, $p = 0.264$), suggesting that the variances of the scores prior to the intervention were equivalent across both groups. Similarly, the results for the post-test also indicated homogeneity of variances ($F(1, 16) = 0.347$, $p = 0.564$), confirming that the variances post-intervention were comparable.

The absence of significant differences in variances, along with the previously obtained results from the Shapiro-Wilk test confirming the normality of distributions, provides a solid foundation for the use of parametric tests, such as the independent samples t-test, in our study. These findings underscore the validity of applying parametric analyses to compare the average scores between the control and experimental groups in both the pre-test and post-test.

To investigate the differences in academic performance between the control group (CG) and the experimental group (EG) before and after the intervention, an independent samples t-test was conducted. The test results for the pre-test showed no statistically significant difference in the average scores between the groups ($t(16) = 2.00$, $p = 0.065$). This indicates that, prior to the intervention, the performance of students in both groups was comparable.

In contrast, the analysis of the post-test revealed a statistically significant difference ($t(16) = -2.705$, $p = 0.016$), suggesting that the average scores of the experimental group significantly improved compared to the control group after the intervention. This finding suggests that the intervention had a positive and significant impact on the performance of students in the experimental group.

These results underscore the effectiveness of the intervention implemented in the experimental group, as reflected in the significant improvement of their scores compared to the control group. The absence of significant differences in the pre-test between the groups strengthens the attribution of this change to the effect of the intervention.

4. Implications of the findings

This study underscores the significance of virtual reality as a pedagogical tool in resource-limited and rural settings, and its potential to bridge educational gaps in mathematics. The findings suggest that virtual reality can be an effective resource to enhance the quality and accessibility of mathematical education, which is critical in areas where educational resources may be sparse.

The research also highlights the need to train educators in the integration of advanced technologies and pedagogical approaches in the classroom. The effectiveness of virtual reality in the study was augmented by the presence of trained teachers, underscoring the necessary synergy between technological innovation and conventional teaching methods.

However, it is crucial to acknowledge the study's limitations, including the lack of random assignment and a sample confined to a specific subject area, which could introduce potential biases in the results and limit the generalizability of the findings to other educational contexts and subjects.

Future research should extend the scope to larger samples and multiple subject areas. Furthermore, it would be beneficial to explore how virtual reality can be effectively integrated into the curriculum and ascertain its impact in comparable rural settings.

Regarding practical applications, this study emphasizes the need to adopt innovative educational approaches that leverage technology, especially in underserved educational scenarios. The results support investment in educational technology and teacher training to enhance instruction.

5. Conclusion

This study has investigated the effectiveness of virtual reality as a pedagogical tool in teaching mathematics at a rural secondary school in Antiguo Morelos. The data obtained indicate a significant improvement in the performance of students exposed to virtual reality compared to those who followed a traditional didactic sequence. This finding suggests that virtual reality may be a valuable resource in the rural educational environment, particularly within the context of mathematics.

The results support the notion that virtual reality has the potential to enhance the teaching and learning process by encouraging greater participation, interaction, and understanding of complex mathematical concepts. Immersion in virtual environments offers students more engaging and stimulating experiences, which could help overcome barriers to accessing advanced technology in rural communities.

However, it is important to acknowledge that while virtual reality showed promising outcomes, it is not a panacea for all educational challenges. It must be emphasized that the presence and support of a teacher during the teaching process with technology remain crucial for success.

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