Vol. 10, Issue 2, pp. 1-14 | DECEMBER 2025
DOI: https://doi.org/10.53840/myjict10-2-217

THE ROLE OF VIRTUAL REALITY IN ICT-ENHANCED LEARNING FOR STUDENTS WITH AUTISM: A DUAL APPROACH USING EXPLORATORY AND INQUIRY-BASED METHODS

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Article history:
Submission date: 8 July 2025
Received in revised form: 12 November 2025
Acceptance date: 15 November 2025
Available online: 3 December 2025

Keywords:
Virtual Reality, Autism, Learning Approach, Special Education, Immersive Learning.

Funding:
This work was supported by a national research grant under the Academic Research Grant (ARGS), with Project Code: R502-KR-ARU005-0000000585-K134. The authors are affiliated with Universiti Sains Malaysia. The research funding and materials were provided by the institution.

Competing interest:
The author(s) have declared that no competing interests exist.

Cite as:
Mohd Hamizi, M. A. A., Mohamed Mokmin, N. A., & Ariffin, U. H. (2025). The Role of Virtual Reality in ICT-Enhanced Learning for Students with Autism: A Dual Approach Using Exploratory and Inquiry-Based Methods. *Malaysian Journal of Information and Communication Technology (MyJICT), 10(2)*, 1-14. https://doi.org/10.53840/myjict10-2-217

ABSTRACT

This study examines the impact of a Virtual Reality (VR) Safari learning environment on the interest levels and engagement behaviors of students with autism spectrum disorder (ASD) using two instructional strategies: Inquiry-Based Learning (IBL) and Exploratory Learning (EL). Utilizing an explanatory sequential mixed-methods approach, 30 Form 4 science students from special education settings in Malaysia were assigned to either IBL or EL interventions. A quasi-experimental pre- and post-test design was used alongside observation and interviews to capture both quantitative and qualitative insights. Although the Mann-Whitney U test revealed no statistically significant difference in interest levels between the groups, qualitative data highlighted five core themes: emotional resonance, curiosity, sensory sensitivity, autonomy in interaction, and social sharing. These findings underscore the capacity of VR to foster inclusive, personalized learning experiences for autistic learners, with implications for universal design and pedagogical adaptation. The study affirms VR's potential as a flexible educational tool that responds to the sensory and cognitive diversity of students with autism.

Introduction

In recent years, Virtual Reality (VR) has emerged as a transformative educational tool, particularly effective in enhancing student engagement and motivation across various learning domains (Yang J.; Ma, Y.; Yu, J.; Cao, H.; Zeng, A., 2025). For learners with Autism Spectrum Disorder (ASD), VR presents unique opportunities due to its immersive, visually rich, and controllable environments that can be tailored to accommodate individual needs (Ekman, 2023). ASD is characterized by challenges in social communication, restricted interests, and sensory processing issues, which often complicate participation in conventional classroom settings (Jyoti & Kajal, 2025). VR, therefore, offers a promising solution by enabling personalized, low-anxiety learning spaces that support both cognitive and affective learning outcomes (Yang J.; Ma, Y.; Yu, J.; Cao, H.; Zeng, A., 2025). The integration of VR into science education has shown particular promise in improving understanding and retention of complex concepts (Hamilton et al., 2021) such as animal behaviour. Traditional methods, such as textbooks or static images, often capture obstacles for understanding the dynamic and interactive nature of animal interactions compared to VR (Bastien et al., 2025). VR environments, by contrast, simulate real-world ecosystems, allowing students to observe animal behaviors, habitats, and interactions in real time (Marougkas et al., 2024). These immersive experiences can significantly increase student interest, particularly among those who benefit from experiential learning (Hoffman, 2023). However, effective learning in VR is not solely dependent on the technology but also on the pedagogical approach employed within the environment (Marougkas et al., 2023).

This study investigates the comparative effects of two instructional strategies, which are: Inquiry-Based Learning (IBL) and Exploratory Learning (EL), within a VR Safari environment for students with autism. IBL provides guided learning through questioning and structured exploration, while EL offers learners greater autonomy to navigate content. Although both strategies hold potential, there is limited empirical research examining their effectiveness for neurodiverse learners within immersive environments. To address this gap, this study tends to achieve several research objectives which are: (i) to investigate the effectiveness of VR Safari on the interest levels of students with autism engaged in Inquiry-Based Learning (IBL) and Exploratory Learning (EL) in a Virtual Reality (VR) environment (ii) to explore students' experiences, perceptions, and engagement behaviors during VR-based learning and (iii) to identify the sensory, cognitive, and social factors that influence learning interest and interaction among students with autism in VR settings. This research's objectives will answer the following research questions: (i) Is there a significant difference in interest levels between students with autism participating in Inquiry-Based and Exploratory VR learning experiences? (ii) What are the perceptions and emotional responses of students with autism regarding their learning experience in a VR environment? (iii) What challenges or barriers (e.g., sensory overload, cognitive load) do students with autism face when engaging in VR-based learning?

Building on these research objectives and questions, the structure of this paper is outlined as follows. Section 2 reviews relevant literature, emphasizing the use of Virtual Reality in special education, instructional strategies for autistic learners, and factors influencing engagement and learning outcomes. Section 3 details the research methodology, including the study design, participant selection, procedures, and data collection techniques. Section 4 presents the findings, beginning with quantitative results, followed by qualitative insights, and concluding with an integrated discussion. Section 5 discusses the implications of the findings for VR-based learning among students with autism, considering both pedagogical and technological aspects. Finally, Section 6 concludes the paper by summarizing key findings, discussing limitations, and suggesting directions for future research.

Literature Review

Virtual Reality in Special Education

Virtual Reality (VR) has demonstrated significant effectiveness in enhancing social, emotional, and cognitive skills among children and adolescents with autism spectrum disorder (ASD). A comprehensive

2025 meta-analysis reported meaningful improvements in social and emotional functioning following immersive VR interventions in ASD youth (Yang J.; Ma, Y.; Yu, J.; Cao, H.; Zeng, A., 2025). Similarly, an earlier randomized-controlled trial meta-analysis (2024) confirmed VR's benefits in cognitive, social, and emotional domains (Astafeva et al., 2024). However, these benefits were also accompanied by sensory side effects such as dizziness and overload (Chattha et al., 2020), underscoring the need for careful design. From a Theory of Mind (ToM) perspective, VR offers controlled scenarios where autistic learners can safely practice interpreting others' emotions and social cues, supporting social cognition development (Astafeva et al., 2024; Rodríguez & Souza, 2025). According to IDC Theory, learning is most effective when it follows an "interest loop": triggering curiosity, immersing learners in flow, and extending interest through meaningful activities (Wong et al., 2020). VR's immersive qualities naturally support these stages by capturing attention, sustaining involvement, and making learning personally relevant (Aleksić, 2020; Hassan et al., 2020).

Moreover, incorporating Mayer's Voice and Personalisation Principles, such as conversational narration and relatable avatars, makes the experience more accessible and motivating (Mayer, 2024). Despite its promise, VR can overwhelm users cognitively and sensorially. Cognitive Load Theory (CLT) warns against sensory clutter and navigation complexity that increase extraneous load (Nasri, 2025). To mitigate this, design frameworks use Mayer's Coherence and Segmentation Principles by Mayer (2024), which emphasize clarity and chunked presentation of information (Nasri, 2025). The current study extends these principles to create sensory-friendly VR learning tailored to ASD learners. Building on the demonstrated benefits of VR, the way content is delivered within these environments becomes crucial. This leads to an important pedagogical consideration on how different instructional strategies, particularly Inquiry-Based Learning and Exploratory Learning, can shape autistic students' engagement and learning within VR.

Pedagogical Strategies in VR: Inquiry-Based vs. Exploratory Learning

Instructional strategies significantly shape the learning outcomes in VR. Inquiry-Based Learning (IBL) emphasizes structured exploration, questioning, and reflection, aligning with Self-Determination Theory (SDT) by Ryan and Deci (2020), supporting learners' autonomy, competence, and relatedness (Kourtesis E.-C.; Roussos, P., 2023). Scaffolding techniques and Mayer's Signalling and Coherence Principles are essential in VR to direct attention and reduce distraction (Mayer, 2024; Mohd Hamizi et al., 2022). Conversely, Exploratory Learning (EL) fosters curiosity and independence (Tang et al., 2025), consistent with both IDC Theory and SDT. Effective EL for autistic learners requires minimizing extraneous cognitive load, managing task complexity, and providing adaptive supports such as attention guidance, clear instructions, and scaffolding (Moon et al., 2023). Recent research in VR environments promotes hybrid instructional models, balancing exploration with strategic cues and structured reflection (Hamizi, 2023; Mohd Hamizi et al., 2022; Mokmin & Ridzuan, 2022). Although IBL and EL have been compared in neurotypical learners, limited research explores their application in immersive learning environments for neurodiverse students.

This study addresses this gap by integrating both strategies within a VR Safari environment and aligning their design with Mayer's multimedia principles to accommodate autistic learners' cognitive and sensory profiles. Understanding the impact of these strategies requires a closer look at how they influence student interest and engagement, key outcomes that drive meaningful learning in any educational context, especially in VR.

Interest, Engagement, and Learning Outcomes

Interest is a critical driver of learning engagement, especially for students with ASD. According to Renninger and Hidi (2022), triggering situational interest through novelty can evolve into sustained interest when paired with relevance and meaning. VR is uniquely positioned to elicit this type of engagement through immersive, emotionally resonant experiences, especially when aligned with autistic learners' specific fascinations (Ekman, 2023; Zhang et al., 2025). Studies confirm that VR promotes high levels of engagement and user satisfaction among students with autism, though this does not always translate into academic gains without well-designed instructional scaffolding (Kourtesis E.-C.; Roussos, P., 2023). Biometric studies further validate this by showing that increased physiological responses, like gaze and heart rate, often correlate with deeper focus and performance (Nasri, 2025). To harness this, pedagogical strategies like IBL and EL must be purposefully aligned with learners' cognitive profiles. This study uses a mixed-methods approach, combining quantitative measures, pre- and post-tests on interest, with qualitative techniques to explore how interest manifests under each instructional strategy. This approach ensures a comprehensive understanding of how VR influences engagement among neurodiverse learners. Thus, to fully appreciate how students with autism engage in VR, it is essential to consider the unique sensory and cognitive factors that mediate their experiences and responses to learning stimuli.

Sensory and Cognitive Considerations in Autism and VR

Students with ASD often face distinct sensory sensitivities, including hypersensitivity to light, sound, or motion (Astafeva et al., 2024). Poorly designed VR environments can lead to overstimulation, discomfort, or withdrawal. As such, design adaptations like adjustable brightness, simplified visuals, and volume controls, informed by Mayer's Coherence Principle, are vital for accessibility (Mohd Hamizi et al., 2022). On the cognitive front, autistic learners may possess strengths in visual memory and detail orientation, face difficulties with executive functions such as shifting attention or handling complex tasks (Bastien et al., 2025). To address this, the use of segmented instruction (Mayer's Segmentation Principle) and visual prompts (Signalling Principle) can help scaffold learning in VR (Mayer, 2024; Mohd Hamizi et al., 2022). While EL supports autonomy, IBL can provide essential cognitive organization through structured prompts and pacing. By incorporating Universal Design for Learning (UDL) principles, this study ensures the VR Safari experience accommodates diverse needs. Learners can engage in either guided or open-ended paths depending on their preferences and support needs. This dual-path approach reflects the VR Safari, where analysis of learner needs informs the design, development, implementation, and evaluation of VR learning environments.

Methodology

Research Design

This study employed a mixed-method approach, incorporating both quantitative and qualitative methodologies. The quantitative study was initially undertaken, followed by qualitative research to reach a result. This is referred described as the "explanatory sequential mixed method" (Creswell & Plano Clark, 2018). A two-group design incorporating a pre-test and post-test was executed utilizing a quasi-experimental methodology for the quantitative analysis. A quasi-experimental design utilizing non-equivalent groups was implemented due to the impracticality of random assignment. Students were already grouped into intact classrooms according to school administration protocols, and reallocating students for study purposes would disrupt standard school operations. Consequently, pre-existing courses were allocated to the intervention groups through a quasi-experimental approach, maintaining authentic classroom environments while facilitating significant group comparisons. Furthermore, Zubair (2023) asserts that the principal aim of statistical analysis is to ascertain a causal relationship between the dependent and independent variables being examined and to compare two or more groups.

This research utilized three quantitative methodologies: field trials, correlational analyses, and surveys. Simultaneously, observation and interview techniques were employed to ascertain the qualitative methodology. Qualitative research can enhance quantitative findings by elucidating the objective, establishing research quality, contextualizing the study, and employing reflexivity (Wilson & Anagnostopoulos, 2021). Each study objective is paired with specific research questions that offer a systematic method to tackle every facet of the investigation. The quantitative method was employed to comprehensively explore RQ1 in relation to RO1. Simultaneously, the observation was employed to assess the participation and behaviour of 10 students in this study. The identical 10 students were chosen to participate in the interview to evaluate their involvement and behaviour regarding VR Safari, which can corroborate the levels of interest. Vasileiou et al (2018) assert that ten participants are adequate for qualitative analysis. This qualitative approach, RO2 and RO3, will examine RQ2 and RQ3. The study design is illustrated in Table 1 below:

The Experimental Research Design Procedure:

$$A_1 - O_1 - X_1\, O_2 - O_3,\ O_4,$$
$$A_2 - O_1 - X_2\, O_2 - O_3,\ O_4,$$

Note: O represents observations (pre- and post-tests), and X represents the intervention applied to the groups.

where:

- O_1 = Pre-Level of Interest (LIPre)
- A_1 = Experiment Class Group 1
- A_2 = Experiment Class Group 2
- X_1 = Intervention A (Inquiry-based Learning)
- X_2 = Intervention B (Exploratory Learning)
- O_2 = Observation (Rubric and Field Note)
- O_3 = Post-Level of Interest (LIPost)
- O_4 = Interview

Table 1: The Experimental Research Design Procedure

Group	Pre-Test	Intervention (X)	Post-Test (O_3, O_4)
A_1	O_1	$X_1\, O_2$	O_3, O_4,
A_2	O_1	$X_2\, O_2$	O_3, O_4,

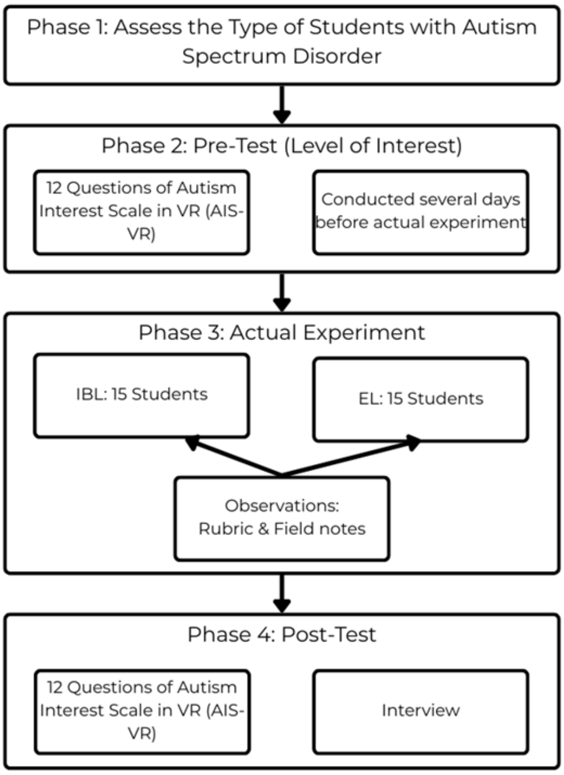
Participants and Grouping

This study involved Form 4 students participating in scientific sessions at designated special education institutions in Malaysia. Participants were randomly selected within each school to enhance representativeness and mitigate selection bias. Since all eligible students possessed a uniform academic background in Form 4 Science, random sampling guaranteed that each student had an equal chance of participating in the study, hence enhancing the validity and generalizability of the findings. Exclusion criteria were implemented to refine the sample. Students unfamiliar with VR technology, those who do not experience motion sickness, and individuals with pre-existing health concerns were excluded. Furthermore, non-compliant schools are excluded from selection. Students were disqualified if they: (i) are not enrolled in the Science course, (ii) have trouble comprehending instructions, (iii) cannot collaborate with researchers, or (iv) experience substantial challenges in utilizing technology. The final sample comprised two matched cohorts of 15 kids with learning disabilities. Group 1 participated in an inquiry-based learning intervention, whereas Group 2 engaged in an exploratory learning intervention.

Procedure

This experiment consists of four phases, which are: (i) Access the Type of Students with Autism Spectrum Disorder, (ii) Pre-Test (Level of Interest), (iii) Actual Experiment, and (iv) Post-Test, as shown in Figure 1 below.

Figure 1: Research Procedure



This study began with Phase 1, where the research began with the collection of a student list provided in advance by the classroom teacher. This list was essential for identifying and classifying the types of autism spectrum disorder (ASD) present among the participants. Understanding the specific needs and characteristics of each student ensured that the intervention could be conducted ethically and appropriately, with accommodations where necessary. In Phase 2, several days before the actual experiment, a pre-test was conducted to measure the students' initial interest in the learning content. A structured questionnaire was distributed to all participating students. This questionnaire was designed to assess baseline interest levels and served as a comparison point for post-intervention analysis. Then, in Phase 3, during the intervention, the 30 participating students were randomly divided into two equal groups: Inquiry-Based Learning (IBL) and Exploratory Learning (EL), with 15 students in each group. Both groups utilized the VR Safari platform to explore and learn about animal behavior as part of a science education activity. While students interacted with the virtual environment, researchers randomly selected 10 students from both groups for observation. These observations were guided by an engagement rubric and supplemented with field notes to document behavioral indicators of interest and engagement during the session. Figures 2 and 3 below show the intervention of VR-based learning for EL and IBL respectively.

Figure 2: Intervention of VR Safari Exploratory Learning

Figure 3: Intervention of VR Safari Inquiry-Based Learning

Lastly, in Phase 4, after the VR-based learning session, all 30 students were given the same set of interest-level questions as in the pre-test, but arranged in a different sequence to minimize response bias. This post-test was used to measure any change in interest levels following the intervention. Additionally, the same 10 students who had been observed earlier were invited to participate in a follow-up interview session. These interviews provided qualitative insights into their learning experience, emotional responses, and perceived engagement during the VR activity.

Data Triangulation

To ensure credibility and trustworthiness, data triangulation was employed in the qualitative phase (Quintão et al., 2020). Observational data, field notes, and interview responses were cross-validated to identify patterns, confirm findings, and enhance the robustness of qualitative interpretations. The results from the qualitative analysis were used to support, refine, or challenge the conclusions drawn from the quantitative findings. This integration provided a more comprehensive understanding of how different pedagogical approaches influenced learner interest, especially in the context of special education.

Results and Findings

Quantitative Findings

i. Descriptive Analysis

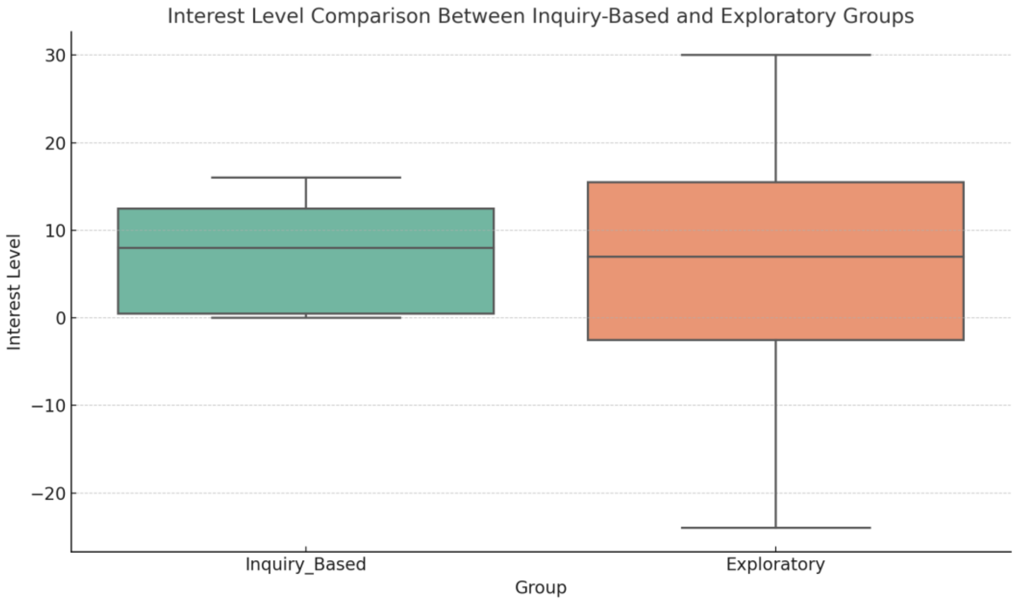
Descriptive analysis was conducted to examine the distribution of interest level scores in both instructional groups: the Inquiry-Based Learning (IBL) group (G1–G15) and the Exploratory Learning (EL**)** group (O1–O15). As shown in Table 2, the IBL group (M = 7.13, SD = 6.23) demonstrated slightly higher mean interest levels compared to the EL group (M = 4.87, SD = 14.89). However, variability was substantially greater in the EL group, as evidenced by the higher standard deviation.

Table 2: Descriptive statistics for interest level scores by instructional group.

Group	N	Mean	SD	Min	Max
Inquiry-Based Learning	15	7.13	6.23	0	16
Exploratory Learning	15	4.87	14.89	-24	30

A boxplot in Figure 4 below illustrates the distribution of scores across the two groups. The EL group exhibits a wider range and greater dispersion of scores, though both groups show overlapping medians and interquartile ranges.

Figure 4: Distribution of score across both interventions IBL and EL



ii. Normality and Outlier Assessment

Normality tests were performed using the Shapiro-Wilk test. Results indicated that the interest level scores in the IBL group deviated significantly from a normal distribution, $W = 0.873$, $p = .037$. In contrast, the EL group did not significantly deviate from normality, $W = 0.961$, $p = .702$. Outlier analysis was conducted using the Interquartile Range (IQR) method. No extreme outliers were identified in either group. Table 3 below shows the clear comparison between two interventions.

Table 3: Normality Analysis for Interest Level Scores in IBL and EL Interventions

Interventions	Shapiro-Wilk W	p-value	Normality
Inquiry-Based Learning (IBL)	0.873	.037	Not normally distributed
Exploratory Learning (EL)	0.961	.702	Normally distributed

iii. Homogeneity of Variance

The Levene's test for equality of variances revealed a significant difference in variance between the groups, $F(1, 28) = 6.35$, $p = .018$, suggesting heterogeneity of variance as shown in Table 4 below. Given the combination of non-normality in one group and unequal variances, assumptions for parametric analysis (e.g., independent samples t-test or ANOVA) were violated.

Table 4: Levene's Test for Equality of Variances Between IBL and EL Interventions

Test	Degree of Freedom (df1)	Degree of Freedom (df2)	F	p-value	Variance Equality
Levene's Test	1	28	6.35	.018	Violated (heterogeneous)

iv. Inferential Analysis

Due to the violations of parametric test assumptions, a non-parametric test was employed. The Mann-Whitney U test was used to compare the distributions of interest level scores between the IBL and EL groups. The analysis revealed no statistically significant difference in interest levels between the groups, $U = 119.5$, $p = .787$, as shown in Table 5 below.

Table 5: Mann-Whitney U Test Results for Interest Level Scores Between IBL and EL Interventions

Test	U Statistic	p-value	Significance
Mann-Whitney U Test	119.5	.787	Not statistically significant

Qualitative Findings

Thematic analysis followed the six-phase approach outlined by Braun & Clarke (2006). In the first phase, the researchers familiarized themselves with the data by thoroughly reading the interview transcripts, field notes, and VR participation rubrics. Initial insights and notable patterns, such as repeated references to joy, curiosity, and difficulty focusing, were noted. In the second phase, a systematic coding process was conducted. Codes such as "happy," "excited," "confused by sound," "wanted to share with friends," and "used controllers to explore" were applied across the dataset. These codes were then organized into broader themes in the third phase. For instance, expressions of happiness and excitement were grouped under "Emotional Resonance and Joy of Immersion," while difficulties with brightness and noise formed the basis for "Sensory Sensitivity and Cognitive Overload." In the fourth phase, themes were refined by reviewing all coded data within each theme and assessing the themes' coherence across the dataset. Some themes were merged or renamed for clarity and relevance.

During the fifth phase, final theme definitions were established. These included five key themes: (i) Emotional Resonance and Joy of Immersion, (ii) Curiosity and Desire to Learn More, (iii) Sensory Sensitivity and Cognitive Overload, (iv) Interaction and Autonomy, and (v) Social Sharing and Peer Influence. Finally, in the sixth phase, these themes were written up as part of the qualitative results and discussion. They were interpreted in the context of the research questions and triangulated with quantitative findings, providing a rich, holistic understanding of the students' learning experience in the VR environment. The analysis revealed five core themes that illuminate how students perceived and interacted with the VR environment. Table 6 below shows a step-by-step of analysis qualitative data by using Braun and Clarke (2006).

Table 6: Braun and Clarke's Steps

Steps		Description	Application in This Study
i.	Familiarization	Immersion in the data through reading and re-reading.	Researchers reviewed interview transcripts, field notes, and rubric comments multiple times, noting initial ideas.
ii.	Generating Codes	Systematic identification of meaningful features across the dataset.	Initial codes like "happy," "curious," "dizzy," and "telling friends" were assigned to relevant text segments.
iii.	Searching for Themes	Grouping codes into broader potential themes.	Related codes were clustered into preliminary themes such as emotional engagement and sensory challenges.
iv.	Reviewing Themes	Refining and checking themes against the data for internal consistency.	Themes were verified and refined by comparing coded extracts across sources, ensuring alignment with full data.
v.	Defining & Naming	Clearly describing the essence of each theme.	Five final themes were defined and named: Emotional Resonance, Curiosity, Sensory Sensitivity, Interaction, Social Sharing.
vi.	Producing the Report	Writing the narrative of the themes, supported by data extracts and linked to research questions.	Themes were integrated into the qualitative findings and triangulated with

Theme 1: Emotional Resonance and Joy of Immersion

Many students described feeling happy, excited, and amazed during their VR experience. These emotional responses were particularly strong among first-time users. Statements such as "I was really happy because it was my first time using it" (G6) and "I felt happy because I saw the behaviour of giraffe" (O4) highlight the emotional appeal of VR immersion. These findings were echoed in field notes describing spontaneous verbalizations like "woah" (O10) and physical reactions like jumping or bending over to touch animals (O6, O4). This emotional engagement appeared to be a catalyst for interest, with several learners expressing a desire to share the experience with peers: "Yes, I want to tell them about the VR experience and how clearly I could see everything" (G2).

Theme 2: Curiosity and Desire to Learn More

A recurrent theme across interview responses was a heightened curiosity, particularly about animals. Students commonly responded "Yes, I want to learn more about the animals" (G10, O6). The immersive environment stimulated inquiry, with some learners asking "What does a tiger eat?" or "Where does it live?" (G4). The field notes also noted a behavioral manifestation of curiosity, students moving continuously to explore and describe what they saw (O2, O4), and actively engaging in verbal exchanges about animal behaviors.

Theme 3: Sensory Sensitivity and Cognitive Overload

Although most responses were positive, several students noted sensory-related barriers. For example, G8 reported: “I feel dizzy because it is too bright”, while G10 mentioned: “Too noisy, so many sounds in VR Zoo.” These sensory challenges align with characteristics of ASD and highlight the importance of designing sensory-friendly VR environments. Field notes reinforced this observation: students like G10 needed teacher assistance to focus, while others (e.g., O8, O10) appeared less expressive and slightly overwhelmed.

Theme 4: Interaction and Autonomy

The extent of interaction varied widely. While students like O4 and O6 “kept walking around to explore the VR Zoo” and attempted to touch animals, others were more passive explorers, primarily observing in silence (G2, G8). The participation rubric also revealed differences in interaction scores, ranging from “Fair” to “Excellent.” This variability underscores the individualized learning preferences of learners with ASD. Some preferred non-verbal exploration, while others actively narrated their experiences or asked questions.

Theme 5: Social Sharing and Peer Influence

Social interaction emerged as a motivating factor for several students. Many expressed a desire to tell their friends about the VR experience. Statements like “Yes, because I want to share more widely” (G4) and “Yes, because it is very good for others to know it” (O8) suggest that peer-sharing contributes to positive reinforcement and learning validation. Field observations echoed this, noting how students like O2 engaged their peers by saying what they saw, and O10 frequently verbalized surprise and amazement to those nearby.

Integration with Quantitative Findings

The qualitative findings align with the non-significant difference in interest scores between the two groups. Both the Inquiry-Based and Exploratory groups demonstrated engagement and enthusiasm, with variations attributable more to individual sensory or interaction preferences than instructional style. While statistical analysis found no significant group-level difference in interest, the qualitative data highlights how and why students found VR engaging, suggesting the technology's potential lies in its ability to meet diverse learner needs, especially for those with autism.

Discussion

This study explored the impact of two instructional strategies, which are Inquiry-Based Learning (IBL) and Exploratory Learning (EL), on student interest within a virtual reality (VR) environment, specifically among learners with autism. The quantitative results indicated no statistically significant difference in interest levels between groups. However, the qualitative data revealed meaningful patterns of engagement, interaction, and emotional responses, offering insights that extend beyond numerical outcomes. The findings suggest that VR serves as a highly engaging medium for learners with autism, sparking emotional connection, sensory stimulation, and curiosity-driven learning. Although traditional assessments showed no group-level differences, the richer picture from qualitative analysis illustrates that VR enabled personalized learning pathways. Some students actively explored, interacted with avatars, or narrated their experiences, while others engaged more passively yet meaningfully. The theme of sensory sensitivity highlights a critical consideration in VR design: brightness, noise levels, and navigation complexity must be adapted to suit neurodiverse learners. This supports calls for universal design for learning (UDL) in immersive education.

Moreover, the consistent desire among students to share their experiences socially aligns with theories of social constructivism, suggesting that VR can support not only cognitive but also socio-emotional development. This study underscores the importance of mixed-methods approaches in special education research. Where statistical results may appear neutral, qualitative voices provide depth, context, and meaning. Future research should expand on this approach, potentially integrating biometric or eye-tracking data to capture real-time engagement. This study was limited by its small sample size and short-term exposure to the VR environment. Longitudinal studies with larger cohorts could better assess lasting impacts on interest, retention, and learning outcomes.

Conclusion

This study examined the efficacy of VR Safari experiences on the engagement levels of students with autism involved in two instructional frameworks: Inquiry-Based Learning (IBL) and Exploratory Learning (EL). Quantitative analysis indicated no statistically significant difference in interest levels between the two groups, implying that both methods are equally effective in maintaining engagement within a VR context (RO1). However, assumption violations (non-normality and unequal variances) required the use of a non-parametric Mann-Whitney U test, which confirmed the absence of significant differences. Despite the lack of statistical differentiation, descriptive data showed that both groups reported relatively high levels of interest, with IBL slightly higher in mean scores.

The findings suggest that the immersive quality of VR may be more significant than the educational paradigm in fostering student engagement. Qualitative data offered profound insights into students' experiences during the VR sessions (RO2). Thematic analysis indicated significant emotional resonance, curiosity, and positive engagement behaviors in both groups. A multitude of pupils conveyed enthusiasm, an eagerness to acquire knowledge about animals, and a willingness to socially share their experiences. Simultaneously, others encountered sensory difficulties, like vertigo or auditory overload, which impacted their concentration and comfort (RO3). These findings underscore the significance of sensory-sensitive design, adaptable interaction modes, and social reinforcement in VR learning environments for students with autism. This study confirms the potential of VR Safari as an inclusive and stimulating platform for science teaching, while highlighting essential design aspects that could enhance its efficacy.

Acknowledgement

This work was supported by a national research grant under the Academic Research Grant (ARGS), with Project Code: R502-KR-ARU005-0000000585-K134. The authors are affiliated with Universiti Sains Malaysia. The research funding and materials were provided by the institution.

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