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Research Article

Virtual Reality for Math Learning: Turning End Users' Views into a Multidimensional Scale Development and Validation

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Abstract

Recent literature discusses how virtual reality technology is used in learning, raising questions about which tools best support immersive experiences and how to measure student behavior and engagement. The study develops and validates a multidimensional scale to assess user experiences with virtual reality (VR) headsets in mathematics education. The methods involved the following key steps: identifying the scale dimensionality and item indicators through a literature review and focused group discussion (FGD); conducting validation with four experts; revising items based on expert feedback; and establishing the psychometric properties of the scale through EFA and CFA. The participants included ten pre-service math teachers in the FGD, four experts for the instrument validation, and 138 respondents in the pilot survey. This study developed the Immersive Virtual Reality Learning Scale (IVRLS) in mathematics, a 15-item instrument comprising three dimensions: immersive learning experiences (4 items), user acceptance (7 items), and issues (4 items). Results demonstrated

acceptable fit measures, high reliability, and convergent and discriminant validity. This study concludes with recommendations for utilizing the developed scale to assess VR learning experiences and their implications to teaching and learning.
Keywords: *Mathematics Education; Scale Development; Validation; Virtual Reality*

1. Introduction

Technological advancements led to increased involvement and interaction among students. It promotes engagement where interaction is a key potential enhancement to achieve an interactive teaching and learning process (Tuma, 2021). The role of technology shifts from a mere tool of learning and inquiry to an approach that can be integrated into education (Ohler, 2011). Educational technology changes due to the increasing pervasiveness of computer applications which could facilitate immersive experiences (Collins & Halverson, 2010). One of the immersive technologies in today's generation is the virtual reality (VR). It enables interactions in five senses, particularly the visual, auditory, and tactile senses, to provide an experience similar to reality. Through these senses, immersive VR systems allow users to experience where they are, who they are with, and what they do as if it were an authentic experience. VR offers a unique opportunity for students to visualize and engage with abstract concepts in a way that traditional learning methods often cannot (Dede, 2009). Knowing the abstract nature of mathematics, often considered a complex subject, VR can provide an immersive approach, specifically in areas like geometry and calculus, in which spatial reasoning and visualization are essential to a more profound understanding (Freina & Ott, 2015). It enhanced engagement and increased learning outcomes by providing experiential, hands-on learning experiences in science, engineering, and medicine (Merchant et al., 2014). VR has been altering the traditional methods of learning in which complex concepts can be visualized, and abstract ideas can be transformed into interactive and tangible lessons (Chen et al., 2020). It provides an entirely immersive learning experience, given its three-dimensional (3-D) multimedia environment, where individuals can interact realistically through simulated experiences based on reality or imagination (Zhang et al., 2020).

VR has brought changes in many aspects, emphasizing the advantages of imaging and projection for students' comprehension of mathematical ideas, and that modern visualization techniques must be used in teaching (Demitriadou et al., 2020). Mathematics education faces challenges in making abstract concepts more concrete for students. For example, understanding three-dimensional geometry, algebraic structures, or calculus can be complex for students relying solely on traditional instructional methods. VR can help address these challenges by allowing students to visualize mathematical concepts in a virtual environment, manipulate objects in real-time, and engage in interactive problem-solving (Walkington et al., 2021). VR's potential to provide a highly engaging and visual learning experience could revolutionize how students approach mathematical learning (Freina & Ott, 2015). Several studies have documented VR's pedagogical benefits. For instance, immersive learning experiences can engage learners more deeply, making abstract concepts easier to understand (Dede, 2009). This means that they can increase motivation and sustain student interest throughout the lesson. It has also been shown to improve learner engagement and overall academic outcomes (Freina & Ott, 2015). However, while these studies emphasize technical and pedagogical benefits, less studies focus on the perceptions and experiences of end users, students, and teachers interacting with the technology in real-world learning environments.

While previous research has explored the immersive characteristics of VR and potential benefits, comprehensive studies on user experiences in VR-based learning still need to be uncovered (Radianti et al., 2020). Literature focus on technical aspects rather than subjective experiences and factors influencing user acceptance and validation (Snelson & Hsu, 2020). With its abstract concepts and spatial reasoning demands, mathematics is well-suited for VR integration. A validated, multidimensional scale is needed to capture diverse user experiences, including immersive learning experiences, users' perspectives, acceptance, validation, and challenges. Such a tool would provide educators and developers with a valuable resource for evaluating and improving VR-based learning environments. Additionally, educators must be equipped to guide students in effectively and responsibly using educational technology (Fransson et al., 2020). While technology has improved many aspects of life, it can also pose risks to physical and mental well-being. In the digital age, continuous monitoring and careful guidance are essential to ensure the positive use of technology.

The paper aims to develop a scale to measure and assess the latent construct of user experiences in VR while learning mathematics. The scale can support a framework for evaluating users' experiences and challenges, enabling scholars in the field to explore hypothetical connections with various behavioral concepts and better understand the complexities of VR headset integration in the mathematics education system. Focusing on utilizing VR and comprehensively exploring the multifaceted dimensions of user experiences and perceptions when employing VR to learn mathematical concepts. The multidimensional scale development captures the different aspects of users' experience, including immersion, usability, engagement, and effectiveness in understanding mathematical ideas in VR settings.

2. Literature Review

This section presents an overview of relevant studies to contextualize the development of the scale on virtual reality use in learning. It first examines existing research on the integration of virtual reality technologies in learning, followed by a discussion of user experience and challenges that inform the dimensions captured in the proposed instrument.

2.1 The Use of Virtual Reality in Mathematics Education

VR is increasingly being adopted in educational settings, including mathematics education, due to its immersive and interactive potential in teaching and learning. VR in teaching can help students understand mathematical and logical concepts and reduce their misunderstandings (Mikropoulos & Natsis, 2011). VR learning aids give students a stronger sense of immersion and presence. Immersion allows students to feel realistic through virtual simulations, while presence provides students with different levels of sensory experience. The immersion mechanism can effectively stimulate students' motivation to learn new knowledge (Wang et al., 2018). VR technology has essential advantages, including increasing students' motivation to learn, exploring principles, and visualizing abstract things. The VR learning environment can allow students to manipulate virtual characters, change their position and size, and use the control interface to manipulate mathematical geometries, learning basic mathematical concepts of geometry (Guerrero et al., 2016).

Integrating VR in mathematics education also brought collaborative learning that has attracted attention due to its potential impact on educational outcomes. Existing study contributes valuable insights to understanding collaborative immersive learning and its correlation with using VR devices in teaching (Su et al., 2022; Huang et al., 2023). The experimental group demonstrated confidence in their grasp of geometry, and the game's completion mode successfully gave them a sense of achievement, demonstrating how immersive technology can improve comprehension and engagement.

Thus, using VR technology to assist students' learning as a teaching aid is an innovative way to teach mathematical geometry. The diversity of VR technology in any mathematical concept education can be further promoted. Immersive technologies like (VR) in the curriculum provide many teaching benefits. For example, it can provide a platform to increase students' enjoyment and give students a different learning experience (Osypova et al., 2020). Immersive technologies in the curriculum can increase learning effectiveness and enhance students' motivation in class (Osypova et al., 2020).

2.2 User Experience and Challenges

The immersive nature of VR offers a transformative user experience in education. It has been a helping hand in enhancing student learning and catching the students' interest and engagement. VR-based systems aid in comprehending analytical and geometric structures in high school competencies (Simonetti et al., 2020) and emphasize the spatial understanding that VR provides compared to traditional methods in teaching analytics and geometry. The immersive nature of VR offers a transformative user experience in mathematics education. VR's ability to create dynamic, 3D environments allows users to engage with mathematical concepts in ways that are often difficult in traditional 2D settings. VR enables students to interact hands-on with mathematical objects and concepts, fostering better understanding. For instance, manipulating geometric shapes or observing how formulas affect visual representations provides learners with more meaningful and engaging experiences (Ibáñez & Delgado-Kloos, 2018).

One of the greatest strengths of VR is its capacity to turn abstract mathematical concepts into visual experiences. Complex subjects, like 3D geometry, calculus, or trigonometry, are easier to grasp when students can visualize and manipulate objects in a virtual space. This improves comprehension and retention (Arici et al., 2019) and often promotes math self-concept, which has been shown to be associated with achievement (Awado et al., 2024). VR also integrates elements of gamification, making learning more engaging and motivating. Challenges, rewards, and interactive problem-solving scenarios within the VR environment can stimulate students to persist through complex concepts. This gamified aspect has increased enthusiasm, especially among students who might find mathematics intimidating or uninteresting in traditional settings (Freina & Ott, 2015). VR can cater to individual learning paces and styles. Students can repeat activities, receive instant feedback, and interact with learning materials at their speed. This is particularly useful in mathematics, where mastery of foundational concepts is essential before progressing to more advanced topics (Parong & Mayer, 2018).

Despite the advantages of VR in education, several challenges impact the user experience and the broader adoption of the technology. One of the challenges is the cost of VR hardware and software. High-quality VR headsets, compatible computers, and the necessary educational software can be prohibitively expensive for many schools and educational institutions, especially in underfunded regions. This raises concerns about equitable access to these emerging technologies, as students in more affluent areas might benefit from VR while others are left behind (Merchant et al., 2014). VR requires considerable technical support for smooth implementation. Glitches in the software, hardware malfunctions, and the need for frequent updates can disrupt the learning process. Moreover, schools may lack IT staff capable of addressing these issues, making teachers hesitant to adopt the technology (Southgate et al., 2019). Teachers often face a steep learning curve when integrating VR into their lessons. Many educators may not have the technical skills or pedagogical knowledge to effectively use VR, which can result in suboptimal usage or a lack of integration into the broader curriculum (Alalwan et al., 2020). Professional development and training are essential for teachers to leverage the full potential of VR in education. While VR provides immersive experiences, it can lead to cognitive overload if not correctly managed. The rich, multi-sensory environment can sometimes distract students from the educational content, particularly younger learners or those who struggle with focus. Overwhelming visual and auditory stimuli in VR may also reduce comprehension if not carefully designed to enhance learning objectives (Makransky et al., 2019).

Prolonged use of VR can cause discomfort for some students, including symptoms such as motion sickness, eye strain, and disorientation (Conner et al., 2022). These health issues could limit students' time in virtual environments and necessitate breaks that disrupt learning. This condition can cause nausea, dizziness, headaches, and eye strain, especially after prolonged use (Chang et al., 2020). The concerns about the long-term impact of VR use on children's physical and psychological well-being are still being researched (Kavanagh et al., 2017). VR applications in mathematics must align with established curricula to ensure that they contribute meaningfully to students' learning goals. While VR can be exciting, if the content does not align with learning standards or assessments, it may be seen as a distraction rather than a learning tool.

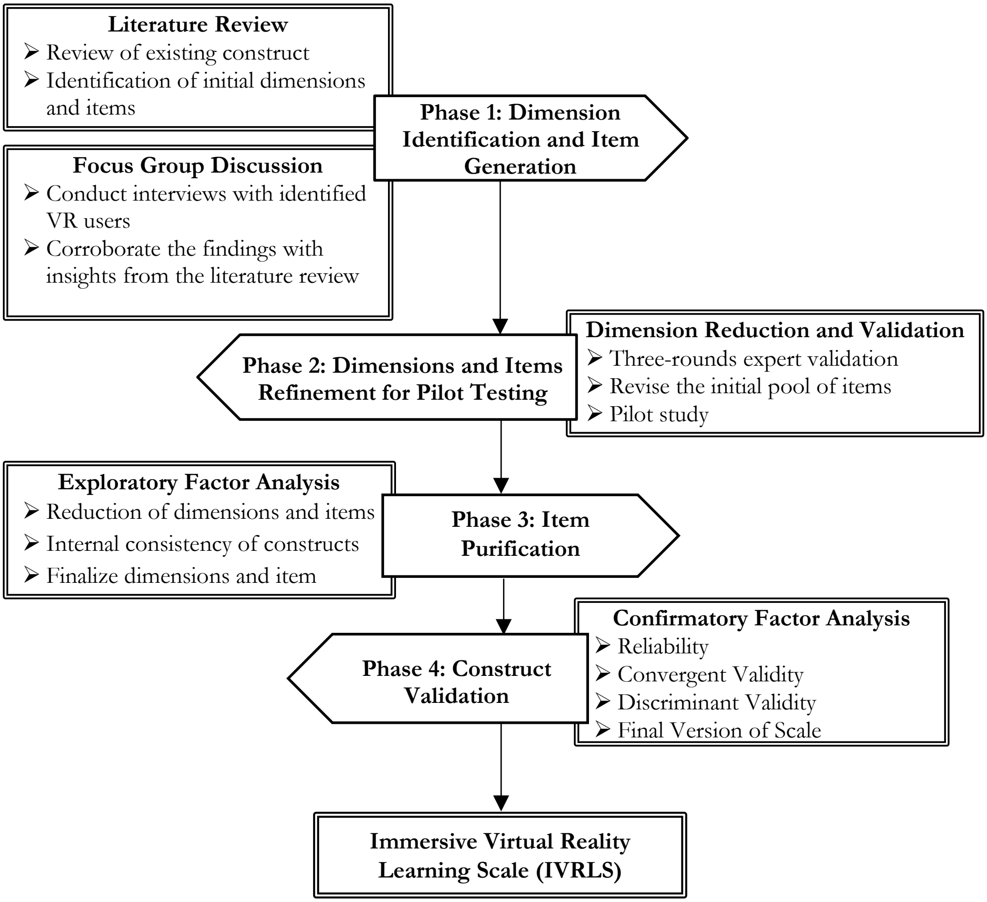
3. Methods

This paper develops a scale to assess VR user experiences and challenges and evaluate their readiness to integrate VR into learning. It followed a four-phase process with specific steps. The researchers established the initial dimensions by reviewing related literature to capture the existing constructs and indicators, and a focus group discussion of identified VR users to corroborate the review of existing constructs and indicators.

Sensitizing from the process flow based on the work of (Jorolan et al. (2025), Figure 1 outlines contextual steps of creating a reliable and valid multidimensional scale. It identifies the relevant dimensions with the assistance of a literature review, focus group discussion, expert review, item generation, refinement, and construct validation through statistical techniques, such as EFA and CFA. Each phase ensures the scale is accurate, reliable, and suitable for measuring the intended construct.

The resulting instrument developed through the process presented in Figure 1 is referred to as the Immersive Virtual Reality Learning Scale (IVRLS). This scale is specifically designed to measure learners' perceptions and experiences within immersive virtual reality educational environments. By systematically integrating insights from prior research, stakeholder input, and psychometric validation, the IVRLS captures the multidimensional nature of immersive learning, encompassing cognitive, affective, and behavioral dimensions. The robust development approach ensures that the IVRLS is both theoretically grounded and empirically validated, providing researchers and practitioners with a reliable tool to assess the effectiveness and impact of virtual reality learning interventions.

Figure 1
Scale Development and Validation Process



3.1 Participants

The study participants consisted of three distinct groups, each defined by specific inclusion and exclusion criteria and the nature of the data being gathered. The first group included informants from the focus group discussions conducted during Phase 1 of the scale's dimensionality development. This group comprised ten preservice teachers participating in FGDs. The inclusion criteria for preservice teachers required current enrollment in a teacher education program and experience using VR headsets in their classes under the supervision of a professor or having experience using VR in learning mathematics.

The second group of participants consisted of four expert validators, who were selected based on specific criteria: they must hold the position of associate professor or full professor in a college of teacher education, have publications related to scale development or factor analysis in Scopus-indexed journals, and possess a doctorate in education. The last respondent group comprised students who volunteered to participate in the pilot survey, with inclusion criteria limited to those preservice mathematics teachers and engineering students who had experienced VR in learning mathematics. In the data quality audit, we eliminated four responses due to failing to pass the sincerity test. The homogeneity of the response was evaluated using standard deviation, where a standard deviation of zero means that all responses are insincere, based on the brain operations process as explained by Tourangeau et al. (2000), through which the variation in response length suggests such engagement to be legitimate, as it results from cognitive effort and processing. Then, a total of 138 responses were deemed suitable for analysis. The demographic characteristics of the final participant cohort are presented in Table 1.

Table 1
Demographic Characteristics

Category		Total, *N*=138	
		n	%
Sex			
	Male	46	33.33
	Female	92	66.67
Year Level			
	Freshman	34	24.64
	Sophomore	36	26.09
	Junior	61	44.20
	Senior	7	5.07
Age			
	18-19	37	26.81
	20-21	81	58.70
	22-23	20	14.49

3.2 Ethical Review Clearance

This study received institutional ethics review clearance on April 18, 2024. The research processes and data collection were classified as "exempted" for low risk. To protect all participants ' rights and well-being, the research team remained fully committed to upholding ethical standards, including interviews, surveys, data analysis, reporting, and publication. Participants received detailed information about the study's purpose, procedures, potential risks and benefits, confidentiality, and privacy. The research team upholds these ethical standards from data collection to analysis, reporting, and publication.

4. Scale Development

4.1 Phase 1: Dimension Identification through Literature Review

To establish baseline dimensions of users' experiences using VR, the authors generated an initial pool of items from a thorough review of academic literature and existing constructs and focused group discussion. The FGD was participated in by the ten students who were asked to share their experiences using VR in learning mathematics. The initial pool contained items and constructs designed to measure users' VR experiences in higher education while learning mathematics. After establishing the initial pool, dimensions, and indicators that could not be directly applied to the VR usage were removed.

4.1.1 Narrative Literature Review

A narrative literature review is a descriptive approach to summarizing and interpreting existing research to provide an overview of a topic and identify key dimensions or themes within it (Green et al., 2006). In this study, the review focused on capturing dimensions of users' experiences and challenges in using VR for learning. The goal was to develop a narrative review to inform the dimensions and indicators of a measurement tool.

Table 2

Dimensionality Identification through Narrative Literature Review

Dimensions	Sources	Type	Publisher
Immersive Learning	(Kuhail et al., 2022)	Journal Article	MDPI
	(Aguayo & Eames, 2023)	Journal Article	Taylor & Francis
	(Hurrell & Baker, 2021)	Journal Article	Taylor & Francis

	(Sanfilippo et al., 2022)	Journal Article	MDPI
Pedagogical Issues	(Çakıroğlu et al., 2024)	Journal Article	Taylor & Francis
	(Geng et al., 2021)	Journal Article	Taylor & Francis
	(Cevikbas et al., 2023)	Journal Article	MDPI
	(Sanfilippo et al., 2022)	Journal Article	MDPI
	(Cardullo & Wang, 2022)	Journal Article	Springer
	(Hagge, 2021)	Journal Article	Taylor & Francis
User Acceptance	(Huang, 2013)	Journal Article	Taylor & Francis
	(Cabero-Almenara et al., 2021)	Journal Article	MDPI
	(Sagnier, 2020)	Journal Article	Taylor & Francis
	(Sanfilippo et al., 2022)	Journal Article	MDPI
	(Aburbeian et al., 2022)	Journal Article	MDPI
User Perspective	(Sanfilippo et al., 2022)	Journal Article	Taylor & Francis
	(Marikyan et al., 2019)	Journal Article	Elsevier
	(Hagge, 2021)	Journal Article	Taylor & Francis
	(Cooper et al., 2019)	Conference Paper	Taylor & Francis
User Validation	(Cevikbas et al., 2023)	Journal Article	MDPI
	(Huang et al., 2023)	Journal Article	Taylor & Francis
	(Kamińska et al., 2019)	Journal Article	MDPI
	(Özçakır & Özdemir, 2022)	Journal Article	Taylor & Francis
	(Nesenbergs et al., 2020)	Journal Article	MDPI

Table 2 presents the final list of references, the selection of which is based on their credibility and reputation in reputable journals and publishers.

The literature review identified five potential dimensions of users' experiences and challenges in using VR. These dimensions include immersive learning, pedagogical issues, users' acceptance, perspective, and validation. From the concepts mapped in Table 2, we establish the dimensionality of users' experiences and challenges in using VR.

4.1.2 Qualitative Triangulation and Dimension Reduction

The focus group included six preservice teachers specializing in mathematics education, who revealed discerning perspectives on VR integration in mathematics education. Participants shared their experiences using VR, offering reflection dimensions and possible indicator systems to measure the construct. Their responses present recurring themes, which were analyzed for word frequency using NVivo Pro version 11 software. The analysis consistently aligned with the proposed dimensions, confirming their relevance as latent constructs. Table 3 summarizes the node analysis, which shows that the nodes were linked to the five identified dimensions of VR users' experiences and challenges. The qualitative interviews conducted with our focus group led to the identification of key dimensions for VR integration in education. Utilizing NVivo software, we analyzed the data and generated dimensions of the core themes. A word cloud was created from the interview responses to visualize the frequency and relevance of terms, providing insights related to VR adoption. The five identified dimensions, "user perspective, user validation, user acceptance, immersive learning, and pedagogical issues," align with the existing constructs found in the literature. These dimensions are essential in assessing the readiness of individuals to adopt VR as a tool for enhancing learning.

Additionally, we overviewed the nodes, sources, and references identified within each dimension, providing substantial information about the scope and depth of research coverage in various fields. Table 2 shows the summary of the node analysis. An investigation of research dimensions about using VR in education is presented in Table 2. It shows an overview of the nodes, sources, and references identified within each dimension, providing substantial information about the scope and depth of research coverage in various fields. The initial five dimensions examined are immersive learning, pedagogical issues, user acceptance, user perspective, and user validation.

Table 3

Summary of Node Analysis

	Summary		
Dimension	***Nodes***	***Sources***	***References***
Immersive Learning	48	10	783
Pedagogical Issues	44	10	795
User Acceptance	48	10	777
User Perspective	54	10	868
User Validation	46	10	774

Table 3 summarizes node analysis from a qualitative study focusing on various dimensions of VR user experiences and challenges. The analysis highlighted five key dimensions. We identified specific subcategories (nodes) for each dimension, the number of sources we used, and how often the data appeared in those sources. This study explored both the conceptual and operational sides of the topic. Using NVivo, the node is a category that groups the related data from interviews and transcripts. Each central theme identified as a dimension in this study was broken down into several nodes or subcategories. It indicates that the number of nodes for each dimension tells us how detailed the analysis was. For the sources, it employs a consistent dataset of ten sources that includes transcripts of the interviews to ensure a fair comparison. The references showed how often the data relates to each dimension in the sources. The higher the number of references, the more frequently the data was mentioned and discussed.

Within the dimension of Immersive Learning, the findings show a strong foundation comprising 48 nodes, supported by 10 sources and 783 references. This indicates the profound and multifaceted literature that upholds immersive learning experiences facilitated by VR technology in the context of mathematics. The Pedagogical Issues dimension encompasses 44 nodes, 10 sources, and 795 references, emphasizing the importance of addressing educational challenges and opportunities within mathematical learning environments of VR technology. Subsequently, User Acceptance, where 48 nodes, 10 sources, and 777 references are identified, shows the essence of understanding end users attitudes and perceptions when integrating VR technology into learning. The User Perspective dimension, consisting of 54 nodes, 10 sources, and 868 references, highlights users' diverse viewpoints and experiences when engaging with VR in mathematical learning contexts. Lastly, the User Validation dimension, consisting of 46 nodes, 10 sources, and 774 references, suggests an approach to verify the effectiveness and utility of VR-based mathematics learning experiences. All these dimensions create a broad narrative, highlighting the complexities of adapting and implementing VR technology. This study highlights the need for a holistic and user-centered approach to scale development and validation to address the crucial role of VR in transforming mathematical learning experiences. To sum up, the dimensions that have been described offer a framework for further investigation and advancement, explaining the constantly changing field of VR technology in education and indicating a paradigm shift in favor of immersive and user-focused teaching methods.

Before using VR headsets, respondents offered insightful views about how VR technology could change the nature of education. Based on their pre-experience perspectives, participants showed their understanding of VR, which indicates that they were aware of the immersive qualities of this technology. Respondent 6 suggested that *"VR technology might be used to create realistic learning environments by allowing users to understand and interact with the virtual environment as if it were real."* Respondent 2 also explained that *"VR brought us into a virtual math world where users can explore geometric forms and solve mathematical challenges."* Respondent 4 pointed out that VR worked by *"displaying 3D images that made you feel like you were in another place,"* implying that dynamic and immersive learning environments might be created with it, regarding the incorporation of VR in learning. Respondent 5 expected it would improve student and teacher interaction and enhance learning outcomes. Furthermore, Respondent 6 expressed the expectation that *"VR will facilitate understanding and learning complex concepts more easily*," highlighting the potential of VR to break down learning challenges and excite students. Based on the overall expectations of the respondents, VR will transform mathematics education by offering immersive, dynamic, and engaging learning opportunities that support a variety of learning preferences and styles.

Contrary to what they expected, the respondents' firsthand experiences with VR gave them concrete insights into the possibilities of integrating this technology in teaching mathematics. *"Learning 3D math is much easier with the help of technology, especially using VR,"* said Respondent 1, giving insights the ease of using VR for self-directed learning. This statement highlights the practicality and efficacy of VR for independent study. *"VR experience changed the way I understood things,"* said Respondent 2, emphasizing the immersive experience and enhanced comprehension of mathematical ideas made possible in VR learning environment. Respondent 3 agreed, emphasizing the accessibility and clarity of VR-enhanced learning by pointing out that *"compared to traditional techniques, some topics in Math may be understood more easily with VR."* "*VR headsets brings a change because you can see the shapes right in front of you*," said respondent 4, confirming the visual clarity and interactive aspects, which suggests a higher degree of spatial cognition.

Moreover, respondents offered a balanced viewpoint on the pros and drawbacks of VR integration. They discussed issues like confusion and technical difficulties while recognizing benefits like increased engagement and motivation. In addition, participants highlighted the possibility of cooperative learning and interactive problem-solving within a VR environment. They also include some recommendations, such as enhancing internet connectivity, making information more individualized, and improving accessibility to increase the efficacy of VR technology in learning. These suggestions demonstrated an innovative approach to enhancing VR technology for educational purposes. Overall, respondents had good assessments regarding using VR in mathematics learning, which are the main advantages of improved comprehension, fun, and engagement.

4.2 Phase 2: Dimensions and Items Refinement for Pilot Testing

During the item generation process, the researchers seek advice and validation from four (4) experts. In the first revision, the initial dimensions included were Immersive Learning, User Perspective, User Validation, User Acceptance, and Pedagogical Issues. During the process, the dimension "User Perspective" was removed, as suggested by the experts, due to its broad scope, as it encompassed various aspects already covered by the other dimensions. In the second revision, we refined and improved the dimensions of Immersive Learning Experiences, User Acceptance, User Validation, and Issues. 'Immersive Learning' is given improvement and changed to 'Immersive Learning Experiences' so that this dimension will highlight the sensation of being part of the VR environment, and 'Pedagogical Issues' is changed to 'Issues' to encompass considerations beyond education, including cost and health implications. As for our item statements, we perform a three-round expert validation before achieving the concrete dimensions and final item statements, as shown in Table 3. The dimension reduction and improved dimensions suggested by the experts during the item generation process aid in creating more precise survey item statements.

With the three-round expert validation shown in Table 3, in the first round, experts examined the initial 40 items suggested for the scale. The validation come up with revisions of the items. In the first round, 21 items undergone major revisions. In round 2, experts identified accepted items with 12 required minor revisions. Forty items were accepted in the final round as shown in Table 4.

Table 4

Three-Round Expert Validation Summary

Dimensions	1st Round			2nd Round			3rd round		
	Accepted	Rejected	Revise	Accepted	Rejected	Revise	Accepted	Rejected	Revise
Immersive Learning Experiences (ILE)	7	0	3	8	0	2	10	0	0
User Acceptance (UA)	5	0	5	6	0	4	10	0	0
User Validation (UV)	6	0	4	8	0	2	10	0	0
Issues (I)	1	0	9	6	0	4	10	0	0

To establish construct validity, the pool of items was tested on VR headset users to identify the key components that underlie the measurement tool. The number of observations per variable in this study met the desired ratio of 5:1 recommended by Hair et al. (2014). This phase presents the preliminary analysis of the dimensions by testing their correlations and descriptive statistics to ensure that the initial variables have a good internal consistency by analyzing Cronbach's alpha. An exploratory factor analysis (EFA) was conducted to reduce the dimensions and items using the IBM Statistical Package for the Social Sciences (SPSS).

4.2.1 Preliminary Analysis

Before conducting the primary analysis for dimension reduction, we examined the zero-order correlation table to gain insights into the relationships between the identified variables for inclusion in the following analysis. This statistical method is ideal for assessing the strength and direction of linear relationships between two variables. All the variables are measured on continuous scales using a revised initial pool of items after the expert's review. Zero-order correlation helps quantify the degree to which these variables co-vary, which provides insights into how changes in one variable might relate to changes in another. Table 4 presents the zero-order correlations, identifying potential associations and guiding decisions regarding factor structures. All relations observed in the zero-order correlation analysis are statistically significant except the ISS, highlighting the strong connections between ILE, UA, UV, and ISS. The significant positive correlations emphasize the interconnectedness of these variables and their collective influence on VR users' experiences. This enhances the study's validity and theoretical coherence (Hair et al., 2010). The internal consistency was measured using Cronbach's alpha. The results demonstrated high reliability across all sizes. Specifically, the ILE has a Cronbach's alpha of 0.892, indicating excellent internal consistency. The UA showed an even higher reliability with a Cronbach's alpha of 0.942. Similarly, the UV was highly reliable, with a Cronbach's alpha of 0.928. Lastly, Iss exhibited good internal consistency with a Cronbach's alpha of 0.872. All indices reflected good to excellent evaluation. While statistically significant, none of the correlation coefficients approach values close to 1. This suggests that the variables are reasonably distinct (Schober et al., 2018), providing initial information on the low risk of multicollinearity.

Table 5

Zero-order correlations and descriptive statistics of the initial study variables

Study variables	1	2	3	4
1. ILE	1	.652**	.702**	.188*
2. UA	.652**	1	.841**	0.109
3. UV	.702**	.841**	1	.222**
4. ISS	.188**	0.109	.222**	1
Mean	6.1283	5.8645	5.9797	5.5616
Standard Deviation	0.68455	0.89343	0.78982	0.86828

The zero-order correlations between the initial study variables, shown in Table 5, do not yield statistically significant results. However, it is important to realize that a lack of significant results does not always indicate no connection between the variables. The correlation between ILE Ave and ISS Ave indicates a positive relationship, even though it is not statistically significant ($r = 0.188$, $p > 0.05$).

4.2.2 Exploratory Factor Analysis

Due to some interrelated data to be extracted in the initial pool of dimensions and items, we define the structure behind the relationships of constructs included in the study using EFA (Hair et al., 2014). The analyses were done using principal component analysis in IBM SPSS 24. The EFA results and reliability indices, by Cronbach's alpha, are presented in Table 5. Fit measures and factor loadings were evaluated based on the following: the Kaiser–Meyer–Olkin (KMO) value must be >0.80 (highly satisfactory), Bartlett's test of sphericity must be significant at the 0.05 alpha level, factors with eigenvalue <1.0 should be deleted, communality value should not drop for less than 0.30, and the factor loading for each item must be >0.50 (Hair et al., 2010).

The EFA procedures removed the UV dimension with all its items due to cross-loading, and items ILE8 and ISS10 were removed due to low factor loading and low communality indices. After removing the dimension and items, the results showed that the values of the factor loading range from 0.506 to 0.963, which indicates that the factors included in the study are considerably important. The KMO value for the model was highly satisfactory at 0.860, with Bartlett's test of sphericity of 2688.447 (significant at $p < 0.01$). Using promax rotation, we found three factors with eigenvalues from 4.042 to 8.273. Cronbach's alpha showed high measures ranging from 0.872 to 0.942, demonstrating adequate reliabilities (Hair et al., 2014). The final set of items retained for the confirmatory factor analysis (CFA) is presented in Table 6.

Table 6
EFA results

Factor	Item	1	2	3	Communality	Eigenvalue	α
Immersive Learning Experience	ILE1	0.790			0.551	8.273	0.892
	ILE2	0.710			0.496		
	ILE3	0.589			0.468		
	ILE4	0.650			0.428		
	ILE5	0.538			0.426		
	ILE6	0.773			0.520		
	ILE7	0.591			0.336		
	ILE9	0.640			0.464		

	ILE10	0.708			0.483		
User Acceptance	UA1		0.506		0.482	7.678	0.942
	UA2		0.547		0.615		
	UA3		0.709		0.672		
	UA4		0.544		0.613		
	UA5		0.577		0.596		
	UA6		0.811		0.636		
	UA7		0.963		0.771		
	UA8		0.790		0.696		
	UA9		0.939		0.702		
	UA10		0.878		0.708		
Issues	Iss1			0.561	0.322	4.042	0.872
	Iss2			0.546	0.315		
	Iss4			0.652	0.439		
	Iss5			0.817	0.660		
	Iss6			0.796	0.644		
	Iss7			0.834	0.713		
	Iss8			0.697	0.525		
	Iss9			0.603	0.408		

4.2.3 Construct Validation

This construct validation study replicated the data collection procedure in the item purification phase. A Confirmatory Factor Analysis (CFA) was performed on 138 VR headset users to test the scale using IBM SPSS Amos 21.0. The factor structure demonstrated the best model fit and reliability estimates of the three dimensions examined. The CFA included one hundred thirty-eight valid responses to confirm the model's validity. Reliability was assessed by calculating the CR, which measures the proportion of actual variance relative to the total score variance. CR values above 0.7 are considered good (Hair et al., 2017). During the validation, items ILE 1, 2, 7, 9, 10, UA 1, 2, 4, and Iss 1, 2, 4, 9 were eliminated due to low factor loadings below 0.7 (Hair et al., 2010) to help achieve an acceptable model fit. Figure 3 presents the standardized path diagram for the three-factor structure, while Table 7 outlines the standardized loadings, composite reliability (CR), and average variance extracted (AVE).

Figure 3
A Factor Structure Model of the Scale

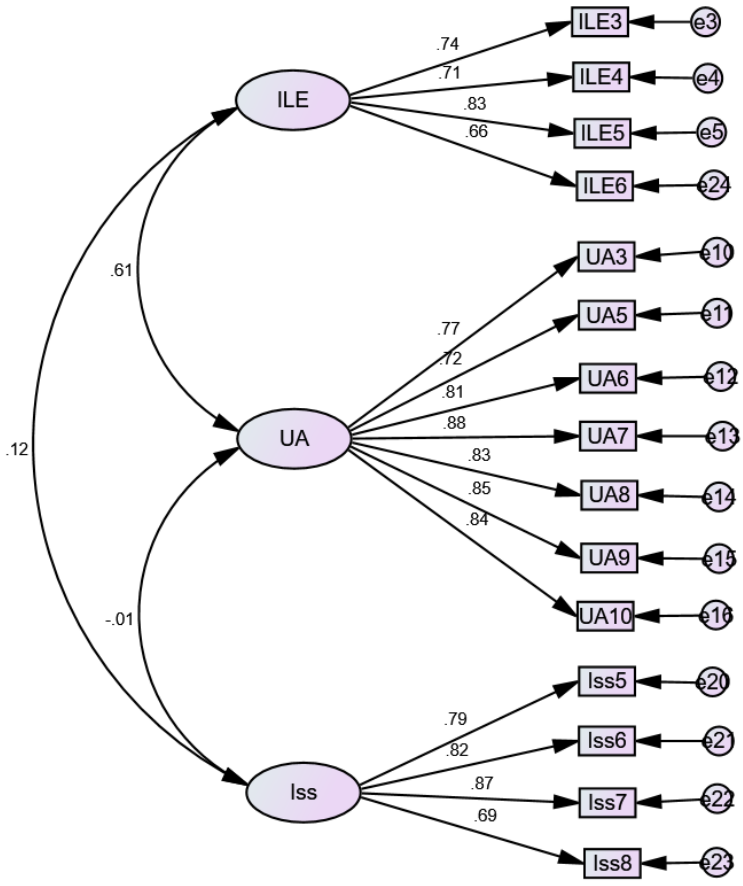


Table 7
Model Fit Indices

Fit Index	Recommendation	Estimates
x^2/df	<3.000	1.602
RMSEA	≤ 0.070	0.066
SRMR	≤ 0.080	0.054
GFI	≥ 0.900	0.892
AGFI	≥ 0.900	0.851
TLI	≥ 0.900	0.949
CFI	≥ 0.900	0.958
IFI	≥ 0.900	0.958
NFI	≥ 0.800	0.897

Table 7 reveals that all model fit indices needed to establish the validity of the final model were satisfactory. The $\chi 2/\mathrm{df}$ ratio (1.602) is below the threshold value of 3, suggesting that the observed data fit the proposed model reasonably well (Kline, 2011). The RMSEA (0.066) is below the threshold value of ≤0.070 (Steiger, 2007), and the SRMR (0.054) is below the threshold value of ≤0.080 (Brown, 2006). The GFI (0.892) and AGFI (0.851) indicate a marginal fit, indicating an acceptable model (Hu & Bentler, 1999). The CFI (0.958) was above the threshold value of 0.9, indicating excellent fits despite the marginal fit GFI since it holds closer results and other fits surpass the threshold values, signifying that the proposed model accurately represents the relationships among the variables in explaining the observed data. The TLI (0.949) and IFI (0.958) hold the ≥ 0.900 (Hu & Bentler, 1999), and the NFI (0.996) holds the ≥ 0.800 (Hooper et al., 2008), respectively. The standardized difference between the observed and model-implied covariance matrices is acceptable, and the model comprising the identified dimensions provides a close fit to the observed data (Kline, 2011).

Table 8
CFA results of the final measurement model

Construct	Item	Standardized loadings	CR	AVE	α
Immersive Learning Experience	ILE3	0.735	0.825	0.543	0.892
	ILE4	0.713			
	ILE5	0.830			
	ILE6	0.660			
User's Acceptance	UA3	0.770	0.873	0.633	0.942
	UA5	0.717			
	UA6	0.806			
	UA7	0.881			
	UA8	0.829			
	UA9	0.846			
	UA10	0.843			
Issues	Iss5	0.792	0.873	0.634	0.872
	Iss6	0.821			
	Iss7	0.875			
	Iss8	0.685			

Reliability was assessed by computing composite reliability (CR), the total amount of actual variance concerning the total score variance. Composite reliabilities above 0.7 are considered good, and values between 0.6 and 0.7 are acceptable (Hair et al., 2017). The results support reliability as each composite reliability for each factor was greater than 0.7 (Table 7). The Confirmatory Factor Analysis (CFA) results show strong validity and reliability for the final measurement model's Immersive Learning Experience, User Acceptance, and Issues constructs. For the Immersive Learning Experience construct, standardized loadings varied from 0.653 to 0.740, with an average variance extracted (AVE) of 0.492 and a composite reliability (CR) of 0.886. The high CR and Cronbach's alpha (α = 0.892) demonstrate good internal consistency and reliability, even though the AVE is slightly below the 0.5 threshold. The User's Acceptance construct demonstrated even better findings, indicating excellent reliability and convergent validity with loadings ranging from 0.761 to 0.883, a CR of 0.930, an AVE of 0.690, and an alpha of 0.942. The Issues construct yielded acceptable results, displaying loadings ranging from 0.638 to 0.860, with a composite reliability (CR) of 0.883, average variance extracted (AVE) of 0.561, and an alpha of 0.872. These findings indicate that the measurement model is strong because all components show good convergent validity and high reliability. Given the satisfactory CR values above 0.7 for all constructs, we concluded that our model achieves strong convergent validity, thereby proving the integrity of the theoretical framework of our research study.

4.2.4 Convergent and Discriminant Validity

Convergent and discriminant validity are established by assessing the patterns of correlation among factors (Tabachnick et al., 2007). Convergent validity can be evaluated by inspecting the factor loadings, which should be statistically significant and greater than 0.5, ideally higher than 0.7 (Hair et al., 2017). All standardized loadings were statistically significant and were above the threshold of 0.5, providing evidence of convergent validity (Table 8). Convergent validity can also be evaluated by examining the average variance extracted (AVE), the variance in the observed variables explained by the latent construct. The threshold vale AVE is greater than 0.5. (Hair et al., 2017). Given the fact that all the CRs are satisfactory and above 0.7 (Table 8), the authors concluded that convergent validity was achieved.

Table 9

Square root of AVE and inter-correlations - CFA

	1	2	3
Immersive Learning Experience	**0.737**		
User Acceptance	0.611	**0.796**	
Issues	0.121	-0.010	**0.796**

Discriminant validity is established by demonstrating that the square root of the AVE is greater than the correlation coefficients (Hair et al, 2017). Table 9 illustrates that the values of the square root of the AVE are all larger than the correlation coefficients. This result supports the discriminant validity of the measurement model.

4.2.5 The Final Item Indicators of the Scale

Table 10 presents the final version of the IVRLS, including all validated items and their corresponding dimensions.

Table 10

The Final Immersive Virtual Reality Learning Scale (IVRLS)

Items	Immersive Learning Experiences
ILE3	The use of immersive virtual reality allows learners to simulate real-world problem-solving scenarios (e.g., mathematics).
ILE4	Virtual reality provides simulations with immediate feedback, enabling me to learn from my errors.
ILE5	A hands-on experience provided by virtual reality environments helps learners improve their retention of lessons.
ILE6	Virtual reality gives dynamic learning experiences designed to meet specific needs.
	User Acceptance
UA3	I am open to incorporating virtual reality into my regular learning routine.
UA5	Virtual reality has been a beneficial addition to my learning style.
UA6	I am willing to invest time learning how to use VR headsets for learning.
UA7	I will adapt my learning habits to incorporate virtual reality into my studies (e.g., mathematics).
UA8	I am excited about the possibilities of virtual reality in transforming how I learn.
UA9	I am eager to embrace virtual reality technology to enhance my learning experience.
UA10	I recommend integrating virtual reality to create an engaging learning environment.
	Issues
Iss5	Virtual reality headsets may lead to eye strain or discomfort.
Iss6	Virtual reality headsets could contribute to fatigue among students.

Iss7	Virtual reality headset usage in learning (e.g., mathematics) might cause motion sickness and other health conditions.
Iss8	Integrating virtual reality into learning may incur additional costs.

5. Discussion

Measuring users' experiences using VR headsets in learning can identify students who are progressing in class, are at risk of handling new technology, and need additional assistance. Using VR headsets in learning mathematics can be valuable for assessing student progress and potential challenges in adapting to new technology. By tracking how individuals interact with VR-based learning, educators can identify students who excel in the virtual environment and those who may struggle with the technology, requiring additional support. Specialized instruments have been designed to capture VR users' perspectives, experiences, and learning outcomes when using VR tools in mathematics.

This study shows that users' perspectives and experiences in using VR headsets in learning mathematics are influenced by three components: immersive learning experiences, user acceptance, and issues. Consistent with the previous literature, learning experiences brought by VR environments can facilitate constructivist learning by providing learner-centered conditions that make learning more flexible and give students a unique learning experience (Papanastasiou et al., 2019). In the user acceptance of VR environments component, students exhibited interest and engagement when learning mathematical topics through VR exercises. They also discovered that teachers believed VR technology was an effective tool to help students grasp abstract mathematical ideas better, raising their interest and motivation to study the subject (Su et al., 2022). The emergence of technology brought a massive change in assisting people in their daily lives, but it also brought devastating issues that need to be overcome. VR has gathered attention as a potential tool for enhancing mathematics education due to its immersive and interactive nature; however, its implementation raises concerns regarding health, pedagogical efficacy, and financial costs. Extended exposure to VR can induce symptoms like nausea, eyestrain, and headaches, particularly among susceptible individuals (Nichols & Patel, 2002).

The current study has made a theoretical contribution by conceptualizing VR users' experiences and challenges in learning mathematics as having three discrete dimensions and empirically testing this theoretical assumption by developing a scale. There is a general lack of multidimensional instrumentation for measuring VR users perceptions. VR technology can integrate mathematical geometry concepts into the content, allowing students to use the VR immersive mathematics geometry system (Su et al., 2022). They highlight that students can immerse themselves in the content-learning process of mathematics. Students are expected to be motivated and inspired to take the initiative to learn.

Teachers and researchers can use the scale as a diagnostic and assessment tool. To optimize engagement and learning outcomes, educators can use the scale's results to guide their judgments on how best to teach, such as identifying students who might require different support methods or customizing VR exercises. Developers can use the scale's three dimensions to design or refine VR learning applications that are pedagogically effective, user-friendly, and inclusive. To integrate the scale into practice, (1) in curriculum design, educators can administer the scale during pilot implementations of VR lessons to gather student feedback and refine lesson plans accordingly; (2) in technology evaluation, schools or educational institutions can use the scale during beta testing phases of VR tools to assess user acceptance, identify usability issues, and determine whether the immersive learning objectives are being met, and (3) in teacher training, the scale can be embedded as part of professional development workshops, enabling teachers better to understand the dynamics of student interaction with VR and adapt their teaching strategies accordingly.

In policy or procurement decisions, education stakeholders can employ the scale as evidence for selecting VR technologies that align with pedagogical goals and learner needs. This study provides actionable knowledge for future educational technology development and use by theoretically confirming that teachers and students can comprehend the VR learning experience through immersive learning, user acceptance, and technological challenges.

6. Conclusion

Given the growing use of virtual reality in education, there is a need to better understand learners' experiences with this technology. This study develops and validates a multidimensional scale to assess user experiences with virtual reality (VR) in mathematics education. The methods included identifying the scale dimensions and item indicators through a literature review and focus group discussion (FGD), validating the items with four experts, revising the items based on expert feedback, and establishing the psychometric properties through exploratory and confirmatory factor analyses.

The Immersive Virtual Reality Math Learning Scale (IVRLS) was developed in this study - a 15-item instrument comprising three dimensions: immersive learning experiences (4 items), user acceptance (7 items), and issues (4 items). The scale offers a reliable tool for evaluating VR-supported learning. Findings demonstrate high reliability and validity of the constructs, indicating that the scale effectively captures student engagement, acceptance, and potential issues in using VR for learning. The development of IVRLS represents a step in the theoretical development process related to VR usage and technology adoption. The results identified key dimensions that help both users and educators integrate this technology into teaching and learning. The study contributes to VR research by providing a validated multidimensional scale for assessing VR learning environments, helping educators and researchers optimize VR use in education (e.g., mathematics) to improve student engagement and learning outcomes.

7. Declaration of AI-assisted technologies in the writing process

The author used generative artificial intelligence (GenAI) to improve language fluency and readability. All content generated with the assistance of the tool was subsequently reviewed and edited by the authors, who assume full responsibility for the final version of the published article.

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