Enhancing Self-Efficacy of Chinese Secondary STEM Students through Virtual Reality Assisted Teaching: The Mediating Role of Spatial Ability

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ABSTRACT

This research seeks to determine the effect of VR-assisted teaching on students' self-efficacy, special emphasis on immersion, interactivity, and realism. In this context, the student's spatial ability and learning motivation are examined as moderators in this relationship. The quantitative research methodology was combined with a questionnaire, while the qualitative part was derived from participants' feedback. Thus, studies show that a vast level of improvement in self-efficacy through engagement, conceptual understanding, and increased autonomy in learning is brought by the incorporation of features of virtual reality. This research area is valuable for educational technology because it establishes that VR can enhance student's confidence and motivation in students. Further research studies must consider more long-term impacts and less limited education settings.

Keywords—VR-assisted teaching, Self-efficacy, Immersion, Interactivity, Realism, Spatial ability, Learning Motivation.

INTRODUCTION

One sector in which the introduction of VR technology has altered is the education sector because it provides learning experiences. In STEM education, concreteness and complexity of educational content are strong factors that make it difficult for students to understand. VR, as a mediator, is considered a valuable tool for improvement. With the help of VR, students cannot only view the material and study the phenomena observed but also affect the phenomenon in a way that is impossible with other teaching methods. Hence the adoption of including VR in the secondary school's educational curriculum has received considerable attention to increasing the appeal of STEM education to maintain the standard of competition in technological enhancement in China (Wang & Zhou, 2024). However, with the application of VR in teaching, there is hopeful agreement on the benefits thereof. However, the authors are concerned about the impact of self-efficacy among students when using VR in teaching. Self-efficacy, the perceived capability to perform specific tasks, has been widely recognized as influential in academic performance (Chen & Chu, 2024). Higher levels of self-efficacy also suggest a student's ability to commit substantial effort to learning activities, which are critical in STEM disciplines as they tackle various complexities.

Despite the various benefits of using VR in teaching, several factors limit the use of VR-assisted teaching in Chinese secondary schools. Specifically, one significant issue is whether the implementation of VR in learning increases students' confidence; however, it is used as an appealing tool for learning with little, if any, impact. Though the construct of immersion seems to improve motivation and interest for students in a physically distanced environment, the relationship between the two is not clear as it relates to self-efficacy (Li et al., 2024). Also, the active nature of VR lessons, in which learners can change the position of objects or interact with them and get feedback instantly, is thought to impact learners' achievements positively. However, it is still necessary to investigate whether such interactivity supports achieving the second principle of competence and mastery in students. Realism is another element of VR-assisted teaching that is thought to help close the gap between theory and practice since the applications in question are based on real-life simulations (Serna-Mendiburu & Guerra-Tamez, 2024). While the study's author acknowledges that realism in educational VR experiences can enhance the conception of constructs, research has not determined how practically the variable affects self-efficiency among Chinese secondary STEM students.

Another research question related to the effectiveness of the approach explored is the influence of VR-assisted teaching on students' spatial skills and learning motivation. Spatial ability, defined as the ability to rotate objects mentally, is also one of the predictors relevant to STEM disciplines, including physics, engineering, and mathematics. Previous studies confirm that VR can improve spatial ability; however, its ability to mediate self-efficacy is still uncertain (Liu et al., 2024). Similarly, Teaching motivation, which is perceived as the extent of students' interest and commitment to accomplish academic work tasks, is said to be enhanced by VR-assisted teaching. Nevertheless, one can still raise the question of how the influence of motivation on the specified connection depends on VR experiences. Based on such gaps, this research seeks to establish the impact of immersion, interactivity, and realism in STEM education with the aid of VR on the self-efficacy of Chinese secondary school STEM students while moderating the correlation between spatial ability and learning motivation.

Objectives

1. To examine the effect of the immersion of VR-assisted teaching (IV1) on the self-efficacy (DV) of Chinese secondary school students.

2. To analyze how the interactivity of VR-assisted teaching (IV2) influences the self-efficacy (DV) of Chinese secondary school students.

3. To evaluate the impact of the realism of VR-assisted teaching (IV3) on the self-efficacy (DV) of Chinese secondary school students.

4. To assess the mediating role of students' spatial ability (MeV1) in the relationship between VR-assisted teaching (IVs) and self-efficacy (DV).

5. To determine the mediating effect of learning motivation (MeV2) in the relationship between VR-assisted teaching (IVs) and self-efficacy (DV).

This study is important as it examines the impact of integrating Virtual Reality technology in teaching and the improvement of self-efficacy among Chinese secondary students majoring in STEM subjects. By contributing to the literature on the use of educational technology, the analysis of immersion, interactivity, realism, and their interaction with spatial ability and learning motivation will help educators, policymakers, and curriculum developers enhance the effective use of VR-assisted learning in STEMS education environments to increase student engagement and better achievement outcomes.

LITERATURE REVIEW

With the incorporation of Virtual Reality (VR) into the learning systems, it has received much interest from all over the world due to the effectiveness of the traditional learning process. Due to the fact that students who follow STEM disciplines experience difficulties in terms of learning abstract information, comprehension, involvement, and motivation, virtual reality applied to teaching can benefit students, teachers, and schools. Nevertheless, the values regarding students' self-efficiency are still vast and need to be further investigated more profoundly. Self-efficacy, one of the components of academic achievement motivation, enables students to overcome obstacles and learn problem-solving skills, according to Atal, Admiraal, and Saab (2024). Despite the fact that previous research proves the benefits of using VR in education, contributions of immersion, interactivity, and realism to self-efficacy are still not well investigated. Also worthy of further investigation are the mediating roles of spatial ability and learning motivation, as they were examined to a limited extent only in the current study. This research reviews the literature on studies using VR as a teaching medium. It identifies its impact on self-efficacy and mediators to provide a framework for the present study. This research has discussed how technological advancement in VR has influenced the educational sector to incorporate technology into the learning process. As noted by Yan and Lowell (2022), VR presents an effective way of teaching students, allowing them to learn without having to engage in a face-to-face learning environment. VR has been realized to have potential in STEM fields, where it is challenging to grasp abstract concepts due to the complexity involved in the courses. For instance, Yu and Duan (2024) noted that students who used VR perceived better and comprehended more information than those who used conventional ways of learning. On the same note, Liu et al. (2024) established that due to its inherent characteristics, VR always offers an opportunity to experiment, visualize, and manipulate real objects, enhancing logical understanding. However, the overall potential of VR has been recognized in learning matters. However, regarding learners' self-efficacy, there is limited research on how specific characteristics of VR bring about confidence in learning.

Immersion is unique to VR and can be described as the extent to which the user feels situated within the virtual environment. To the same effect, Ruan (2022) insisted that immersion in VR is realized through applications such as sensory, spatial, and interactive involvement that thus fosters and expands user experience. According to the theoretical assumption of consumers, highly anchored aspects of VR can lead to enhanced student motivation as well as engagement, which, in turn, can lead to a positive outcome in self-efficacy. According to Cai (2022), applying VR supported learning increases positive beliefs about first-order learning of concepts and ensures students have control over learning processes. Tai, Chen, and Todd (2022) established that students who took the immersive VR lessons attained higher boosts in their confidence when performing experiments in science, especially in physical and chemical experiments. Many researchers also posit that immersion in a particular subject will enhance learning motivation although they indicate that too much of immersion decreases the learning impact due to cognitive overload (Seufert et al., 2022). Hence, this study aims to establish the right immersion level that will increase self-efficacy, not by overstressing the students.

The last characteristic of VR-assisted teaching is its interactivity, which enables students to engage with objects and environments modeled in the virtual space. Based on the study done by Huai et al. (2024), it was found that VR-assisted teaching enhances learning activities by fostering interactivity, which actively engages learners rather than positioning them as passive recipients of information. Active learning has been positively linked to self-efficacy, as students who participate in meaningful tasks tend to feel more competent in performing them. According to Luo, Gao & Liu (2022), the usage of IVR in training enables a student to practice for different outcomes and receive feedback promptly. Similarly, Wang et al. (2023) established that those students who engaged with interactive VR tools had better self-efficacy in Mathematics as compared to the students who engaged with statically presented digital tools. However, it is important to note that this is not always positive as many times, it is likely to create distractions and unnecessary complications which can hamper learning outcomes, as per Zhou, Thompson & Zhou (2024). Since the findings presented above are mixed, the purpose of this study is to examine the extent of the effect of interactivity on students' self-efficacy as well as if there is a difference between forms of interactivity.

The incorporation of realistic environments is frequently highlighted as a critical factor in the effectiveness of VR for learning. Realism refers to the extent to which realistic elements are integrated into the virtual environment, allowing students to perceive their experiences as closely aligned with real-world scenarios. According to Wang et al. (2024), the synthesis effect is achievable through the use of realistic VR environments as such make the connection between concepts and practice. In STEM education, where certain experiments may be too dangerous or costly to conduct in traditional settings, VR offers a viable alternative for practical learning. Lei et al. (2022) observed that adopting students to realistic VR representations of molecular structures enhances the spatial stability and competence of those learners in the teaching practice of theoretical knowledge. However, some authors acknowledge the fact that realistic simulations cannot always be a plus, as the learner is immersed in an experience that they state is distracting from the learning goals and objectives stated by Hong et al. (2022). Based on these different approaches toward realism, the purpose of this study is to assess the level of self-efficacy that realism fosters when teaching and if the nature of the content influences this self-efficacy. Mental imagery, or the ability to reason and perform operations on the mental images of objects, is a critical factor in STEM education. Many studies have argued and evidenced that spatial visualization ability is related to students' achievement, especially in physics, engineering, and mathematics,

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as per Jiang et al. (2022). There has been some evidence that identified the prospect of increased spatial ability as one of the benefits of using VR as a way to do modeling since it enables the students to manipulate the objects physically; and, therefore, to understand the relations between them better, commented by Wang & Pan (2023). Nevertheless, spatial ability's role in the relationship between VR-assisted teaching and self-efficacy was not explored for these programs in this study. According to Ran et al. (2022), the mediating effect is likely among students with high spatial ability and high confidence in STEM subjects. This research identifies and finds out if the students' spatial ability will mediate the effect of VR-assisted teaching on the students' self-efficacy and whether the low spatial ability students will benefit more from the VR interventions.

Altruistic self-efficacy is another teaching factor that can mediate between VR-assisted teaching and learning motivation. Self-motivation has been a factor seen to have a great influence on academic performance since it helps students to work harder when faced with difficulties in the study of Kong and Yasmin (2022). It was proposed that VR enhances motivation by providing an element of fun in learning, as per Man et al. (2024). However, how exactly motivation fulfills the role of a mediator between VR and self-efficacy has been partially revealed. Another research by Wang & Zhou (2024) established that the students who completed the VR-assisted learning activities had higher motivation and self-confidence than the ones who had to follow traditional practices. However, other researchers have warned that simply enhancing self-efficacy through motivation cannot complete the pattern; other cognitive and affective factors should be considered, according to Chen and Chu (2024). Specifically, this study will explore if increased motivation due to the use of VR in teaching results in higher self-efficacy for varied sets of levels of learning, if there exists a significant difference between self-efficacy levels of students with an active level of learning. Despite these insights, the overall impact of incorporating VR into STEM education on students' self-efficacy remains inconclusive. While Li et al. (2024) have discussed the roles of immersion, interactivity, and realism, previous studies have not clearly delineated how each of these factors individually influences the self-efficacy of participants. This study seeks to address this gap by examining the distinct effects of these VR characteristics on students' self-efficacy. Additionally, the roles of spatial ability and learning motivation have garnered significant attention, prompting suggestions for further research. By addressing these gaps, this study aims to contribute knowledge on the extent and mechanisms through which self-efficacy can be enhanced via VR-assisted teaching among Chinese secondary STEM students, ultimately improving teaching and learning practices.

Conceptual Framework

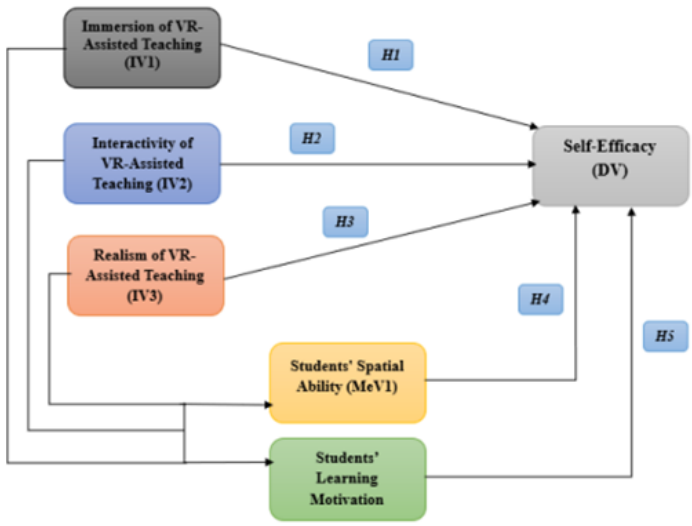

Fig 1. Conceptual Framework

Figure 1 has presented the conceptual framework which has been proposed for analyzing the impact of the teaching elements that incorporate VR, and students' self-efficacy will be regarded as both direct and moderating factors, with students' spatial ability and learning motivation as mediators. IVs are important factors in VR, and each of the IVs contributes to the improved learning experience of the students in the learning process. It is assumed that these factors would directly increase self-efficacy (H1, H2, H3) and

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indirectly by way of interaction with spatial ability (H4) as well as learning motivation (H5). This shows how all the proffered dynamic attributes of VR enhance the knowledge retention aspect and the student's confidence level, making the model a holistic model that comprehensively captures the effect of using VR in facilitating teaching.

RESEARCH METHODOLOGY

The research method used in this study involves using quantitative and qualitative data collection instruments to gather information that would enable a comprehensive understanding of the effects of teaching with VR on students' self-efficacy. A quantitative study has been carried out in the form of a survey incorporating a Likert scale with a total of 150 participants to measure the levels of immersion, interactivity, realism, and spatial ability (Harefa et al., 2023). It has also been necessary to take a broad overview of the student experience to make statistical generalizations and to find out whether there was any causal link between the two variables. Adopting a Likert scale facilitated responses from participants, which subsequently simplified the measurement of study variables (Robinson, 2024). In addition, primary explorative interviews were carried out with five participants. This approach was adopted to gain greater insight into how students feel towards VR-assisted learning, wherein information is inaccessible through a quantitative approach. The qualitative interview format provided vivid accounts of how students engage with immersive VR environments and how these experiences positively boost their confidence and motivation (Calvert & Hume, 2022). Mixing both qualitative and quantitative approaches enabled the study to respond satisfactorily to the issues under investigation. Specifically, combining surveys and interviews into the research design helped validate and deepen the research findings. The quantitative survey allowed generalizing results from a large sample covering a vast population. At the same time, qualitative interviews provided insight into the post-action reasoning after the preliminary actions were performed (Karunarathna et al., 2024). This methodological choice increased the study's credibility and helped to focus on several aspects of the impact of VR-assisted teaching on students' self-efficiency at once. The strength of analyzing both quantitative data and qualitative data was optimal and made the study more authentic for educational settings.

RESULTS

Quantitative

Table I Demographic Analysis

What is your Gender?

	N	%
Male	71	47.3%
Female	79	52.7%

How old are you?

	N	%
16 years old	50	33.3%
17 years old	38	25.3%
18 years old	62	41.3%

Have you used Virtual Reality (VR) for learning before?

	N	%
Yes	86	57.3%

No	64	42.7%

How confident are you in using VR for learning?

	N	%
Not confident	30	20.0%
Slightly confident	76	50.7%
Moderately confident	26	17.3%
Very confident	18	12.0%

How motivated are you to learn with VR technology?

	N	%
Not motivated	43	28.7%
Slightly motivated	35	23.3%
Moderately motivated	57	38.0%
Highly motivated	15	10.0%

As the Table I shows, the demographic profile of each participant involves important features that should be understood to facilitate a better interpretation of the study's results regarding the perception of VR-assisted learning. The distribution of gender is quite fair, with 47.3% of the respondents being male and 52.7% being female. Even representation is crucial to guarantee that the conclusions produced within the study also include a variety of concerns related to VR-assisted education. The age distribution indicates that most of the participants are eighteen years old (41.3%), followed by sixteen-year-old individuals (33.3%) and seventeen-year-old participants (25.3%). This means most respondents are in the later age of secondary education, a sensitive stage in academic productivity. Students (self-efficacy) beliefs in STEM subjects influence their future educational pathways and career choices. An assessment of the existing experience had been made from the survey, and as it showed, more than half of the participants, 57.3%, had prior experience with Virtual Reality for learning; this shows that 42.7% had no such experience. This means that while more than half of all viewers are not entirely novices to VR-assisted education, a considerable number still have little to no exposure to it, perhaps calling for some briefing or sensitization to get the best out of it. In addition, on the aspect of confidence level, regarding the use of VR for learning, 12.0% of the respondents responded very confident, 50.7% were slightly confident, 17.3% were moderately confident, and 20.0% were not confident at all. This suggests that while many students are willing to use VR, their confidence levels differ; hence, there is a need to create an appropriate learning environment to boost the comfort and efficiency of the students. Thus, it was also found that the students' motivation levels in relation to VR-assisted learning differ. Of these, 38.0% of the participants said they were moderately motivated, whereas a significant 28.7% said they were not motivated, and 23.3% said they were slightly motivated. The learners were as follows: 46.8% moderately motivated, 10.0% highly motivated, and 43.2% low motivated, meaning there is a gap in motivating the learners to use VR as an educational tool best suited for delivering the training. This study implies that while there are benefits of increasing self-efficacy and engagement due to virtual reality, the implementation into learning calls for several solutions to ensure that motivation is increased, probably through the use of more interactive techniques of teaching with an element of virtual reality and based on the needs of the students.

Table II Reliability Analysis

Scale	**N of Items**	**Cronbach's Alpha**
Immersion of VR-Assisted Teaching (IV1)	5	0.873

Interactivity of VR-Assisted Teaching (IV2)	5	0.819
Realism of VR-Assisted Teaching (IV3)	5	0.848
Students' Spatial Ability (MeV1)	5	0.894
Learning Motivation (MeV2)	5	0.855
Self-Efficacy (DV)	5	0.810

As it can be seen in Table II, the research variables used in the study provide information on the internal consistency of the survey items based on Cronbach's Alpha. Cronbach's Alpha is recognized at 0.70 and above as acceptable, with higher value being more desirable as it indicates higher reliability. All the variables have also been shown to achieve high reliability, which implies that the identified and selected questionnaire items effectively reflect the research concepts. In the case of IV1 (Immersion of VR-Assisted Teaching), the values obtained using Cronbach's Alpha are 0.873. Therefore, the internal consistency in the present study is good to excellent. This suggests that the items developed to assess the level of immersion in VR-assisted teaching constructs do indeed attend to what students have undergone in terms of immersion in teaching-learning environments. As for Cronbach's Alpha of IV2 (Interactivity of VR-Assisted Teaching), the score is acceptable, which is equal to 0.819. Therefore, it can be stated that it is highly reliable. As interactivity is an important aspect of the VR learning environment, this coherency helps establish that the students' feedback represents their interaction with VR study elements, practices, and operations, such as the simulative manipulation, simulations, and operations in real-time. In the case of the Realism of VR-Assisted Teaching (IV3), Cronbach's Alpha is 0.848, which marks it as highly reliable. Here, it is reasonable to say that the items do indeed capture students' opinions concerning how realistic the virtual reality simulations are in emulating real-life STEM environments. Realism refers to how realistic an experience is, and usually, a high level of realism means better engagement and knowledge retention; this is a factor considered in the study. Among the participants, MeV1, the Students' Spatial Ability, has the highest reliability coefficient, 0.894, to support internal consistency. This is important as spatial ability is a mediator in the study. A highly reliable scale ensures that the total discovery of the responses is complementary to the hypothetical state of the students in the VR-assisted learning environment with a capacity to conceptualize spatial information. Students' motivation toward VR-assisted learning exhibits strong consistency in measurement according to Cronbach's Alpha value of 0.855 in the Learning Motivation (MeV2) assessment. This scale's reliability regarding motivation ensures valid interpretations of study outcomes, as motivation controls engagement and self-efficacy. The Pandemic Impacts Self-Efficacy scale demonstrates reliable measurement as its reliability score comes to 0.810, indicating students' confidence levels in STEM learning. The study's validity is strengthened through reliable self-efficacy measurement, which indicates that findings related to student efficacy remain robust and dependable.

Table III Descriptive Analysis

	N	Minimum	Maximum	Mean	Std. Deviation
Immersion of VR-Assisted Teaching	150	1	5	3.99	0.951
Interactivity of VR-Assisted Teaching	150	1	5	3.69	0.989
Realism of VR-Assisted Teaching	150	1	5	3.70	0.893
Students' Spatial Ability	150	1	5	3.90	0.758
Learning Motivation	150	1	5	3.58	0.998
Self-Efficacy	150	1	5	3.93	0.928
Valid N (listwise)	150				

The descriptive statistics provided in Table III show how research variables move around their mean values to show student opinions about VR-assisted instruction and its effect on their learning process. Students hold generally positive views about the variables investigated according to their mean scores, which are between 3.58 and 3.99. The variable response ranges show moderate variation from 0.758 to 0.998, revealing different student perspectives. Most students report a high perception regarding VR-assisted teaching immersion, as its mean stands at 3.99 and its standard deviation is 0.951. Research indicates that VR technology efficiently holds students' attention in their education environment by improving their mental engagement and concentration. Research revealed that students view VR-assisted learning interaction levels at a good point, where the mean reaches 3.69 with a standard deviation of 0.989. The standard deviation is high as students exhibit different levels of engagement control based on their learning approaches and the way they receive VR instructions. According to the analysis, students view VR learning as realistic, which shows a 3.70-point average and a 0.893 standard deviation. The results indicate that the proper design of virtual reality environments demonstrates the capacity to reproduce real-world situations to help with experiential learning effectively.

Table iv Correlation Analysis

		Immersion of VR-Assisted Teaching	Interactivity of VR-Assisted Teaching	Realism of VR-Assisted Teaching	Students' Spatial Ability	Learning Motivation	Self-Efficacy
Immersion of VR-Assisted Teaching	Pearson Correlation	--					
	N	150					
Interactivity of VR-Assisted Teaching	Pearson Correlation	0.194**	--				
	Sig. (2-tailed)	0.000					
	N	150	150				
Realism of VR-Assisted Teaching	Pearson Correlation	0.224**	0.190**	--			
	Sig. (2-tailed)	0.000	0.000				
	N	150	150	150			
Students' Spatial Ability	Pearson Correlation	0.186**	0.157**	0.209**	--		
	Sig. (2-tailed)	0.000	0.000	0.000			
	N	150	150	150	150		
Learning Motivation	Pearson Correlation	0.191*	0.309**	0.360**	0.205**	--	
	Sig. (2-tailed)	0.019	0.000	0.000	0.000		
	N	150	150	150	150	150	
Self-Efficacy	Pearson Correlation	0.960**	0.970**	0.907**	0.873**	0.859**	--

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	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	
	N	150	150	150	150	150	150

Table IV has presented the correlation analysis involving the variables of this research. It is worth noting that the Pearson correlation values represent the degree of these relationships, and the corresponding significance levels indicate the strength of these values at a certain threshold. This implies that it is possible to identify correlations between the use of different elements of the VR-assisted teaching approach and learners' self-efficacy, motivation to learn, and spatial skills. The dependent variable is self-efficacy, which has a highly significant and positive correlation with all the independent and mediating variables. The strongest correlations are revealed with the interactivity of the VR-assisted teaching variable ($r = 0.970$, $p < 0.001$) and the immersive learning with the help of VR in teaching ($r = 0.960$, $p < 0.001$), which points to the fact that if the applied VR-assisted learning is regarded as more interactive and if a student has a feeling immersing in the learning process, his/her self-efficacy is considerably higher. The Realism of VR-assisted teaching is also making a positive progression ($r = 0.907$, $p < 0.001$), which signifies that the VR experiences can enhance the overall circulation of the confidence level of the students in their learning capabilities. Preliminary analysis that examined the correlation between the participants' spatial ability and the identified aspects of video-based learning revealed a significant positive correlation with immersion ($r = 0.186$, $p < 0.001$), interactivity ($r = 0.157$, $p < 0.001$), as well as realism ($r = 0.209$, $p < 0.001$). These moderate relationships imply that VR-assisted learning positively affects space learning, possibly as learning activities are engaging and the learning environment in VR is in 3D.

It is demonstrated that there are moderate relationships between learning motivation and realism ($r = 0.360$; $p = 0.001$), interactivity ($r = 0.309$; $p = 0.001$), and immersion ($r = 0.191$; $p = 0.019$). This means that students who consider VR learning realistic and interactive tend to have high motivation levels. From the results obtained, it is clear that there exists a positive correlation between motivation and spatial ability, where $r = 0.205$ at a significant level of = 0.001. The correlations agree that the learning media's immersion, interactivity, and realism significantly improve students' self-efficacy, learning motivation, and spatial ability. These observations from a well-designed teaching method that uses virtual reality should encourage more engagement and confidence among learners.

Table V Regression Analysis

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.784[a]	0.734	0.718	0.020
2	0.899[b]	0.878	0.871	0.015

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	1.966	0.334		5.881	0.000
Immersion of VR-Assisted Teaching	0.597	0.093	0.600	1.044	0.000
Interactivity of VR-Assisted Teaching	0.352	0.087	0.376	4.028	0.000
Realism of VR-Assisted Teaching	0.574	0.091	0.571	0.804	0.000

(Constant)	0.471	0.327		1.441	0.000
Immersion of VR-Assisted Teaching	0.738	0.078	0.039	0.486	0.000
Interactivity of VR-Assisted Teaching	0.491	0.074	0.404	2.570	0.000
Realism of VR-Assisted Teaching	0.755	0.078	0.753	-0.699	0.000
Students' Spatial Ability	0.226	0.112	0.294	6.463	0.000
Learning Motivation	0.110	0.080	0.110	-0.120	0.000

Dependent Variable: Self-Efficacy

Table V presents the model summary and coefficient analysis offering information about IVs based on their statistical significance in predicting self-efficacy, the DV of the study, and MeVs. The R Square values give the proportions of variance in the dependent variable caused by the independent and mediating variables. According to the results obtained in Model 1, the R Square of 0.734 indicates that about 73.4% of the self-efficacy variance can be attributed to the three IVs, which include immersion, interactivity, and realism of VR-assisted teaching. The R Square of the second model, which includes the mediating variables as students' spatial ability and learning motivation, is 0.878, which shows that 87.8 % of the variance in self-efficacy is accounted for, meaning the current model is a better fit and accounts for more variance in the existing data. The index of adjusted R Square shows a high reliability of the results obtained (0.718 for Model 1 and 0.871 for Model 2). It is evident that the standard error of the estimate reduces in Model 2 to 0.015 as compared to Model 1, 0.020, indicating that the forecast of self-efficacy becomes more precise with the mediation analysis. In the following coefficient table, gains for each variable are shown. Analysis of Model 1 indicated that all the independent variables had a positive and significant impact on self-efficacy: immersion ($\beta = 0.600$, $p < 0.001$), interactivity ($\beta = 0.376$, $p < 0.001$), and realism ($\beta = 0.571$, $p < 0.001$). Adding mediators improves the model by enhancing the strength of the mentioned relationships; thus, realism ($\beta = 0.753$, $p < 0.001$) and immersion ($\beta = 0.738$, $p < 0.001$) become predictors of the model. The effect of dummy variables for students' spatial ability ($\beta = 0.294$, $p < 0.001$) and learning motivation ($\beta = 0.110$, $p < 0.001$) provide conclusive evidence that learners with better spatial ability and increased motivation can perform better in self-efficacy tasks using VR. These findings, therefore, support the premise that users' immersion, interactivity, and realism significantly increase the student's self-efficacy to support their studies, and this is improved so much more by spatial ability and motivation. These outcomes support the use of VR in augmenting student confidence and enhancing the quantity of participation.

Qualitative

Theme 1: Impact of VR Immersion on Self-Efficacy

The ideas drawn forward get credence here, citing that the engagement of VR teaching augments the confidence level among students in STEM matters. Students and faculty said that feeling absorbed in a virtual learning modality promotes understanding of ideas. Some of them commented that traditional methods discourage learners; however, with VR immersion, lessons are more engaging. Prior literature, which revolves around the use of immersive virtual environments, captures the interaction, revealing that it aids in decreasing learning anxiety yet increases the perceived competence levels of the students. These percentages are supported by the participants in this study, who appreciated how VR enhances learning since it helps them interact with the content in an environment that simulates real-life conditions; however, there are no negative repercussions. This way, the students will be able to learn concepts in general STEM areas much better, as they can develop theories into practical skills using a virtual environment. Many participants reported that studying the practicality of VR not only improves understanding but also increases confidence in carrying out STEM activities. The latter is a type of simulation that enables the trainee to practice the required skills so that they become more confident in achieving a particular goal in the field due to the increased self-efficacy that results from the practice. Therefore, learners perceive that they are equipped to solve STEM-related problems, thereby supporting the idea of using VR in education. Some of the concerns raised were related to the finding stating that the positive environment encourages the students to look for more information outside the classroom, thus promoting self-directed learning. However, some issues can be referred to as shortcomings, such as adapting to VR technology and distraction. In general, the analysis of themes indicates that the level of immersion influences the students' self-efficacy positively as the learning process becomes more effective, participatory, and realistic.

Theme 2: Influence of VR Interactivity on Self-Efficacy

The second theme is focused on the influence of VR interactivity on students' self-perceived competence in this subject. The arguments given show that the VR mode of learning enhances learning process since the students are actively involved in learning STEM concepts instead of passive learning. They mentioned that they became confident when they could simulate various objects, execute experiments, and solve problems in a virtual environment. This fact corroborates other studies showing that interactivity in educational technology increases learner interaction and improves learning. Technological education methods promote students' engagement as it presupposes that learning occurs through the active participation of learners who solve problems and modify and control aspects that would usually allow an individual to get feedback on processes and knowledge. One of the most important points that many participants mentioned is that the lack of a real-life consequence for the action in a VR environment is the ability to experiment, thus developing improved conceptual understanding due to a trial-and-error thinking approach. Therefore, virtual reality in learning also empowers learners to control their learning process and choose the ways and pace with which they are comfortable. This also motivates the learners while enhancing self-efficacy since the students will have a positive attitude towards understanding and applying knowledge gained from learning. This way, the lesson not only becomes interesting to the students in the classroom, but the students enjoy the benefits of learning and absorbing information in a dynamic and meaningful new manner. However, some participants expressed that excess interactivity was a prerequisite as it can be used advantageously; additionally, one's skills can be tested when encountering technical challenges during a course. This is true as the thematic analysis reveals that interactivity in VR-assisted teaching is central to effectively improving students' self-efficacy through practical learning, feedback provision, and focusing more on the learners.

Theme 3: The Role of Realism in STEM Concept Retention

From the interviews, it became possible to determine that the aspect of realism of VR-assisted teaching was considered to be the one that enhances the chances of retention of concepts within the STEM discipline. This is supported by the participants' assertions that mere informative teaching methods do not offer an effective training method as that offered by realistic simulations. When students can observe objects and events and drag them around to feel the effect on an object, then the knowledge goes straight to the heart, that is, the brain. This is in ensemble with the cognitive learning theory that posits that meaningful or experiential learning is most effective in improving knowledge retention, comprehension, and recall. As per such theories, the practical use of the learning resources enhances understanding or utilization of them by a great deal. These connectionist theories are particular to VR environments. Many participants pointed out that realistic environments in VR help improve the understanding of concepts as they relate to the practical application of the abstract theoretical concepts being taught. For instance, comprehending concepts in physics or engineering that would be very hard to grasp in a typical classroom setting is very easy when demonstrated in a real-life simulation setting. While using traditional didactic forms of studying, such as reading from textbooks or even having lectures, VR offers a more engaging mode of learning where learners can change different values in an attempt to analyze the effect they produce in a particular system and solve received problems. Thirdly, participants also pointed out that using actual realism in a case assists one in relating the concepts taught and developed in their memory. The engagement level also has an impact on the retention of the data supplied since many authentic and interactive courses are fascinating and memorable. Nevertheless, some people note that compelling realism is still a good thing. However, live-like graphics with no interaction would be anything yet essential. Ultimately, the author establishes that realism positively impacts STEM content by making it more comprehensible, fun, engaging, and practical in the VR learning environment.

Theme 4: The Influence of Spatial Ability on STEM Learning in VR

This theme concerns the role of spatial ability in understanding STEM concepts within a VR-supported

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learning context. The gathered responses imply that the subject matters advantageously apply VR's 3D perspective as causal structures appear to be easier to rotate or transform mentally, structures are more straightforward to differentiate or comprehend in spatial relationships, and what can likely occur as an effect. Some participants observed that since the application involves designing for users with high spatial ability, it was easier to learn in VR environments than to read complex STEM concepts. This corroborates prior research as it shows that spatial ability is correlated with STEM subjects, especially engineering, physics, and mathematics. On the other hand, students with poor spatial skills suggested that although they first experienced VR as a difficult task, they noticed an improvement in their visualization abilities over time. Sure, students pointed out that there is more in VR as it builds skills over time than any other learning model. Regarding the practical functions, constant rotation and zooming of objects were mentioned as helpful for visualizing concepts and ideas. However, some participants hypothesized that VR alone cannot adequately address the issue with spatial skills, and it can require additional training programs. The above thematic analysis shows that Spatial ability is highly relevant in the context of the use of VR in the enhancement of learning in STEM subjects, with the use of VR in enhancing the learning process being both a facilitator and a developmental factor in spatial reasoning.

Theme 5: The Role of Learning Motivation in Self-Efficacy Development

The last theme is determined by the impact of learning motivation on self-efficacy when attending STEM lessons through virtual reality. Several of the participants highlighted that learning is made easier and more exciting by using VR. Thus, the participants are motivated to learn more about STEM. The informants often spoke of the novelty and interactivity of virtual reality as features that keep the students engaged and promote curiosity-based learning models. This is based on self-determination theory, which states that motivation is crucial in determining students' grades. Using VR in the learning process enhances their self-efficacy since they are sure that what they are learning is correct and achievable. Some of the responses also mentioned that VR minimizes the fear of failure as the virtual solutions cannot affect the real world. This leads to the development of a growth mindset, which allows students to take higher risks with ideas and be more persistent while solving a problem. However, a few participants noted the exclusion of continued motivation after using VR as an effective tool to enhance learners' motivation; however, it should be appropriately organized. If not well incorporated into the curriculum, there is the risk of the technology being simply utilized as a mere gadget. The second theme is learning motivation and interaction in the process within the context of using VR, which increases self-efficacy by increasing the willingness of students to learn and continue learning in STEM fields.

DISCUSSION

Key Findings from Quantitative Analysis

The demographic results indicated that 52.7% of the participants were female, with 81.0% of participants being 16 to 18 years old. However, overall, regarding VR use, only 12% claimed to be very confident, while 50.7% were slightly confident. Even though the motivation levels were average and high, only 10% of the respondents pointed out that for VR to be effective, there are still so many areas that need to be addressed, including motivational design and technological literacy. The reliability test supported measurement constructs such as immersion, interactivity, realism, spatial ability, learning motivation, and self-efficacy; these showed high alpha coefficient values above 0.80 to indicate the reliability of the responses made by the participants. Mean scores for immersion were 3.99 (SD = 0.951) and for spatial ability 3.90 (SD = 0.758); these scores supported the notion that students had a positive perception of the VR environments. The correlation analysis revealed positive and significant correlations between the IVs and self-efficacy, cross-correlates ($p < 0.001$) with immersion, interactivity, and realism linked to self-efficacy, particularly immersion, cross-correlate = 0.960. Regression analysis upheld these analyses, and as Model 2 depicted, the multiple R^2 is 0.878, acknowledging that immersion, interactivity, realism, spatial ability, and motivation have a significant relationship with self-efficacy.

Qualitative Insights from Thematic Analysis

Some of the important aspects regarding teaching with the use of VR emerged from such questions, as

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suggested by the thematic analysis of the interviews. First of all, students mentioned that VR is highly immersive, bringing this statement into agreement with quantitative results, according to which the three main components of VR having the highest mean value was immersion (3.99). Regarding the use of realistic simulations, some participants stated that it helped them understand more quickly and, hence, better. Second, interactivity proved to be relevant, with the students praising the constructors for the inclusion of interactivity since it made learning colorful, improving participation, corresponding to the correlation analysis that showed a positive relationship between interactivity and self-efficacy (Werme et al., 2022).

Another of the rising trends, as seen in the study, was spatial ability, whereby students who applied good spatial abstraction performed better in VR teaching. This question was also supported quantitatively since spatial ability had a very high level of relationship with self-efficacy ($r = 0.873$). Moreover, the level of motivation also affected the result, with some students saying that, although virtual reality was interesting, lack of contact with it affected motivation; the data was consistent with the descriptive study, having a mean score of 3.58 for motivation. However, there were complaints of technological challenges and challenges in accessing relevant learning materials and resources. Therefore, there is a need for improved technological infrastructure as well as proper training of students on how to use the technology available (Okoye et al., 2023). This research supports VR-mediated teaching in raising the self-efficiency skills of the students, mainly through absorption, interactivity, and reality. Statistical analysis confirmed the assertion of the hypothesis and provided additional details on the advantages VR has when teaching concepts such as angular velocity and acceleration; student engagement can be improved, as well as ways in which technical difficulties affect VR education (Sokoloff, 2023). Based on these results, educators should encourage using highly engaging VR while ensuring students have enough practice to enhance learning from VR. Future studies can focus on the effects of using VR-assisted learning on children's performance and cognitive advancement in different successive years.

CONCLUSION

This present research emphasizes the importance of using the VR-assisted teaching approach in increasing the students' self-efficacy, interest, and facets of spatial skills. The results show that these aspects, including immersion, interactivity, and realism, were significant to the students. Although the use of case studies for practice in a virtual reality environment was positive, the students' issues of confidence and motivation remain questionable. The quantitative and qualitative measures show that virtual reality can be used as an effective instructional tool, but with the current subject of accessibility and training in its application. Altogether, as far as learning is concerned, VR can transform occasions into instructional methods that help learners explore and interact with the physical environment by making more alterations to improve learners' performance and future academic achievements.

Future Research

Therefore, future research is required to determine the long-term impact of VR-assisted learning on the students' performance, thinking abilities, and knowledge. This will involve long-term studies to determine whether efficiency and engagement will be enhanced through the use of VR in the future. It is also deemed necessary to continue the research with other age groups where university students and adult learners were not involved, as widening VR practice strategies for different educational levels and subject areas can add valuable information. The comparison of the effectiveness of learning with VR and learning without VR will provide a better understanding of how popular VR contributes and can contribute to various forms of learning (Liu et al., 2024). Future studies should also be devoted to using artificial intelligence in VR-assisted education systems to provide an individualized approach. The long-term use of AI within the development of Virtual Reality learning environments can help teachers adapt to students' different learning abilities, enhancing their learning capability. Nevertheless, high economic analysis plays an inevitable role in determining the possibility of expanding the use of VR-assisted learning in larger organizations and incorporating this technique to train nurses in schools with limited resources (Yu & Duan, 2024). Using VR in conjunction with conventional teaching approaches can be more effective and beneficial for students and teachers, creating an ideal strategy for managing the educational process.

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APPENDICES

Appendix-I: Survey Questionnaire

Section A: Demographic Questions

- **What is your gender?**
- ☐ Male
- ☐ Female
- **How old are you?**
- ☐ 16 years old
- ☐ 17 years old
- ☐ 18 years old
- **Have you used Virtual Reality (VR) for learning before?**
- ☐ Yes
- ☐ No
- **How confident are you in using VR for learning?**
- ☐ Not confident
- ☐ Slightly confident
- ☐ Moderately confident
- ☐ Very confident
- **How motivated are you to learn with VR technology?**
- ☐ Not motivated
- ☐ Slightly motivated
- ☐ Moderately motivated
- ☐ Highly motivated

Section B: Research Variable-Related Questions

Research Variables	*Items*	*Source*
Immersion of VR-Assisted Teaching (IV1)	I feel fully immersed when learning with VR.	Huai *et al.* (2024)
	VR lessons make me feel present in the virtual space.	
	I lose track of time while using VR for learning.	
	VR makes learning more engaging and realistic.	
	I feel deeply connected to the VR learning environment.	
Interactivity of VR-Assisted Teaching (IV2)	I can actively interact with VR learning materials.	Yu (2023)
	VR allows me to explore concepts in a hands-on way.	
	I receive immediate feedback from VR activities.	
	I enjoy controlling my learning experience in VR.	
	VR learning keeps me engaged and focused.	
Realism of VR-Assisted Teaching (IV3)	The VR environment looks realistic and detailed.	Xie *et al.* (2022)
	VR helps me visualize real-world applications of concepts.	
	The sounds and visuals in VR feel authentic.	
	I find VR-based learning more realistic than textbooks.	
	VR makes abstract concepts easier to understand.	
Students' Spatial Ability (MeV1)	I can mentally rotate objects in different orientations.	Li *et al.* (2024)
	VR helps me improve my spatial thinking skills.	
	I can navigate and understand 3D spaces easily.	
	VR enhances my ability to visualize spatial relationships.	
	I feel more confident in solving spatial problems.	
Learning Motivation (MeV2)	I feel motivated to learn when using VR.	Man *et al.* (2024)
	VR lessons make learning more exciting for me.	
	I enjoy learning new concepts through VR experiences.	
	VR increases my interest in STEM subjects. I ammore engaged in lessons when VR is used.	
	I ammore engaged in lessons when VR is used.	
Self-Efficacy (DV)	I believe I can succeed in VR-based learning.	Chen & Syu (2024)
	VR learning improves my confidence in STEM subjects.	
	I can complete challenging tasks in VR without help.	
	I feel capable of understanding difficult concepts in VR.	
	I trust my ability to learn effectively using VR.	

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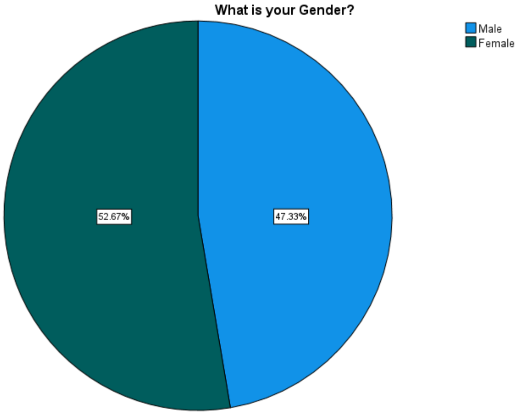
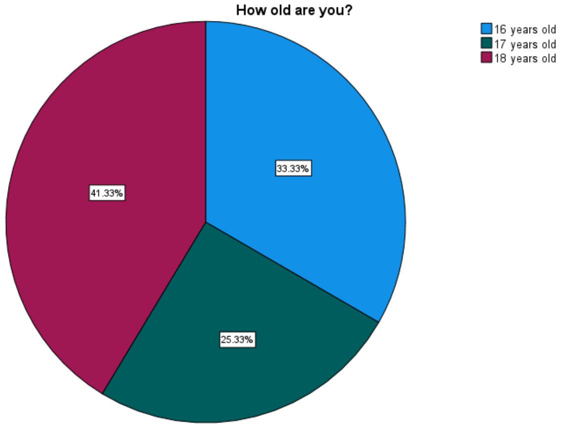
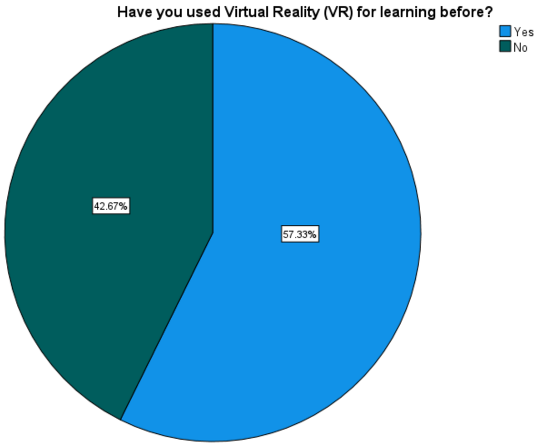
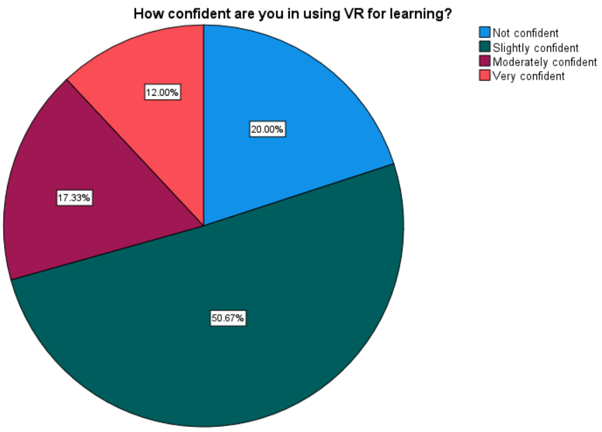
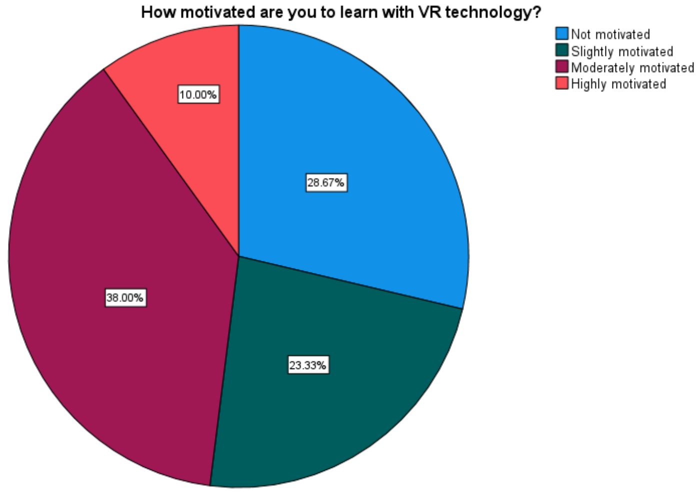
Appendix-II: Demographic Statistics











Appendix-III: ANOVA[a]

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	30.003	3	10.001	14.870	.000[b]
	Residual	98.191	146	.673		
	Total	128.193	149			
2	Regression	62.617	5	12.523	27.500	.000[c]
	Residual	65.576	144	.455		
	Total	128.193	149			

Appendix-IV: Interview Transcript

1. How has your experience with VR-assisted teaching influenced your confidence in learning STEM subjects?

Interviewer: Thank you for joining this interview. To begin, how has your experience with VR-assisted teaching influenced your confidence in learning STEM subjects?

Participant 1: My confidence in STEM subjects has increased significantly since using VR-assisted learning. The immersive experience allows me to engage more deeply with the material, making it easier to understand complex topics. As a result, I feel more assured when solving problems and participating in class discussions.

Participant 2: I have noticed a positive change in my confidence. Before using VR, I often hesitated to attempt difficult STEM problems. However, the interactive simulations provide a clearer understanding, allowing me to practice concepts repeatedly, which has strengthened my self-efficacy in STEM learning.

Participant 3: VR-assisted teaching has provided me with a new perspective on learning. I used to struggle with abstract concepts, but now I can visualize them in a three-dimensional space. This has made me more confident in my ability to grasp complex ideas and apply them effectively in problem-solving.

Participant 4: I feel much more comfortable engaging with STEM subjects now. The immersive aspect of VR lessons has helped me understand theoretical concepts in a way that textbooks could not. This has given me the confidence to approach challenging topics without feeling overwhelmed.

Participant 5: VR-assisted learning has played a crucial role in improving my confidence. By allowing me to interact with STEM concepts in a more tangible way, I feel better equipped to tackle academic challenges and apply my knowledge in practical scenarios.

Interviewer: Thank you all for sharing your experiences. Your insights will contribute significantly to this study.

2. In what ways do you think the immersion of VR-assisted teaching affects your understanding of complex STEM concepts?

Interviewer: Thank you for your responses so far. Now, I would like to ask: In what ways do you think the immersion of VR-assisted teaching affects your understanding of complex STEM concepts?

Participant 1: The immersive nature of VR-assisted teaching has greatly enhanced my understanding of complex STEM topics. It allows me to engage with abstract concepts in a more visual and interactive manner, making it easier to comprehend difficult subjects such as physics and chemistry.

Participant 2: I find that immersion in VR lessons helps me retain information better. Traditional teaching methods often rely on memorization, but VR allows me to experience the subject firsthand. This makes abstract theories more concrete and easier to grasp.

Participant 3: The immersive environment of VR lessons creates a deeper learning experience. Instead of just reading about scientific phenomena, I can visualize and interact with them. This hands-on approach helps me understand concepts more effectively than traditional classroom learning.

Participant 4: For me, immersion in VR-assisted learning bridges the gap between theory and practical application. I can explore models and conduct virtual experiments, which enhances my ability to understand and apply STEM concepts in real-world scenarios.

Participant 5: I believe VR immersion significantly improves comprehension because it eliminates distractions and creates an engaging learning atmosphere. The ability to manipulate 3D models and simulate real-world applications has strengthened my understanding of complex STEM topics.

Interviewer: Thank you all for your detailed responses. Your perspectives are valuable to this research.

3. How does the interactivity of VR-assisted lessons impact your engagement and motivation in learning?

Interviewer: Thank you for your insights. Now, I would like to ask: How does the interactivity of VR-assisted teaching influence your engagement in STEM learning?

Participant 1: The interactive nature of VR-assisted teaching keeps me actively engaged in learning. Unlike traditional lectures, where I am mostly passive, VR allows me to manipulate objects, conduct virtual experiments, and participate in simulations, making learning more dynamic and enjoyable.

Participant 2: I find that interactivity plays a crucial role in keeping me focused. When I actively engage with the material through VR, I am less likely to lose concentration. It makes learning more immersive and encourages me to explore topics in greater detail.

Participant 3: VR-assisted teaching provides a hands-on learning experience, which significantly boosts my engagement. Instead of just reading about scientific concepts, I can interact with them in a virtual space. This makes me more curious and motivated to explore STEM subjects.

Participant 4: The interactivity of VR lessons makes learning feel like an adventure. Instead of just receiving information passively, I can test different scenarios, make adjustments, and see immediate results. This interactive approach helps me stay engaged and develop a deeper interest in STEM subjects.

Participant 5: I believe that interactivity enhances my engagement by making complex subjects more accessible and less intimidating. By actively participating in simulations and problem-solving activities, I feel more involved in the learning process, which ultimately improves my understanding and interest in STEM topics.

Interviewer: Thank you for your detailed responses. Your perspectives are highly valuable to this study.

4. Do you feel that the realism of VR simulations helps you visualize and comprehend abstract STEM concepts better? Why or why not?

Interviewer: Thank you for your responses. Now, I would like to ask: In what ways does the realism of VR-assisted teaching impact your ability to retain STEM concepts?

Participant 1: The realism in VR-assisted teaching helps me remember STEM concepts more effectively because it feels like a real-life experience. When I can visualize and interact with 3D models, the information stays with me longer compared to reading textbooks or watching videos.

Participant 2: I find that realistic VR environments make abstract concepts more concrete. When I can see real-time simulations of scientific principles in action, I understand them better, and this helps me recall the concepts more easily during exams and practical applications.

Participant 3: The high level of realism in VR-assisted lessons enhances my retention because I feel like I am actively experiencing the learning process. Seeing real-world applications of STEM concepts makes them more meaningful and easier to remember in the long run.

Participant 4: VR realism allows me to explore STEM topics in a way that feels natural. Instead of just memorizing formulas or theories, I can see their effects in an interactive space, which helps reinforce my knowledge and improves my long-term retention of the material.

Participant 5: I believe that the more realistic the VR simulation is, the more engaged I become, and this naturally improves my memory. When concepts are presented in a visually engaging and interactive manner, they are easier to recall and apply in real-world scenarios.

Interviewer: Thank you all for your detailed responses. Your insights are highly valuable for this research.

5. How do you perceive the role of VR-assisted teaching in enhancing your spatial ability and overall self-efficacy in STEM learning?

Interviewer: Thank you for your insights. Now, I would like to ask: How does your spatial ability influence your understanding of STEM concepts in a VR-assisted learning environment?

Participant 1: I believe my spatial ability significantly enhances my understanding of STEM concepts in VR. Since I can mentally visualize and manipulate 3D objects, I find it easier to grasp concepts related to geometry, physics, and engineering. VR provides a practical way to apply my spatial skills to learning.

Participant 2: My spatial ability helps me navigate and interact effectively with the virtual environment. When studying complex STEM topics, such as molecular structures or mechanical systems, I can mentally rotate and analyze the models, which makes the learning process smoother and more intuitive.

Participant 3: I have noticed that my spatial ability plays a crucial role in understanding VR lessons. When dealing with abstract STEM concepts, such as forces and motion, I can visualize the changes happening in real time, which deepens my comprehension and retention.

Participant 4: While my spatial ability is not very strong, VR-assisted learning has helped me improve it. By interacting with 3D simulations, I have become more comfortable with spatial reasoning, which has positively impacted my ability to understand and apply STEM concepts.

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Participant 5: My ability to mentally manipulate and visualize objects has made VR-assisted STEM learning highly effective for me. The immersive experience allows me to engage with the material in a hands-on way, reinforcing my understanding and making abstract concepts more tangible.

Interviewer: Thank you all for sharing your thoughts. Your responses provide valuable perspectives for this study.