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Developing and validating the motivation toward virtual reality scale: its associations with science anxiety, academic buoyancy, and grit

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ABSTRACT

As immersive technologies gain traction in education, understanding their psychological impacts becomes crucial. This study developed and validated the Motivation toward Virtual Reality Scale and examined its associations with science anxiety, academic buoyancy, and grit. Three studies were conducted with middle school students. Study I (N = 301) involved exploratory factor analysis for scale development. Study II (N = 292) confirmed construct validity and reliability using confirmatory factor analysis, internal consistency metrics (α, ω, λ), Item Response Theory (IRT), measurement invariance, and criterion-related validity. Study III (N = 418) tested a structural model examining the mediating roles of academic buoyancy and grit between VR motivation and science anxiety. Results supported a 14-item, three-factor structure with strong psychometric properties. IRT analyses showed high item discrimination, and invariance analyses confirmed stability across gender. VR motivation was positively associated with VR attitude and acceptance. Structural equation modelling revealed that academic buoyancy and grit mediated the link between VR motivation and science anxiety. Grounded in Self-Determination Theory and related frameworks, findings highlight the role of VR motivation in reducing science anxiety and enhancing students' resilience in technology-integrated learning environments.

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Virtual reality; science anxiety; scale development; academic buoyancy; academic grit

1. Introduction

The world has never been as complex, and science has never been more crucial to understanding it (NGSS Lead States, 2013). Given the growing complexity of the world, science as both a method of inquiry and a body of knowledge intertwined with technology underscores the need for broad scientific understanding (Chakravartty, 2022). Despite its critical importance, science education literature continues to highlight a global decline in young people's interest in pursuing careers in science, technology, engineering, and mathematics (STEM) fields (Cazarez, 2022). Ramsurrun et al. (2025) note that declining enrolment in science and technology education constitutes a 'growing global phenomenon'. This growing disinterest has prompted ongoing discussions and debates regarding the

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efficacy of current science education practices, which remain highly relevant today (Millar et al., 2025). Considering these concerns, STEM educators are increasingly encouraged to implement innovative pedagogical approaches that ensure high-quality and equitable learning experiences for all students (Makransky et al., 2020; NGSS Lead States, 2013).

Among such innovations, virtual reality (VR) has gained attention as a promising tool for enhancing students' engagement in science learning and fostering motivation to pursue STEM-related careers (Thisgaard & Makransky, 2017). Research supports this claim; for instance, Vogt et al. (2021) found that immersive VR learning environments are generally more motivating and engaging for students than traditional settings. Similarly, Makransky et al. (2019) reported that VR simulations can enhance students' interest and enjoyment in science learning. These motivational benefits are particularly relevant given that science anxiety is known to hinder students' participation in science learning and discourage long-term engagement with science-related pathways (DeWitt & Archer, 2015; Kang et al., 2021). By enabling experiential, interactive, and low risk learning opportunities, VR may help reduce anxiety while supporting students' confidence and intrinsic motivation in science contexts (Cheng & Tsai, 2020; Pahmi et al., 2025). Despite these promising findings, most existing studies rely on general engagement indicators or broad motivational constructs, leaving open the question of how students' motivation toward educational VR is conceptualised and measured.

Existing motivation measures are largely designed for general technology use or digital tools in a broad sense, rather than focusing on the unique context of educational VR. As a result, these instruments often fail to adequately capture VR-specific motivational processes because they do not consider the contextual structure and experiential characteristics of VR environments (Jensen & Konradsen, 2018). Furthermore, critiques indicate that the validity evidence for measurements used in AR and VR research is limited and often overlooks the nature of motivation by focusing primarily on cognitive outputs (Tudor Car et al., 2022). Within the framework of Self-Determination Theory (SDT), this limitation is particularly salient because external motivation is often treated as a single, undifferentiated construct, obscuring meaningful distinctions between different forms of regulation in technology-supported learning (Howard et al., 2017). Taken together, these limitations point to the need for a context-sensitive measurement tool designed to assess how learners experience and regulate their motivation within VR-based learning environments. Such a tool should consider VR-specific features, including immersive interaction, perceived competence, enjoyment, and external pressures associated with the use of VR applications. This context sensitivity requires a measurement approach in which items are explicitly anchored in VR-based learning experiences, allow for the differentiation of motivational regulations within the VR context, and can be meaningfully examined in relation to external constructs relevant to VR-supported learning.

To address these conceptual and methodological limitations, the primary aim of this study is to develop and validate a theoretically grounded scale that measures students' motivation toward the use of VR in educational contexts. Grounded in SDT, the proposed Motivation toward Virtual Reality (MVR) Scale is designed to capture distinct forms of motivational regulation as they manifest in immersive learning environments. Beyond scale development, the study also examines how motivation toward VR relates to key educational variables, including academic buoyancy, academic grit, and science anxiety. By situating VR motivation within a broader network of adaptive and emotional constructs, this study adopts an argument-based approach to validity (Kane, 2013), integrating evidence from internal structure, measurement precision, group invariance, relations with external variables, and theoretical consequences across three complementary studies. Guided by these aims, the present research was designed as a multi-study investigation to ensure both conceptual depth and methodological rigour. Rather than treating validity as a single statistical outcome, the study adopts an argument-based perspective, in which different sources of evidence are combined to support the interpretation and use of scores derived from the MVR Scale (Kane, 2013).

Within this framework, the research proceeded in three interrelated studies, each conducted with a distinct sample to address a specific aspect of the validity argument. Study I aimed to develop an initial item pool for the MVR scale and explore its underlying factor structure through qualitative inquiry and exploratory factor analysis (EFA). Study II sought to validate the factor structure of the MVR Scale and examine its psychometric properties, including construct validity, item quality, measurement invariance, and reliability. Lastly, Study III was designed to investigate the relationships among motivation toward VR, academic buoyancy, academic grit, and science anxiety through the testing of a proposed mediation model using structural equation modelling (SEM). In line with this approach, the study was guided by the following research questions:

RQ1: What is the underlying factor structure of the MVR scale as identified through EFA.

RQ2: What are the item-level psychometric properties of the MVR scale, including factor loadings, distributional characteristics, item–total correlations, and item response parameters?

RQ3: Does the MVR scale demonstrate reliability and measurement invariance across relevant groups?

RQ4: How does the MVR scale relate to theoretically relevant external constructs?

RQ5: Does the MVR scale provide evidence of nomological validity through its role within a broader mediation model?

1.1. Theoretical background and related literature

Research in science education highlights several key features underlying the motivational impact of VR environments. Immersion in VR is often measured by the sense of presence, or the feeling of ‘being there’ in the virtual world and is frequently cited as a driving force for engagement and enjoyment (Bailenson, 2018; Makransky, 2021). This immersive feature allows students to experience scientific concepts realistically and firsthand, which can make learning more engaging and intuitive. Additionally, VR’s interactive and student-centered structure can give students a greater sense of control and autonomy. They can manipulate virtual objects, conduct experiments, and instantly see the results of their actions in a safe environment, which can enhance their sense of competence. Such opportunities can encourage higher motivation and deeper cognitive processing (Keller et al., 2025). VR environments also provide instant feedback and real-time guidance, helping learners correct their mistakes without fear of consequences and improve their understanding (Lin et al., 2023). Considering all of this, it is believed that

VR can be an effective tool in increasing students' motivation and engagement in science education, thereby guiding them toward choosing a STEM-related career. Yet, while VR's motivational features appear impressive, it is necessary to be cautious about how and to what extend these features contribute to the learning process. This is because the real impact may depend on whether students can take these experiences beyond superficial curiosity and how well the environment is designed to serve pedagogical purposes.

One major critique is that most of the existing evidence on the positive effects of VR comes from short-term studies measuring immediate engagement, and very little is known about long-term effects. In a review examining the VR in education, Jiang and Fryer (2024) found that while most studies report an increase in student motivation following VR interventions, there is a lack of long-term research, raising concerns that some benefits may reflect short-term novelty effects. This suggests that students may be highly motivated when VR is new to them, but whether this heightened motivation persist with continued use remains an open question. Additionally, researchers have also noted that simply adding immersive features does not guarantee better learning outcomes. For instance, Ahn et al. (2022) noted that high spatial presence increased participants' engagement but decreased their recall performance. This suggests that high presence may consume resources allocated for information processing due to limited capacity, meaning that greater enjoyment does not always translate to greater learning. Similarly, a meta-analysis conducted by Richardson et al. (2017) indicated that VR generally increases learner satisfaction but doesn't consistently improve learning gains compared to traditional methods. These critiques highlight the need for more rigorous and long-term research on educational VR and for examining when and how the advantages of this technology emerge. Moreover, another criticism is that studies on the use of VR in education mostly focus on cognitive and motivational factors, while the emotional dimension is not sufficiently addressed (Makransky & Petersen, 2021). In this context, it becomes an important question whether the motivational gains observed in VR environments support meaningful emotional outcomes, such as a reduction in science anxiety.

Science anxiety can be defined as a feeling of fear or apprehension that students experience in relation to science courses. It is defined by Megreya et al. (2021) as a debilitating condition in which negative emotions and cognitions occur simultaneously within the context of science learning. Given that this emotional barrier can hinder students' engagement regardless of their academic abilities, addressing it is critical for fostering long-term success in STEM education. In an experimental study by Wilczyńska et al. (2024) found that participants using a newly developed VR device experienced a high level of immersion, accompanied by a significant reduction in anxiety levels. Similarly, Zhang et al. (2025) reported that a VR-based game intervention significantly reduced fear and general anxiety among university students. Consequently, integrating tools such as VR which have the potential to reduce science anxiety holds promise for creating more inclusive and motivating science learning environments.

To better understand the emotional impact of VR in science education, it is important to examine the motivational factors that drive its use and how these may influence science anxiety. Beyond its anxiety-reducing effects, VR also supports students' motivational needs, further enhancing its value as an educational tool. VR has the potential to stimulate students' intrinsic motivation by fostering a sense of autonomy, competence, and social connectedness (Spangenberger et al., 2022; Yoo et al., 2024). In a study by

Garduño et al. (2021), 72% of high school students reported experiencing high levels of attention following a VR session, while 71% expressed high levels of satisfaction with the experience. These findings highlight its importance to further investigate how students' motivation to use VR not only enhances engagement but also influences emotional consequences, such as science anxiety.

The motivation to use VR may influence science anxiety both directly and indirectly. In terms of direct effects, VR applications used with interest and curiosity may lead to an immediate reduction in the anxiety students experience during science-related activities. For example, Gungor et al. (2022) reported a general decrease in students' laboratory anxiety following the use of VR in a chemistry lab setting. On the other hand, existing research has shown that the indirect effects of VR-related motivation are mediated through factors such as intrinsic motivation, academic self-efficacy, and learning engagement (Han, 2020; Klingenberg et al., 2020; Radianti et al., 2020; Vogt et al., 2021). Furthermore, recent studies suggest that academic buoyancy may also play a role in the relationship between VR motivation and emotional outcomes such as science anxiety.

Academic buoyancy is defined as a student's resilience in coping with challenges such as daily academic failures, low grades, and stress (Putwain et al., 2023). Students with high levels of academic buoyancy may be less negatively affected by exam anxiety or short-term academic setbacks. Existing research suggests that academic buoyancy may reflect students' ability to effectively cope with academic pressure and challenges, potentially serving as a protective factor against elevated levels of anxiety (Putwain et al., 2023). Moreover, an experimental study conducted by Tran et al. (2024) compared VR-based training with traditional mannequin-based simulation in surgical education. The results showed that both methods increased academic buoyancy; however, the improvement was statistically significant only for the VR group. Similarly, they found that VR appears to provide a more comfortable and less intimidating environment for learners, helping them build confidence and better manage stress, self-consciousness, and fear of criticism during challenging scenarios. In addition to these factors, personal characteristics such as academic grit may further mediate the impact of VR motivation on students' emotional and academic outcomes.

Academic grit as defined by Duckworth et al. (2007) is a personality trait that reflects perseverance and passion for long-term goals. A study conducted by Musumari et al. (2018) revealed a negative correlation between increasing levels of grit and anxiety. Students with higher levels of grit may be less likely to experience anxiety, as they tend to focus on sustained effort toward their goals rather than dwelling on negative experiences. In the VR context, an increase in motivation may contribute to the development of academic grit by encouraging sustained effort and resilience toward long-term learning goals. Consequently, the motivational boost provided by VR may enhance both academic buoyancy and grit. These improvements can, in turn, contribute to a noticeable reduction in science anxiety.

The literature suggests that, to understand the educational role of VR, broader motivational and emotional structures associated with students' engagement in VR-based learning environments should be considered. Prior research highlights consistent associations among motivation toward VR, adaptive academic characteristics such as academic buoyancy and grit, and emotional experiences related to science learning, including science anxiety. However, these constructs are often examined in isolation or implemented using measurement tools that are not specifically designed to the contextual and experiential characteristics of educational VR. As a result, current findings remain fragmented, and the conceptual consistency between these variables in VR-supported learning contexts has not yet been examined in an integrated manner.

2. Study I

Study I attempted to create and evaluate the initial item pool for the MVR Scale using qualitative data collection and subsequently EFA. This phase focused on incorporating qualitative insights throughout the initial phases of scale development, consistent with the principles of an exploratory sequential mixed methods design (Creswell, 2014).

The qualitative component comprised open-ended interviews with a targeted sample of middle school students with prior experience with VR applications in educational settings. In addition, expert consultation with experts in educational technology and motivation theory were conducted to ensure content relevancy and theoretical coherence. The quantitative component of this study was constituted by an EFA, which was conducted to examine the underlying factor structure of the generated items.

2.1 Method

2.1.1. Participant and procedure

Participants in Study I had been recruited via criterion sampling, one of the purposeful sampling methods. Inclusion criteria for the study were being a middle school student and having experience with VR applications. In this study, VR refers to immersive and interactive environments accessed through head mounted displays or comparable systems. We focused on educational and science-oriented VR applications that involve exploration, simulation, or problem solving rather than entertainment-based or gaming uses. Considering the average age of the sample and to ensure a common understanding of the concept being measured, the meaning of the 'virtual reality' concept was clearly stated before the measurement tool was applied. Students were provided with a standard explanation defining VR as an educational immersive system used in science classes, emphasising its educational purpose, interactive features, and simulation-based structure. The scale instructions also clearly stated that their responses should reflect their motivation regarding these learning-focused VR experiences, not general technology use or entertainment platforms. With this procedure, we sought to minimise differences in students' VR conceptualizations and ensure that their responses were consistent with the intended structure under investigation.

Recruitment was classroom based and conducted by school staff during regular lessons. Study invitations described a study on learning with technology without mentioning motivation, and no incentives were offered, which helped reduce self-selection by highly motivated students. All eligible students in the contacted classes were invited, participation was voluntary with informed consent, and demographics as well as prior VR exposure were recorded without screening on motivation. Data was collected from a total of 301 participants. Participants mean age was 12.26 (*SD* = 1.07). The average number of VR experiences reported by participants was 3.28, with a standard deviation of 4.27. Further information about participants is given in Table 1.

Table 1. Demographic information of participants.

	Study I		Study II		Study III	
Variable	Frequency	%	Frequency	%	Frequency	%
Gender						
Female	161	53.5	139	47.6	207	49.5
Male	140	46.5	153	52.4	211	50.5
Grade						
5th Grade	44	14.6	27	9.2	145	34.7
6th Grade	79	26.2	67	22.9	124	29.7
7th Grade	96	31.9	89	30.5	149	35.6
8th Grade	82	27.2	109	37.3	–	–

Prior to participation, every participant was briefed on the study's nature and objectives and provided informed consent. Participation was entirely voluntary, and no compensation was offered.

To ensure the reliability of the data collected, appropriate scale development procedures were followed throughout the study. While the number of steps articulated in scale development studies may vary across researchers (Carpenter, 2018; Cohen et al., 2007; DeVellis, 2017), the underlying procedures typically reflect common methodological principles. In the present study, the scale development process was systematically carried out in eight distinct steps, in accordance with established guidelines in the literature to ensure methodological rigour and construct validity. These steps were primarily informed by the scale development framework outlined by DeVellis (2017), while also integrating convergent recommendations from other methodological sources, which resulted in differences in terminology rather than in the underlying procedures. Throughout this process, the term 'items' refers to individual statements designed to capture specific aspects of students' motivation toward VR. Meanwhile, the term 'scale' refers to the overall measurement structure consisting of multiple items that are examined through empirical analysis in subsequent stages of development.

Step1. Theoretical framework. In this study, the target construct was students' motivation toward VR. To conceptualise motivation, SDT (Deci & Ryan, 2000) was adopted as the guiding framework. According to SDT, motivation is positioned on a continuum ranging from amotivation to extrinsic and intrinsic motivation. For middle school students, three types of motivation were emphasised to balance conceptual clarity with practical feasibility. These include (a) external regulation, representing the least autonomous form of extrinsic motivation; (b) integrated regulation, the most autonomous form of extrinsic motivation; and (c) intrinsic motivation, in which students engage in VR activities for inherent satisfaction. Focusing on these three categories allowed the scale to capture essential motivational sources without overwhelming respondents with an excessive number of items, which can reduce response quality (Herzog & Bachman, 1981).

Step 2. Item pool generation. After defining the target construct, we created an initial item pool that was deliberately three to four times larger than the anticipated final scale (DeVellis, 2017). Item writing followed established criteria such as clarity, brevity, single facet content, nonjudgmental wording, minimal use of negative phrasing, and age appropriate language based on Clark and Watson (2016). Alongside researcher written items, concept aligned statements were adapted from existing instruments. To ensure coverage and respondent level appropriateness in the VR context, six middle school students with

VR experience were interviewed, and insights from these interviews informed item refinement. These steps yielded an initial pool of 32 items.

Step 3. Response format. In the third step, a five-point Likert-type response format was selected for the items to ensure clarity and reliability for respondents. This decision was made intentionally; because offering too many response options may not increase reliability among children and adolescents (Borgers et al., 2004). The items are presented as declarative statements with sequential categories ranging from 'strongly disagree' to 'strongly agree.'

Step 4. Expert review. The items were evaluated by experts in Turkish language, psychometrics, measurement and evaluation, motivation, and middle school pedagogy. Their assessments guided revisions to enhance content and face validity.

Step 5. Pilot testing. The preliminary item pool was piloted with 37 middle school students who matched the target group in terms of age and VR experience. During the pilot, clarity, response burden, completion time, and distribution of responses were examined. Short cognitive interviews and student feedback were used to identify items that were unclear or ambiguous.

Step 6. Item revision. Based on these inferences achieved on pilot testing and building on the prior expert reviews of language accuracy, age appropriateness, and content validity, problematic items were revised. This process ensured a refined and practical item set for subsequent large-scale administration.

Step 7. Large-scale data collection. Following the pilot revisions, data were collected from a larger sample of more than 300 middle school students to ensure statistical adequacy for factor analysis and validation procedures. This sample size was chosen to meet recommended criteria for item-to-participant ratios in scale development studies, thereby increasing the reliability of the factor structure and the stability of parameter estimates. The larger dataset also provided sufficient power to evaluate the dimensionality of the construct and to conduct further validity and reliability analyses with confidence.

Step 8. Exploratory factor analysis. An exploratory factor analysis was conducted to determine the underlying structure of the scale. Items with low or cross loadings were removed, and the final solution produced 14 items grouped under three factors.

2.1.2. Measures

In Study I, a preliminary 32 item version of the MVR Scale was used for EFA. The items were developed based on SDT (Deci & Ryan, 2000), covering both intrinsic motivation and the four subtypes of extrinsic motivation: external regulation, introjected regulation, identified regulation, and integrated regulation. All items were presented on a 5-point Likert-type response format ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'), reflecting students' motivational responses to VR use in educational settings.

2.1.3. Data analysis

The qualitative data gathered from open-ended interviews were examined through thematic analysis to identify recurring themes, language patterns, and motivational factors related to students' participation in VR applications. The interview data were analyzed following the six-phase guide proposed by Braun and Clarke (2006), which involves data familiarisation, initial coding, theme identification, theme evaluation, theme definition/naming, and final reporting. During the familiarisation phase, transcripts were read multiple times, and analytical memos were taken to capture initial impressions and contextual nuances. The initial coding was performed using a line-by-line inductive approach, remaining close to the participants' statements. The codes were iteratively refined by comparing, splitting, or merging similar elements based on their conceptual relevance. After the initial coding, the relevant codes were clustered to form preliminary themes. Decisions regarding grouping were made based on the conceptual framework of SDT and the patterns that emerged directly from the data. Each potential theme was evaluated by checking the consistency of the coded excerpts and examining whether the theme adequately represented the fundamental motivational processes described by the participants. Themes were then revised, expanded, or collapsed when necessary, and theme boundaries were explicitly defined to avoid conceptual overlap. To enhance reliability, the coding structure and emerging themes were reviewed by the second author and disagreements were discussed until consensus was reached. This review process served as a form of peer review and provided an audit trail for analytical decisions. The examined themes contributed to the development of the initial item pool designed to represent different dimensions of student motivation toward VR use based on SDT. In this respect, themes reflecting different forms of motivation were converted into content items by paying close attention to how students described their reasons for using VR applications. In several interviews, students emphasised that their interest in VR stemmed not from personal interests but from external pressures or obligations. For example, some students reported using VR because the application was mandatory, to avoid possible consequences, or to prevent feelings of embarrassment or exclusion among peers. These statements were initially coded as external pressure, perceived obligation, and avoidance of negative outcomes, and were later grouped under a theme reflecting externally regulated motivation. Consistent with the external regulation component of SDT, this theme informed the development of items reflecting students' use of VR due to obligation, fear of negative consequences, or social pressure.

Following the item generation, a group of experts in the field evaluated the items for clarity, relevance, and content validity. Revisions were carried out to enhance item quality based on their feedback. The revised draft of the scale was subsequently administered to a larger sample for EFA.

EFA was performed using principal components extraction with direct oblimin rotation, as correlations among motivational constructs were theoretically expected. The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity were used to assess the suitability of the data for factor analysis. Items with low factor loadings (below .40), significant cross-loadings, or insufficient communalities were excluded. The final factor structure was determined based on eigenvalues greater than 1, scree plot inspection, and theoretical interpretability. In line with Kane's (2013) argument-based framework, the EFA, together with item-total correlations (Table 3), were conducted as sources of internal-structure evidence, supporting the generalisation and extrapolation inferences by showing that the items coherently represent the theoretical construct of motivation toward VR.

2.2. Results

Prior to conducting EFA, the suitability of the data for factor analysis was evaluated. The KMO measure of sampling adequacy was .762, indicating that the sample size was sufficient for reliable factor extraction (Hutcheson & Sofroniou, 1999). Additionally, Bartlett's Test of Sphericity was statistically significant ($\chi^2 = 907.698$; df = 91; $p < .001$), confirming that the correlations among items were adequate for factor analysis (Tabachnick & Fidell, 2007).

The preliminary analysis revealed several items exhibiting low factor loadings (< .40) or cross-loadings across different factors. These items were eliminated sequentially to enhance the clarity and interpretability of the factor solution. Consequently, a final structure of 14 items and three factors was achieved. Each factor demonstrated conceptual coherence and corresponded with distinct types of motivation that are consistent with the SDT framework.

This three-factor structure explained 50.06% of the total variance, with each factor accounting for 24.32%, 15.09%, and 10.64% of the variance, respectively. The factor loadings for the items within these factors ranged from 0.487 to 0.799, and there were no significant cross-loadings. As a result of the EFA, the MVR Scale with 14 items was formed. A detailed summary of the factor loadings, eigenvalues, and the cumulative variance explained by each extracted factor is presented in Table 2.

An examination of the EFA results presented in Table 2 indicates a three-factor structure consisting of 14 items, with each factor demonstrating adequate loadings and conceptual coherence. The identified factors correspond to distinct forms of motivation aligned with the SDT framework. This factor structure answers RQ1 by demonstrating that motivation toward VR is organised into theoretically meaningful dimensions rather than a single undifferentiated construct.

3. Study II

Study II examined the validity and reliability of the 14-item, three-factor MVR Scale identified in Study I. Construct validity was tested through confirmatory factor analysis

Table 2. Factor loadings, % of variances, total variance, eigenvalues.

	Factor		
	Integrated Regulation	Intrinsic Motivation	External Regulation
Item 4	.793		
Item 7	.733		
Item 1	.725		
Item 5	.664		
Item 10	.526		
Item 2	.506		
Item 12		.799	
Item 8		.723	
Item 14		.669	
Item 13		,650	
Item 3			.779
Item 9			.747
Item 11			.711
Item 6			.487
Eigenvalues	3,406	2,113	1,491
% of variance	24,327%	15,093%	10,647%
Total variance: 50,067%			

(CFA), while Item Response Theory (IRT) analyses evaluated item quality. Measurement invariance across subgroups (gender) was also assessed. Criterion-related validity was examined via correlations with two external VR-related measures. Reliability was evaluated using Cronbach's alpha, McDonald's omega, and Guttman's lambda.

3.1. Method

3.1.1. Participant and procedure

A total of 292 middle school students participated in Study II. Recruitment followed the classroom based procedure described in Study I, with the same inclusion criteria and bias mitigation steps, ensuring methodological continuity. Participants had a mean age of 12.76 (SD = 1.03). All participants had previous experience with VR applications (M = 4.09, SD = 4.71) employed in educational settings. Further information about participants is provided in Table 1.

To data collection, an instrument package was established, comprising the finalised 14-item MVR Scale, in addition to two additional measures: the Educational Virtual Reality Applications Attitude Scale and the Educational UTAUT-Based Virtual Reality Acceptance Scale. These measures were employed to evaluate criterion-related validity.

The researcher directly collected data in classroom settings during school hours. Prior to participation, students were informed about the aims of the research, the voluntary nature of their involvement, and their right to withdraw at any point without consequence. Informed consent was obtained from all participants.

3.1.2. Measures

Motivation toward Virtual Reality Scale (MVR): The MVR Scale consists of 14 items and three factors. These factors are grounded in SDT (Deci & Ryan, 2000) and represent different dimensions of student motivation related to the use of VR in educational contexts. The scale captures both intrinsic and extrinsic motivational components. Each item is rated on a 5-point Likert-type scale, ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). Higher scores on the scale reflect higher levels of motivation toward the use of VR in educational contexts. In this study, Cronbach's alpha for the total scale score was $\alpha = 0.80$.

Educational Virtual Reality Applications Attitude Scale (EdVR-AS): The EdVR-AS scale, developed by Akçelik and Baran (2022), was used to assess students' general attitudes toward the use of VR in educational contexts. The scale consists of 18 items structured under a single-factor model and is administered using a 5-point Likert-type response format, ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). Higher scores on the scale indicate more positive attitudes toward the use of VR in education. In the current study, the scale demonstrated high internal consistency, with a Cronbach's alpha of 0.87.

Educational UTAUT-Based Virtual Reality Acceptance Scale: The scale was developed by Ustun et al. (2023), consist of 18 items. This scale comprises four subdimensions that reflect the core constructs of the UTAUT model: Performance Expectancy, Effort Expectancy, Social Influence, and Facilitating Conditions. The scale yields a total score ranging from 18 to 90, with higher scores indicating a greater level of acceptance toward the use of VR for educational purposes among students. Each item is rated on a 5-point Likert-type scale, ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). In this study, Cronbach's alpha was 0.91 for the overall scale.

3.1.3. Data analysis

Before examining the validity, descriptive statistics (including mean, standard deviation, skewness, and kurtosis) were calculated for each item of the scale, along with the other scales included in this study. The analyses were performed utilising IBM SPSS version 27.

Following this, CFA was conducted using AMOS Graphics 24 to assess the construct validity of the MVR Scale. A measurement model was constructed and examined, and its goodness of fit was assessed using several fit indices (χ^2/df, CFI, GFI, AGFI, TLI, IFI, SRMR, RMSEA). After the CFA, IRT analyses were carried out to obtain a deeper understanding of how participants responded to each item. The IRT analysis was performed using Stata software. Subsequently, measurement invariance testing was conducted to assess whether the scale captured the same underlying construct across gender groups (male and female). To assess the criterion-related validity of the scale, correlation analyses were conducted between the MVR Scale and two external measures: the Educational Virtual Reality Applications Attitude Scale and the Educational UTAUT-Based Virtual Reality Acceptance Scale. Lastly, the reliability of the scale was examined through multiple indicators. Reliability coefficients, including Cronbach's alpha (α), McDonald's omega (ω), and Guttman's lambda-6 (λ6), were calculated. Furthermore, item-total correlation coefficients were calculated for each item. Consistent with Kane's (2013) argument-based validity framework, the IRT results contributed to the scoring and generalisation inferences. Measurement invariance across gender supported the extrapolation inference, while reliability indices further reinforced generalisation, and correlations with external VR-related measures provided additional extrapolation evidence within the overall validity argument.

3.2. Results

The results of the CFA demonstrated that the model fit indices fell within acceptable thresholds [(χ^2/df = 2.30; CFI = .92; GFI = .92; AGFI = .90; TLI = .90; IFI = .92; SRMR = .057; RMSEA = .067)]. All factor loadings for the MVR Scale were statistically significant, ranging from 0.413 to 0.832. In addition, item analysis results for the scale are presented in Table 3.

Given that the MVR Scale uses a Likert-type format, applying IRT provides a more refined analysis of how individuals differentiate among response options. According to Baker (2001), item discrimination is classified as very low (.01-.34), low (.35-.64), medium (.65–1.34), high (1.35–1.69), and very high (>1.70). In the IRT analysis for this study, all the items on the MVR Scale, except for one, surpassed the recommended threshold, indicating strong item discrimination. IRT results are presented in Table 4.

When examining the item-level results reported in Tables 3 and 4, the MVR items exhibit satisfactory factor loadings, appropriate item–total correlations, and adequate discrimination parameters across response categories. These findings indicate that individual items function as intended and contribute meaningfully to the measurement of VR motivation. This pattern of item functioning answers RQ2 by showing that the

Table 3. Factor loadings, descriptive statistics, and item-total correlations.

Item	Factor Loadings	Mean	SD	Skewness	Kurtosis	Item-total correlations
Item 1	.63	3.09	1.19	−0.19	−0.62	.54
Item 2	.58	2.76	1.27	0.19	−1.00	.42
Item 3	.50	3.44	1.22	−0.37	−0.67	.45
Item 4	.69	3.13	1.30	−0.22	−1.03	.54
Item 5	.72	3.33	1.32	−0.35	−0.92	.60
Item 6	.59	3.75	1.28	−0.83	−0.33	.52
Item 7	.73	3.40	1.20	−0.48	−0.58	.61
Item 8	.57	4.33	1.13	−1.73	2.00	.50
Item 9	.55	3.40	1.28	−0.43	−0.85	.48
Item 10	.70	3.15	1.25	−0.31	−0.86	.62
Item 11	.41	2.72	1.37	0.22	−1.13	.30
Item 12	.83	4.53	0.96	−2.20	4.14	.67
Item 13	.66	4.24	1.13	−1.36	0.82	.57
Item 14	.65	4.43	1.01	−1.91	2.98	.54

scale's items possess sound psychometric properties rather than weak or redundant indicators.

Measurement invariance confirms that a scale measures the same underlying construct across different groups or time points (Meredith, 1993). Without establishing invariance, comparisons of scores between groups may lead to inaccurate or misleading conclusions. The results of the measurement invariance analysis supported configural, metric, and scalar invariance, with $\Delta CFI \leq .01$ and $\Delta RMSEA \leq .015$ observed across the tested models. The findings of the measurement invariance are presented in Table 5.

To evaluate the criterion-related validity of the MVR Scale, Pearson's correlation analysis was conducted. The results revealed significant relationships between motivation toward VR and variables such as attitude toward VR, and the subdimensions of the UTAUT-based VR acceptance. Detailed correlation findings are presented in Table 6.

As shown in Table 6, motivation toward VR is positively related to students' attitudes toward VR, their level of acceptance of VR technologies, and adaptive academic characteristics such as academic buoyancy and grit. However, its relationship with science anxiety is limited and dimension specific. This relationship model answers RQ4 by demonstrating that the MVR scale is related to external concepts in theoretically meaningful and differentiated ways, rather than through uniform or indiscriminate correlations.

Table 4. IRT results of MVR scale.

	Item	*a* coefficient	SE	Confidence interval	*z*	*p* > |*z*|
Factor 1	Item 1	1.74	.20	1.34–2.14	8.58	.001
	Item 2	1.57	.18	1.20–1.94	8.38	.001
	Item 4	2.18	.25	1.68–2.68	8.60	.001
	Item 5	2.19	.25	1.68–2.70	8.45	.001
	Item 7	2.09	.24	1.62–2.56	8.66	.001
	Item 10	1.85	.21	1.42–2.27	8.58	.001
Factor 2	Item 3	1.30	.24	0.81–1.79	5.24	.001
	Item 6	1.11	.21	0.70–1.53	5.25	.001
	Item 9	1.59	.31	0.98–2.20	5.13	.001
	Item 11	0.90	.17	0.55–1.24	5.07	.001
Factor 3	Item 8	1.83	.26	1.30–2.35	6.81	.001
	Item 12	4.47	1.12	2.27–6.68	3.98	.001
	Item 13	2.06	.29	1.48–2.65	6.95	.001
	Item 14	2.20	.33	1.55–2.85	6.63	.001

Table 5. MI results of MVR scale.

Invariance	χ^2	*df*		IFI	CFI	SRMR	RMSEA	ΔCFI	ΔRMSEA
Males	136.904	74	1.85	.90	.90	.074	.075	–	–
Females	126.584	74	1.71	.92	.91	.064	.072	–	–
Configural invariance	263.488	148	1.78	.91	.91	.064	.052	–	–
Metric invariance	272.247	159	1.71	.91	.91	.065	.050	.002	.002
Scalar invariance	280.010	170	1.64	.91	.91	.065	.047	.003	.003

Table 6. Descriptive statistics and correlations with MVR scale.

					Correlation with *MVR* scale	
Variables	Mean	SD	Skewness	Kurtosis	*r*	*p*
STUDY II						
MVR	49.76	8.90	−.143	−.413	–	–
VR Attitude	59.45	13.48	−.792	.601	.636**	<0.001
VR Acceptance	61.59	15.08	−.416	.241	.616**	<0.001
STUDY III						
MVR	53.52	9.35	−.330	−.316	–	–
Academic Buoyancy	14.15	4.04	−.342	−.590	.338**	<0.001
Academic Grit	38.55	7.62	−.411	−.551	.417**	<0.001
Science Anxiety						
Value Understanding	9.57	3.58	.338	−.553	−.133**	<0.001
Personal Perception	20.72	8.03	.119	−.563	−.035	>0.05

Table 7. Reliability analysis of MVR scale.

Analyis	Study II (N = 292)	Study III (N = 418)
Cronbach's alpha	.795	.846
McDonald's omega	.800	.865
Gutmann's lambda	.819	.865

Lastly, the internal consistency of the scale was evaluated using Cronbach's alpha, McDonald's omega, and Guttman's lambda coefficients. The corresponding reliability values are reported in Table 7.

Based on the reliability indices and invariance analyses summarised in Tables 5 and 7, the MVR scale demonstrates acceptable internal consistency and retains its measurement structure across gender groups. The reliability coefficients indicate stable score estimation, while invariance results confirm equivalent measurement across groups. Together, these findings answer RQ3 by showing that the MVR scale provides consistent and comparable measurement rather than group-specific or unstable scores.

4. Study III

Building on the psychometric evaluation of the MVR Scale, Study III aimed to explore its relationships with academic buoyancy, academic grit, and science anxiety, while examining these variables within the framework of a proposed theoretical model. Consistent with the validity argument outlined above, Study III is intended to provide nomological validity evidence for the MVR scale. The study began by exploring how the variables were connected and then employed SEM to test the overall pattern of relationships within the proposed framework. Lastly, a bootstrap resampling procedure was employed to assess the statistical significance of the indirect pathways.

4.1. Method

4.1.1. Participant and procedure

Participants in this study were selected using criterion sampling. Recruitment again mirrored the Study I procedure, including the same inclusion criteria and steps to limit motivation related self-selection. Participants had prior experience with VR applications ($M = 4.19$, $SD = 5.60$). A total of 418 participants took part in the study. The mean age of the participants was calculated as 11.80 years ($SD = 1.06$). Further information about the participants is provided in Table 1.

Before taking part in the study, students were informed about the purpose of the research, their voluntary participation, and their right to withdraw at any time without any negative consequences. All participants provided informed consent.

4.1.2. Measures

Academic Buoyancy Scale (ABS): The ABS scale was developed by Martin and Marsh (2008) and translated into Turkish by Aksu et al. (2024). It consists of four items (e.g. '*I'm good at dealing with setbacks*') on a five-point Likert scale ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). Cronbach's alpha value of the scale was calculated as $\alpha = 0.71$ in this study.

Academic Grit Scale: Originally developed by Rojas et al. (2012) and adapted into Turkish by Bozgun and Basgul (2018), the Academic Grit Scale consists of 10 items. Each item is rated on a five-point Likert scale, ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). In this study, the Cronbach's alpha coefficient for the scale was $\alpha = 0.79$.

Science Anxiety of Middle School Students Scale (SAMS): The SAMS was developed by Celik (2021) to assess students' levels of anxiety related to science courses. The scale consists of 13 items (e.g. '*I feel uneasy and anxious during science lessons.*'), each rated on a five-point Likert scale ranging from 1 ('Strongly Disagree') to 5 ('Strongly Agree'). Additionally, the scale consists of two subdimensions: Personal Perception and Value Understanding. The Personal Perception subscale assesses students' emotional responses toward science lessons, while the Value Understanding subscale measures the importance and value students attribute to science education. Cronbach's alpha value of the scale was calculated as $\alpha = 0.82$ in this study.

4.1.3. Data analysis

In Study III, initial analyses involved calculating descriptive statistics for all variables using SPSS. To investigate potential associations, correlation analyses were conducted among motivation toward VR, academic buoyancy, academic grit, and science anxiety. After identifying the patterns of relationships, the proposed theoretical framework was tested through SEM, utilising the AMOS software. The mediation analysis followed a two-step approach: first, the measurement model was examined, and then the structural model was tested. Model fit was evaluated using a range of goodness-of-fit indices, including χ^2/df, CFI, GFI, NFI, IFI, and SRMR. Lastly, a bootstrap resampling procedure with 5,000 iterations was conducted to estimate confidence intervals for the indirect effects. This approach provides a robust method for testing the significance of mediation by accounting for non-normality in the sampling distribution. Aligned with Kane's

(2013) argument-based validity framework, these SEM and mediation analyses furnished extrapolation and consequential inferences by embedding MVR scores within a broader nomological network (predicting academic buoyancy and grit) and by evaluating their implications for science anxiety through indirect pathways, thereby strengthening the overall validity argument.

4.2. Results

First, a significant positive relationship was found between motivation toward VR and academic buoyancy (r = .338, $p < .01$). This suggests that as students' motivation to engage with VR increases, their levels of academic buoyancy also tend to rise. Similarly, a significant positive correlation was observed between motivation toward VR and academic grit (r = .417, $p < .01$). This indicates that students with higher motivation for VR use are also more likely to exhibit greater academic perseverance and effort. Finally, a negative and nonsignificant correlation was observed between motivation toward VR and science anxiety (r = –.071, $p > .05$), indicating that no meaningful association was found between the two variables. However, a significant negative correlation was found between motivation toward VR and the Value Understanding subdimension of science anxiety (r = –.133, $p < .01$), indicating that students who place greater value on science lessons tend to show lower motivation toward the use of VR in educational settings. In contrast, the correlation between motivation toward VR and the Personal Perception subdimension was negative but nonsignificant (r = –.035, $p > .05$), suggesting that students' emotional responses toward science lessons are not meaningfully related to their motivation to engage with VR. Table 6 presents the descriptive statistics for all variables, along with the information outlined above.

To evaluate the proposed model, a SEM approach was employed, which is illustrated in Figure 1. In the initial phase, a measurement model consisting of four latent variables (motivation toward VR, academic buoyancy, academic grit, and science anxiety) and nine observed variables were examined. The measurement model exhibited an acceptable level of fit based on the evaluated indices (χ^2 /df = 5.75; CFI = .92; GFI = .94; NFI = .91; IFI = .92; SRMR = .081). Within this model, all standardised factor loadings were statistically significant, with values ranging from 0.16 to 0.95 ($p < 0.001$). Following the evaluation of the measurement model, the structural model was analyzed. The results showed that the proposed mediation model demonstrated an acceptable fit to the data (χ^2/df = 6.07; CFI = .91; GFI = .93; NFI = .90; IFI = .91; SRMR = .084). Within the model, motivation toward VR had a significant and positive direct effect on academic buoyancy (β = 0.444, $p < .001$) and academic grit (β = 0.216, $p < .001$). Academic buoyancy positively predicted science anxiety (β = 0.326, $p < .001$), whereas academic grit had a significant negative direct effect on science anxiety (β = –0.777, $p < .001$). Furthermore, the indirect effects were statistically significant, as supported by a bootstrap analysis, which is illustrated in Table 8.

An inspection of the structural model presented in Figure 1 and the indirect effects reported in Table 8 indicates that motivation toward VR is embedded within a broader network of theoretically related constructs. The results show that VR motivation is indirectly associated with science anxiety through academic buoyancy and academic

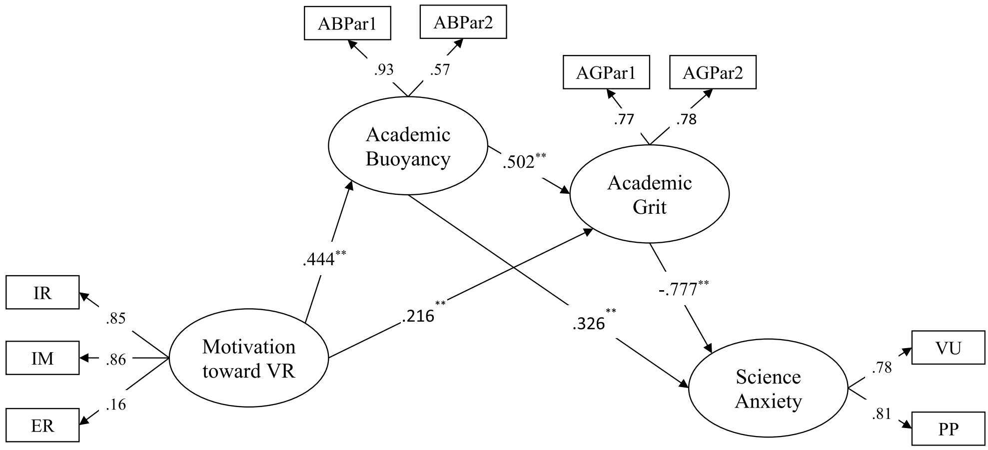

Figure 1. Standardised factor loading for the fully mediated structural model. *Note. N* = 418; ** *p* < .001; *IR* integrated regulation; *IM* intrinsic motivation; *ER* external regulation; *ABPar* parcels of academic buoyancy; *AGPar* parcels of academic grit; *VU* value understanding; *PP* personal perception.

Table 8. Indirect and direct effects for the paths of the model.

		95 % C.I.	
Model Pathways	Estimated	Lower	Upper
Direct link			
MVR → Academic Buoyancy	.424	.304	.549
Academic Buoyancy → Academic Grit	.468	.334	.601
MVR → Academic Grit	.424	.304	.549
Academic Grit → Science Anxiety	−.873	−1.074	−.690
Academic Buoyancy → Science Anxiety	.273	.119	.485
Indirect link			
MVR → Academic Buoyancy → Science Anxiety	.154	.064	.340
MVR → Academic Grit → Science Anxiety	−.328	−.538	−.165
MVR→ Academic Buoyancy → Academic Grit → Science Anxiety	−.230	−.420	−.127

grit, highlighting the mediating roles of these adaptive academic characteristics. This relational pattern answers RQ5 by demonstrating that the MVR scale operates coherently within a theoretically grounded mediation model, providing evidence of its nomological validity rather than isolated or atheoretical associations.

In addition to the proposed model, an alternative model was tested in which motivation toward VR was specified as the independent variable, science anxiety and academic grit as sequential mediators, and academic buoyancy as the outcome variable. Although this model showed an acceptable fit ($\chi^2/df = 5.56$; CFI = .92; GFI = .94; NFI = .91; IFI = .92; SRMR = .082), the direct path from motivation toward VR to science anxiety was not statistically significant ($\beta = -0.046$, $p > .05$). Because the central criterion for model selection was the presence of theoretically consistent and statistically significant pathways, the alternative model was not retained. Instead, the proposed model presented in Figure 1 was preferred, as it ensured that all hypothesised paths were significant. The alternative model has been given in Appendix B.

5. Discussion

Given its potential, the use of VR in educational settings has been expanding rapidly, highlighting the need to investigate its impact on students. In this context, it becomes crucial to explore how VR affects various dimensions of the learning experience, including cognitive, emotional, and motivational outcomes. Therefore, this study aims to develop the MVR scale to better understand students' motivational engagement with this technology and to examine the relationships between their motivation and various other variables. Following Kane (2013), converging evidence across studies was brought together. Study I addressed content and internal structure. Study II demonstrated scoring, generalisation and extrapolation. Study III added extrapolation and consequences, forming a coherent validity argument for the MVR scale.

Before presenting the findings of each study individually, it is useful to first emphasise how the developed MVR Scale contributes to existing theory and practice, as this offers a broader lens through which all studies can be interpreted. The development of the MVR Scale addresses a notable methodological and conceptual gap within the field of educational technology. A recurring limitation in the literature is that researchers frequently rely on adapted versions of general technology-use surveys or broad motivation questionnaires that were not originally designed for immersive and context-dependent environments like VR (Jensen & Konradsen, 2018). Because of this, such generalised instruments often fail to capture the distinctive psychological dynamics that emerge in VR-based learning. Furthermore, critiques in the literature point out that many instruments used in VR and AR research lack sufficient validity evidence and tend to narrow their focus to cognitive outcomes such as knowledge acquisition (Tudor Car et al., 2022). In contrast, the MVR Scale represents a context-sensitive tool developed specifically for educational VR and supported by validity evidence. Its key contribution lies in its capacity to measure not only the level of motivation but also its underlying source and quality. Consistent with SDT, the scale can identify students' motivation for VR usage along the internalisation continuum. Thus, unlike instruments that solely assess technology acceptance or general attitudes, it allows us to distinguish whether students' engagement with VR applications stems from external pressures or from an internalised value aligned with their personal learning goals. This diagnostic capacity may help educators design targeted pedagogical interventions aimed at shifting motivation from externally controlled forms toward more autonomous participation by supporting students' needs for autonomy and competence. Moreover, within the framework of SDT, many existing instruments tend to conceptualise external motivation as a single, undifferentiated construct (Howard et al., 2017), without clarifying whether students engage in activities to obtain rewards or to avoid negative consequences. The MVR Scale addresses this limitation by explicitly distinguishing three forms of motivational regulation along the SDT continuum and operationalising each as a separate subscale.

Continuing with each separate study, in Study I, a 32-item pool was generated based on SDT and supported by qualitative information obtained from student interviews. After being applied to a larger sample group ($n = 301$), the item set was examined using EFA, resulting in a 14-item scale consisting of three subscales: external regulation, integrated regulation, and intrinsic motivation. Although SDT conceptualises motivation through a continuum that also includes introjected and identified regulation, these two subdimensions were not retained in the final structure. This outcome aligns with the theoretical proximity among SDT constructs; external and introjected regulation both reflect controlled forms of motivation, while identified and integrated regulation represent more autonomous stages of internalisation (Deci & Ryan, 2000). Moreover, items that were initially related to the excluded subdimensions were absorbed by theoretically closer factors. For instance, an item originally linked to introjected regulation was placed under external regulation. This pattern suggests that the three subdimensions retained in the final scale capture students' motivational orientations adequately and prevent conceptual overlap that would arise from including closely related categories.

In Study II, the second phase of the research, the scale was examined in terms of its validity, item discrimination, and measurement equivalence across groups through CFA, IRT and measurement invariance analyses. Criterion-related validity was subsequently tested with two external measures, and reliability was assessed through internal consistency analyses. The CFA demonstrated that the scale exhibited a satisfactory model fit and supported the construct structure. Findings of measurement invariance confirmed configural, metric, and scalar invariance across gender, meaning that the scale measured the same construct in the same way for male and female participants, with comparable factor organisation, item relevance, and response tendencies. This indicates that the scale allows for meaningful and unbiased comparisons between gender groups. Reliability analyses conducted using Cronbach's alpha, McDonald's omega, and Guttman's lambda also showed that the scale provided acceptable reliability indicators in all studies.

The correlation analysis revealed significant positive relationships between motivation toward VR, attitudes toward VR, and VR acceptance. These significant relationships have provided evidence for criterion-related validity. Beyond their value as evidence of validity, these relationships reveal a pattern in which motivational and attitudinal variables mutually reinforce each other in learning environments. Based on the findings of this study, it can be interpreted that when students are more motivated to use VR for reasons such as autonomy or personal values, they may develop more positive attitudes toward the technology, which could increase acceptance and usage rates. This interpretation is consistent with the Technology Acceptance Model (TAM; Davis, 1989), which posits that perceived usefulness and ease of use influence users' attitudes and behavioural intentions toward technology. Thus, higher motivation might shape acceptance through its influence on these perceptions (Zhang et al., 2022). The study conducted by Fussell and Truong (2021) showed that perceived ease of use and enjoyment significantly enhanced users' positive attitudes toward VR and their intention to use it for training purposes.

The results obtained from IRT confirmed that the items successfully distinguished individuals with different levels of the measured trait. It also revealed the most discriminative item in each subscale. Each of these most discriminating items within the subdimensions may embody key psychological functions that effectively represent the fundamental nature of the relevant regulatory style. For example, the item indicating that a student uses VR because they are concerned about possible outcomes demonstrates the effect of external pressure and thus distinguishes individuals who exhibit a higher level of controlled motivation. The meanings conveyed by the most distinctive elements can also provide a clearer understanding of students' motivational orientations and point to various implications for the design of VR-based learning environments. The fact that the most distinctive element measuring external motivation is students' perception of the necessity of using VR to avoid potential negative consequences, may provide an important insight into how their needs should be met. From an SDT perspective, it is noted that reward-punishment strategies can weaken students' perceptions of autonomy and thus may lead to controlled motivation (Niemiec & Ryan, 2009). This situation indicates that the developed MVR scale may have successfully captured the dynamic in question and, therefore, that the appearance of the most distinctive item in the external regulation sub-dimension in this way is theoretically consistent.

Finally, in Study III, a structural model was tested using the scale developed in the earlier phases of the research. Additionally, correlation analysis indicated that VR motivation showed significant positive associations with academic buoyancy and academic grit. These findings point to a pattern in which students reporting higher VR motivation also tend to report higher levels of resilience in everyday academic situations and greater persistence toward their goals. VR motivation also showed a positive relationship with the personal perception sub-dimension of science anxiety, while its negative relationship with the value belief sub-dimension was not significant. This indicates that there is no significant connection between VR motivation and students' value judgments related to science in this study.

This outcome may be interpreted by considering that VR applications have the potential to increase students' situational engagement and confidence in their abilities within science classrooms. Gungor et al. (2022) demonstrated that the use of VR laboratories increased students' interest and self-efficacy, which in turn contributed to a reduction in anxiety. Similarly, a reasonable increase in perceived autonomy and control may help lower students' momentary anxiety in science contexts (Aydın & Michou, 2020). According to Lazarus and Folkman's (1984) transactional model of stress, when students feel they have enough resources to handle a learning task, they tend to see it as a 'challenge,' which helps lower their anxiety. On the other hand, if they feel they lack control or the necessary resources, they view the task as a 'threat,' which can increase their anxiety. By providing new learning resources such as opportunities for experimental practice or simulated testing environments VR may help students perceive science-related situations as less threatening. However, such situational elements do not typically correspond to immediate changes in more stable constructs such as value beliefs, which are described in the literature as developing gradually through long-term experiences and sociocultural contexts (Pekrun, 2006).

As for the SEM results, while no direct relationship was observed between VR motivation and science anxiety, indirect relationships were observed through academic buoyancy and grit. The analysis of the bivariate paths indicated that VR motivation positively predicted both academic buoyancy and academic grit. Furthermore, academic grit was a negative predictor of science anxiety. Interestingly, and contrary to prior assumptions, academic buoyancy emerged as a positive predictor of science anxiety. Even more, this situation did not change in the alternative models that were tested. Notably, this pattern held across alternative model specifications: even when modelling science anxiety as a mediator influencing academic buoyancy, the positive association between buoyancy and anxiety remained unchanged. The positive link between buoyancy and anxiety differs from previous work, where buoyancy and anxiety are typically negatively related (Putwain et al., 2023).

A closer look at the structure of academic buoyancy provides one possible contextual frame for this finding. According to the '5C' model proposed by Martin and Marsh (2008), academic buoyancy comprises dimensions such as composure and commitment. While composure reflects low levels of anxiety, commitment refers to sustained effort (Martin et al., 2010). Although students with high academic buoyancy are generally expected to exhibit both lower anxiety and greater perseverance, it is possible that, in practice, only the effort-related aspect of buoyancy was salient in this study. Moreover, from a theoretical perspective, strong determination and high achievement orientation may, in some cases, lead to increased anxiety. For instance, according to Pekrun's (2006) control-value theory, students who attach high value to a task may experience anxiety if they perceive a lack of sufficient control over their performance. Academically buoyant students may hold high expectations and often tend to be performance- or exam-oriented. In such cases, while the perceived value of academic tasks increases, a lack of reinforced control beliefs may lead to elevated levels of anxiety. Similarly, according to the approach-avoidance theory (Roth & Cohen, 1986), academically buoyant students are more likely to confront challenges directly rather than avoid them. During this process, they may experience temporary increases in anxiety. In other words, an academically buoyant student may continue to exert effort and remain engaged even in situations that elicit anxiety. In short, academic buoyancy may not eliminate anxiety; rather, it may reflect the courage to confront anxiety-inducing situations. Therefore, the positive relationship observed in the model might indicate a moderate increase in anxiety stemming from academically buoyant students' willingness to take responsibility for success in science courses.

An alternative interpretation of this paradoxical finding in the model can be explained through the relationship between academic buoyancy and academic grit. While academic buoyancy reflects the capacity to cope with short-term academic challenges, academic grit refers to sustained commitment and passion toward long-term goals. The commitment dimension in Martin and Marsh's 5C model has been directly defined as persistence (Martin et al., 2010), a trait closely aligned with academic grit. In this sense, the perseverance and commitment component of academic buoyancy closely corresponds to the concept of grit as defined by Duckworth et al. (2007). From this perspective, academic buoyancy may strengthen students' tendency not to give up in the face of short-term challenges. However, long-term perseverance is likely to play a more significant role in alleviating anxiety. Therefore, it is plausible that the relationship between academic buoyancy and science anxiety in our model was largely accounted for by the role of grit. In summary, the commitment component of academic buoyancy may facilitate its integration with grit, and together, they may serve as negative predictors of science anxiety. This possibility aligns with the findings of Datu et al. (2023), which suggest that students characterised by greater grit are generally less likely to experience high levels of anxiety.

6. Limitations

The present study offers valuable insights into the structural and relational dynamics among VR motivation, science anxiety, academic buoyancy, academic grit, and students' attitudes and acceptance toward VR. Nonetheless, several limitations should be acknowledged. First, the use of a cross-sectional research design restricts the ability to establish causal relationships between the variables. Although structural equation modelling revealed meaningful indirect effects, the directionality of influence such as whether VR motivation directly affects science anxiety remains uncertain. Future research employing longitudinal or experimental designs is needed to clarify causal pathways. Second, the reliance on self-report measures may have introduced potential biases, including socially desirable responding or distortions in self-assessment. Participants' responses might have been influenced by transient emotional states or prior experiences with VR. To address this issue, future studies could incorporate diverse data sources, such as behavioural observations, digital activity logs, or in-depth interviews, to provide a more comprehensive understanding. Third, although the VR Motivation Scale demonstrated sound psychometric properties in this study, the findings are limited to Turkish-speaking samples. To enhance the scale's generalizability, further validation studies should be conducted across different cultural and demographic groups to assess its measurement invariance. Finally, although participants were instructed to respond on their experiences with educational VR applications, it is possible that individual interpretations of 'virtual reality' varied. Some students may have drawn on prior experiences with entertainment VR or general digital technologies, which may introduce construct-related variability. Future studies should include more explicit procedures, such as standard definitions, illustrations, or concrete examples, to fully ensure conceptual consistency among participants.

7. Implications

In addition to its limitations, the findings of this study hold significant implications for science education research and practice. The validated MVR scale provides educators with a practical diagnostic tool that can be used to identify students with low levels of intrinsic or integrated motivation prior to VR-based instruction. This type of information can help teachers plan targeted support, such as short skills training sessions, specifically designed task options, or clear communication about the value and importance of VR activities, thereby increasing preparation and participation. The tool can also be re-administered after instruction to track changes in motivational quality and to evaluate which features of VR lessons (e.g. embedded guidance prompts, reflection opportunities, or structured assessment discussions) most effectively foster student engagement. At a broader organisational level, scale can provide information for professional development and programme preparation assessments, as correlation analysis has found that higher motivation is associated with more positive attitudes toward VR technologies and greater acceptance.

From a pedagogical perspective, the MVR scale can enable educators to translate measurement results into practical applications in the classroom. For example, teachers can differentiate teaching strategies based on students' motivational profiles, adjust the level of instructional support for those who feel less competent or autonomous in VR environments, or design interventions that specifically address barriers identified in the scale's subscales. The scale's ability to determine motivational profiles can enable more informed decisions about when and how VR should be integrated into science education.

Theoretically, the study contributes to a more integrated understanding of how motivation, emotional responses, and adaptive traits interact within immersive learning environments. SEM results suggest that students' motivation to use VR is linked to science anxiety through shared psychological resources, particularly academic buoyancy and grit, which help them manage academic demands and sustain their efforts. This mediation model emphasises VR's broader role as a context in which motivational and emotional processes are intertwined. Thus, this validated tool enables future researchers to conduct more rigorous studies. These studies may explore topics such as how motivation processes evolve over time, how different VR design features activate or suppress these processes, and how VR-based interventions can be optimised to overcome emotional barriers while increasing engagement.

8. Conclusion

In response to commonly criticised practices in education, VR has gained prominence as a contemporary research focus, given its potential to enhance meaningful learning experiences for students. This study first aimed to develop a scale to measure VR motivation and subsequently tested a structural model incorporating this variable. The findings indicated that the developed scale is a valid and reliable measurement tool. The IRT results showed high item discrimination, and measurement invariance analysis confirmed that the scale functioned equivalently across genders. In the structural model, the mediating roles of academic buoyancy and academic grit in the relationship between VR motivation and science anxiety were examined. The SEM results further revealed that academic buoyancy and academic grit are closely related constructs within the tested model. Grounded in the theoretical perspectives of the 5C model of academic buoyancy, SDT, control-value theory, approach-avoidance theory, and transactional stress theory, the findings highlight the potential of VR as a promising means to reduce science anxiety. Additionally, the results emphasise the importance of sustained perseverance toward long-term academic goals such as grit in mitigating students' experiences of science-related anxiety. Based on these findings, it may be beneficial to design curricula that integrate VR and support student motivation, while also allowing learners to explore personal traits such as perseverance and resilience, to reduce anxiety related to science courses and assessments. In conclusion, the findings draw attention to the complex dynamics of science anxiety in digitally enriched classrooms and stress the need to strengthen students' self-efficacy and long-term perseverance, as these factors play a key role in enabling students to adapt to technological tools like VR and manage the demands of science learning more effectively.

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Authors contributions

Study planning: MYK; **Study plan validation:** All authors; **Project implication:** All authors; **Data collection:** MYK; **Data interpretation:** MYK; **Data analysis**: MYK; **First draft**: MYK; **Review, Rewrite and Edit:** ÜUT; **Final approval:** All authors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval

This research was ethically approved by Yıldız Technical University Institute of Social Sciences Ethics Committee with document number 006025.

Consent to participate

Informed consent was obtained from all the individual participants that were included in the study.

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References

Ahn, S. J. G., Nowak, K. L., & Bailenson, J. N. (2022). Unintended consequences of spatial presence on learning in virtual reality. *Computers & Education*, *186*, 104532. https://doi.org/10.1016/j.compedu.2022.104532

Akçelik, M., & Baran, B. (2022). Developing a scale to investigate learners' attitudes towards educational virtual reality applications (EdVR-AS). *Eğitim Teknolojisi Kuram ve Uygulama*, *12*(1), 21–40. https://doi.org/10.17943/etku.935285

Aksu, Z., Kul, Ü, & Satıcı, S. A. (2024). Number sense and academic buoyancy among middle school students: A serial mediation model of mathematical metacognition awareness and math anxiety. *Anales de Psicología/Annals of Psychology*, *40*(3), 421–431. https://doi.org/10.6018/analesps.600901

Aydın, G., & Michou, A. (2020). Self-determined motivation and academic buoyancy as predictors of achievement in normative settings. *British Journal of Educational Psychology*, *90*(4), 964–980. https://doi.org/10.1111/bjep.12338

Bailenson, J. (2018). *Experience on demand: What virtual reality is, how it works, and what it can do*. WW Norton & Company.

Baker, F. B. (2001). *The basics of item response theory* (2nd ed.). ERIC clearinghouse on assessment and evaluation. https://files.eric.ed.gov/fulltext/ED458219.pdf.

Borgers, N., Sikkel, D., & Hox, J. (2004). Response effects in surveys on children and adolescents: The effect of number of response options, negative wording, and neutral mid-point. *Quality and Quantity*, *38*(1), 17–33. https://doi.org/10.1023/B:QUQU.0000013236.29205.a6

Bozgun, K., & Basgul, M. (2018). Adaptation of academic grit scale to Turkish: Validity and reliability study. *The Journal of Academic Social Science*, *6*(85), 435–445. https://doi.org/10.16992/ASOS.14521

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Carpenter, S. (2018). Ten steps in scale development and reporting: A guide for researchers. *Communication Methods and Measures*, *12*(1), 25–44. https://doi.org/10.1080/19312458.2017.1396583

Cazarez, D. C. M. (2022). Exploring influences on the choice of fields of study in higher education: Evidence from Mexico. *International Journal of Educational Development*, *93*, 102643. https://doi.org/10.1016/j.ijedudev.2022.102643

Celik, M. E. (2021). *Examination of middle school students' anxiety levels towards science* (Publication No. 704995) [Unpublished Master's thesis]. Kırşehir Ahi Evran University. National Thesis Center Open. https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp.

Chakravartty, A. (2022). Scientific knowledge vs. knowledge of science. *Science & Education*, *32*, 1795–1812. https://doi.org/10.1007/s11191-022-00376-6

Cheng, K., & Tsai, C. (2020). Students' motivational beliefs and strategies, perceived immersion and attitudes towards science learning with immersive virtual reality: A partial least squares analysis. *British Journal of Educational Technology*, *51*(6), 2140–2159. https://doi.org/10.1111/bjet.12956

Clark, L. A., & Watson, D. (2016). Constructing validity: Basic issues in objective scale development. *Psychological Assessment*, *7*(3), 309–319. https://doi.org/10.1037/14805-012

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*. Routledge.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications.

Datu, J. A. D., Buenconsejo, J. U., Shek, C. Y. C., Choy, Y. L. E., & Sou, K. L. E. (2023). Grit, academic engagement in math and science, and well-being outcomes in children during the COVID-19 pandemic: A study in Hong Kong and Macau. *School Psychology International*, *44*(4), 489–512. https://doi.org/10.1177/01430343221147273

Davis, F. (1989). Technology acceptance model: Origins. *Working Papers on Information Systems*, 35–59. https://doi.org/10.4018/978-1-4666-8156-9.ch013

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, *11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01

DeVellis, R. F. (2017). *Scale development theory and applications*. Sage Publications.

DeWitt, J., & Archer, L. (2015). Who aspires to a science career? A comparison of survey responses from primary and secondary school students. *International Journal of Science Education*, *37*(13), 2170–2192. https://doi.org/10.1080/09500693.2015.1071899

Duckworth, A. L., Peterson, C., Matthews, M. D., & Kelly, D. R. (2007). Grit: Perseverance and passion for long-term goals. *Journal of Personality and Social Psychology*, *92*(6), 1087–1101. https://doi.org/10.1037/0022-3514.92.6.1087

Fussell, S., & Truong, D. (2021). Accepting virtual reality for dynamic learning: An extension of the technology acceptance model. *Interactive Learning Environments*, *31*, 5442–5459. https://doi.org/10.1080/10494820.2021.2009880

Garduño, H. A. S., Martinez, M. I. E., & Castro, M. P. (2021). Impact of virtual reality on student motivation in a high school science course. *Applied Science*, *11*(20), 9516. https://doi.org/10.3390/app11209516

Gungor, A., Avraamidou, L., Kool, D., Lee, M., Eisink, N., Albada, B., van der Kolk, K., Tromp, M., & Bitter, J. H. (2022). The use of virtual reality in a chemistry lab and its impact on students' self-efficacy, interest, self-concept and laboratory anxiety. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(3), em2090. https://doi.org/10.29333/ejmste/11814

Han, I. (2020). Immersive virtual field trips in education: A mixed-methods study on elementary students' presence and perceived learning. *British Journal of Educational Technology*, *51*(2), 420–435. https://doi.org/10.1111/bjet.12842

Herzog, A. R., & Bachman, J. G. (1981). Effects of questionnaire length on response quality. *The Public Opinion Quarterly*, *45*(5), 549–559. https://doi.org/10.1086/268687

Howard, J. L., Gagné, M., & Bureau, J. S. (2017). Testing a continuum structure of self-determined motivation: A meta-analysis. *Psychological Bulletin*, *143*(12), 1346–1377. https://doi.org/10.1037/bul0000125

Hutcheson, G. D., & Sofroniou, N. (1999). *The multivariate social scientist: Introductory statistics using generalized linear models*. Sage Publications.

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*(4), 1515–1529. https://doi.org/10.1007/s10639-017-9676-0

Jiang, J., & Fryer, L. K. (2024). The effect of virtual reality learning on students' motivation: A scoping review. *Journal of Computer Assisted Learning*, *40*(1), 360–373. https://doi.org/10.1111/jcal.12885

Kane, M. (2013). The argument-based approach to validation. *School Psychology Review*, *42*(4), 448–457. https://doi.org/10.1080/02796015.2013.12087465

Kang, J., Salonen, A., Tolppanen, S., Scheersoi, A., Hense, J., Rannikmäe, M., Soobard, R., & Keinonen, T. (2021). Effect of embedded careers education in science lessons on students' interest, awareness, and aspirations. *International Journal of Science and Mathematics Education*, *21*, 211–231. https://doi.org/10.1007/s10763-021-10238-2

Keller, C., Walker, G., Amenduni, F., Tela, A., & Cattaneo, A. (2025). Find the apartment's flaws! the impact of virtual reality on vocational students' performance in general education classes and the roles of flow experience, motivation, and sense of presence. *Education and Information Technologies*, 1–26. https://doi.org/10.1007/s10639-025-13320-2

Klingenberg, S., Jørgensen, M. L., Dandanell, G., Skriver, K., Mottelson, A., & Makransky, G. (2020). Investigating the effect of teaching as a generative learning strategy when learning through desktop and immersive VR: A media and methods experiment. *British Journal of Educational Technology*, *51*(6), 2115–2138. https://doi.org/10.1111/bjet.13029

Lazarus, R. S., & Folkman, S. (1984). *Stress, appraisal, and coping*. Springer publishing company.

Lin, H. C., Hwang, G. J., Chou, K. R., & Tsai, C. K. (2023). Fostering complex professional skills with interactive simulation technology: A virtual reality-based flipped learning approach. *British Journal of Educational Technology*, *54*(2), 622–641. https://doi.org/10.1111/bjet.13268

Makransky, G. (2021). The immersion principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (3rd ed., pp. 296–303). Cambridge University Press.

Makransky, G., Borre-Gude, S., & Mayer, R. E. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, *35*(6), 691–707. https://doi.org/10.1111/jcal.12375

Makransky, G., & Petersen, G. B. (2021). The cognitive affective model of immersive learning (CAMIL): A theoretical research-based model of learning in immersive virtual reality. *Educational Psychology Review*, *33*(3), 937–958. https://doi.org/10.1007/s10648-020-09586-2

Makransky, G., Petersen, G. B., & Klingenberg, S. (2020). Can an immersive virtual reality simulation increase students' interest and career aspirations in science? *British Journal of Educational Technology*, *51*(6), 2079–2097. https://doi.org/10.1111/bjet.12954

Martin, A. J., Colmar, S. H., Davey, L. A., & Marsh, H. W. (2010). Longitudinal modelling of academic buoyancy and motivation: Do the '5Cs' hold up over time? *The British Journal of Educational Psychology*, *80*(Pt 3), 473–496. https://doi.org/10.1348/000709910X486376

Martin, A. J., & Marsh, H. W. (2008). Academic buoyancy: Towards an understanding of students' everyday academic resilience. *Journal of School Psychology*, *46*(1), 53–83. https://doi.org/10.1016/j.jsp.2007.01.002

Megreya, A. M., Szűcs, D., & Moustafa, A. A. (2021). The abbreviated science anxiety scale: Psychometric properties, gender differences and associations with test anxiety, general anxiety and science achievement. *PLoS One*, *16*(2), e0245200. https://doi.org/10.1371/journal.pone.0245200

Meredith, W. (1993). Measurement invariance, factor analysis and factorial invariance. *Psychometrika*, *58*(4), 525–543. https://doi.org/10.1007/BF02294825

Millar, V., Park, W., & Dillon, J. (2025). The science curriculum: Issues, tensions and future prospects. *International Journal of Science Education*, 1–7. https://doi.org/10.1080/09500693.2025.2504644

Musumari, P. M., Tangmunkongvorakul, A., Srithanaviboonchai, K., Techasrivichien, T., Suguimoto, S. P., Ono-Kihara, M., & Kihara, M. (2018). Grit is associated with lower level of depression and anxiety among university students in Chiang Mai, Thailand: A cross-sectional study. *PLoS One*, *13*(12), e0209121. https://doi.org/10.1371/journal.pone.0209121

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.

Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom: Applying self-determination theory to educational practice. *Theory and Research in Education*, *7*(2), 133–144. https://doi.org/10.1177/1477878509104318

Pahmi, S., Junfithrana, A., Supriyadi, E., Hendriyanto, A., & Muhaimin, L. (2025). Exploring virtual reality's impact on math anxiety: Transforming the learning experience. *Journal of Posthumanism*, *5*(1), 1391–1412. https://doi.org/10.63332/joph.v5i1.683

Pekrun, R. (2006). The control-value theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review*, *18*, 315–341. https://doi.org/10.1007/s10648-006-9029-9

Putwain, D. W., Jansen in de Wal, J., & van Alphen, T. (2023). Academic buoyancy: Overcoming test anxiety and setbacks. *Journal of Intelligence*, *11*(3), 42. https://doi.org/10.3390/jintelligence11030042

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, *147*, 103778. https://doi.org/10.1016/j.compedu.2019.103778

Ramsurrun, H., Elaheebocus, R., & Chiniah, A. (2025). Decline in enrollment in science and technology education: From the perspectives of Mauritian educators. *STEM Education*, *5*(1), 1–18. https://doi.org/10.3934/steme.2025001

Richardson, J. C., Maeda, Y., Lv, J., & Caskurlu, S. (2017). Social presence in relation to students' satisfaction and learning in the online environment: A meta-analysis. *Computers in Human Behavior*, *71*, 402–417. https://doi.org/10.1016/j.chb.2017.02.001

Rojas, J. P., Reser, J. A., Usher, E. L., & Toland, M. D. (2012). *Psychometric properties of the academic grit scale*. University of Kentucky. http://sites.education.uky.edu/motivation/files/2013/08/RojasUsher.pdf.

Roth, S., & Cohen, L. J. (1986). Approach, avoidance, and coping with stress. *American Psychologist*, *41*(7), 813. https://doi.org/10.1037/0003-066X.41.7.813

Spangenberger, P., Geiger, S. M., & Freytag, S. C. (2022). Becoming nature: Effects of embodying a tree in immersive virtual reality on nature relatedness. *Scientific Reports*, *12*(1), 1311. https://doi.org/10.1038/s41598-022-05184-0

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Allyn & Bacon / Pearson Education.

Thisgaard, M., & Makransky, G. (2017). Virtual learning simulations in high school: Effects on cognitive and non-cognitive outcomes and implications on the development of STEM academic and career choice. *Frontiers in Psychology*, *8*(805), 1–13. https://doi.org/10.3389/fpsyg.2017.00805

Tran, M. T., Ahmad, M., Patel, K., Argyriou, O., Davies, A., & Shalhoub, J. (2024). Comparing virtual reality versus simulation to teach the assessment and management of acute surgical scenarios.. *British Journal of Surgery*, *111*(Supplement_2), znae046.089. https://doi.org/10.1093/bjs/znae163.438

Tudor Car, L., Kyaw, B. M., Teo, A., Fox, T. E., Vimalesvaran, S., Apfelbacher, C., Kemp, S., & Chavannes, N. (2022). Outcomes, measurement instruments, and their validity evidence in randomized controlled trials on virtual, augmented, and mixed reality in undergraduate medical education: Systematic mapping review. *JMIR Serious Games*, *10*(2), e29594.

Ustun, A. B., Karaoglan-Yilmaz, F. G., & Yilmaz, R. (2023). Educational UTAUT-based virtual reality acceptance scale: A validity and reliability study. *Virtual Reality*, *27*(2), 1063–1076. https://doi.org/10.1007/s10055-022-00717-4

Vogt, A., Albus, P., & Seufert, T. (2021). Learning in virtual reality: Bridging the motivation gap by adding annotations. *Frontiers in Psychology*, *12*, 645032. https://doi.org/10.3389/fpsyg.2021.645032

Wilczyńska, D., Walczak-Kozłowska, T., Alarcón, D., Arenilla, M. J., Jaenes, J. C., Hejła, M., Lipowski, M., Nestorowicz, J., & Olszewski, H. (2024). The role of immersive experience in anxiety reduction: Evidence from virtual reality sessions. *Brain Sciences*, *15*(1), 14. https://doi.org/10.3390/brainsci15010014

Yoo, J., Lee, S., & Ohu, E. A. (2024). A cross-cultural analysis of VR gaming psychological needs and motivations: A self-determination theory approach. *Managing Sport and Leisure*, *29*(3), 392–412. https://doi.org/10.1080/23750472.2022.2046490

Zhang, M., Shu, L., Luo, X., Yuan, M., & Zheng, X. (2022). Virtual reality technology in construction safety training: Extended technology acceptance model. *Automation in Construction*, *135*, 104113. https://doi.org/10.1016/j.autcon.2021.104113

Zhang, Q., Peng, A., He, L., & Li, X. (2025). Virtual reality gaming: A tool for reducing fear and anxiety in university students. *Frontiers in Psychology*, *16*, 1532753. https://doi.org/10.3389/fpsyg.2025.1532753

Appendices

Appendix A.

	MVR 14 Items
1.	I feel more confident in my learning when I use a virtual reality app to study a topic.
2.	I used virtual reality applications because I aim to develop myself.
3.	I feel confident in my ability to use virtual reality applications.
4.	I think using virtual reality apps is important because they help me learn more easily.
5.	I want to keep using virtual reality apps because they help me learn better.
6.	I had fun learning with the virtual reality app.
7.	I enjoy using virtual reality apps and feel that what I learn is helpful.
8.	I used the virtual reality app because I didn’t want to feel embarrassed for not using it. *
9.	I feel a sense of satisfaction when I succeed in using virtual reality applications.
10.	I prefer using virtual reality apps because they help me feel more comfortable while learning.
11.	I feel closer to my friends when working with virtual reality applications.
12.	I used the virtual reality app because I worried about getting in trouble if I didn’t. *
13.	I used the virtual reality application because I didn’t want to be the only one not using it. *
14.	I used the virtual reality app because I had to. *
	Integrated regulation: 1, 2, 4, 5, 7, 10,
	Intrinsic motivation: 3, 6, 9, 11.
	External regulation: 8, 12, 13 14
	(*) Reverse items
	This measurement tool is available for academic use only and may be utilised without prior permission, as long as appropriate citation is provided.

Appendix B.

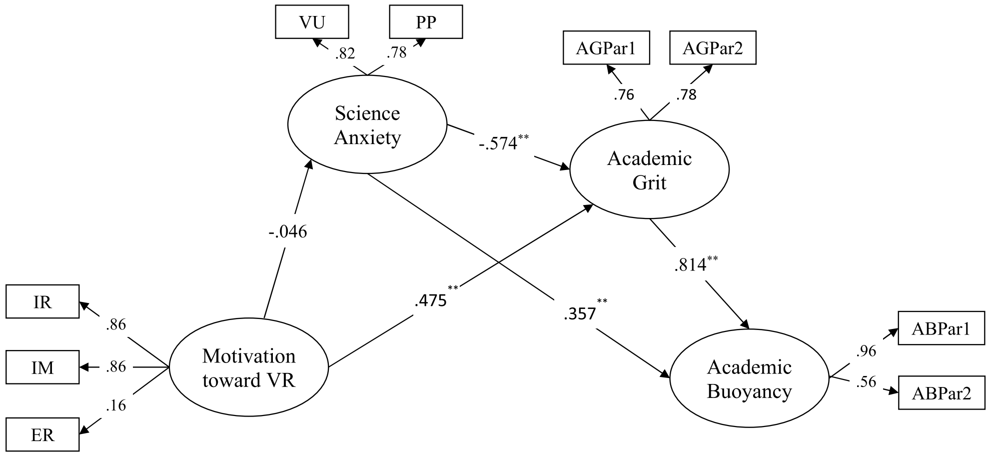

Figure A1. Standardised factor loading for the alternative fully mediated structural model. *Note. N* = 418; ** $p < .001$; *IR* integrated regulation; *IM* intrinsic motivation; *ER* external regulation; *ABPar* parcels of academic buoyancy; *AGPar* parcels of academic grit; *VU* value understanding; *PP* personal perception.