



Metaverse-Based Business Learning and Students' Commitment to Sustainability: The Mediating Role of Sustainability Knowledge Transfer

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Abstract

This study examines how metaverse-based learning environments influence students' commitment to sustainability. While immersive technologies are widely promoted for sustainability education, it remains unclear how they actually lead to behavioural commitment. Drawing on the Unified Theory of Acceptance and Use of Technology (UTAUT), the study proposes that metaverse learning features do not directly create sustainable behaviour but rather operate through the transfer of sustainability knowledge. A quantitative survey was conducted and analysed using structural equation modelling to test the relationships among immersive virtual business simulation, interactive sustainability learning modules, global collaboration and networking opportunities, gamified learning for sustainability, real-time analytics, sustainability knowledge transfer, and commitment to sustainability. The results show that real-time analytics, immersive simulation, gamified learning, and interactive modules significantly improve sustainability knowledge, whereas collaboration alone does not significantly influence understanding. Sustainability knowledge transfer strongly predicts commitment to sustainability, indicating that behavioural change occurs after learners cognitively understand sustainability concepts. The findings extend UTAUT beyond technology adoption by demonstrating that performance and effort expectancy influence behavioural outcomes only through learning cognition. The study suggests that metaverse education should be designed as an experiential decision-learning environment rather than a social virtual space, emphasizing feedback, practice, and structured interaction to foster sustainable attitudes.

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Keywords: Metaverse education; Sustainability knowledge transfer; Commitment to sustainability; Immersive learning; Real-time analytics; UTAUT

Introduction

Sustainability has become a central priority for education systems as societies increasingly face environmental, social, and economic challenges (Droubi *et al.*, 2023)^[23]. Universities are expected not only to deliver knowledge but also to cultivate responsible decision-makers capable of integrating sustainability into professional practice (Málovics *et al.*, 2025)^[59]. However, traditional teaching methods often struggle to translate sustainability concepts into real behavioural commitment because learners frequently perceive sustainability as abstract, theoretical, and disconnected from real-life decision contexts. As a result, students may understand sustainability in principle but fail to internalize it in practice (Elmassri *et al.*, 2025)^[26].

The emergence of the metaverse introduces a new educational environment that merges physical and digital realities into an interactive three-dimensional space where users can experience scenarios through avatars in real time (Shehawy, Khan, *et al.*, 2025) [88]. Unlike conventional e-learning platforms, the metaverse enables experiential learning by allowing learners to observe consequences, test strategies, and engage in realistic decision-making situations (Abdullah *et al.*, 2025) [1]. Through technologies such as virtual reality, artificial intelligence, and data analytics, it provides opportunities for practice-based learning that may help bridge the gap between knowledge and behaviour (S. M. Khan & Shehawy, 2025) [88]. Consequently, metaverse-based education has been proposed as a promising tool for sustainability education because it allows students to experience the outcomes of sustainable and unsustainable actions without real-world risk (Kumar *et al.*, 2026) [55].

Despite growing interest, current research remains fragmented. Many studies discuss the technological adoption of immersive environments, while others focus on sustainability awareness, yet few explain how immersive learning actually leads to sustainability commitment (Dhunnoo *et al.*, 2023; Di Dalmazzi *et al.*, 2025; Roy *et al.*, 2025) [21, 20, 82]. Existing frameworks often assume that exposure to immersive environments directly improves sustainable attitudes, overlooking the cognitive learning processes through which behavioural change occurs (Fantechi *et al.*, 2025; Yaban & Gaschler, 2025) [29, 102]. In particular, the mechanism through which metaverse learning features—such as simulations, interactive modules, gamification, collaboration, and real-time analytics—translate into sustainability commitment remains insufficiently understood (Dwivedi *et al.*, 2022; S. M. Khan & Suhluli, 2025; Yeganeh *et al.*, 2025) [25, 94, 104].

To address this gap, the present study proposes that sustainability commitment emerges through sustainability knowledge transfer. Rather than directly influencing behaviour, metaverse learning features first enhance understanding, and this understanding subsequently shapes commitment. The study adopts the Unified Theory of Acceptance and Use of Technology (UTAUT) as a guiding theoretical lens, extending it from technology adoption to learning outcomes. Within this perspective, immersive learning elements represent performance and effort expectations that improve comprehension, while social interaction represents social influence that may not necessarily produce behavioural change.

Accordingly, this research investigates how immersive virtual business simulation, interactive sustainability learning modules, global collaboration and networking opportunities, gamified learning for sustainability, and real-time analytics affect sustainability knowledge transfer, and how this knowledge subsequently influences commitment to sustainability. By clarifying the learning mechanism connecting immersive technology and sustainable behaviour, the study contributes to both sustainability education and digital learning research and guides designing effective metaverse-based educational environments.

Literature Review

Metaverse and Sustainability

The metaverse is an evolving concept that merges physical and digital realities into a seamless, immersive 3D virtual environment. It allows users to interact with each other and

digital objects in real-time using avatars, breaking down physical barriers (S. M. Park & Kim, 2022) [75]. Combining real and virtual worlds to produce a rich, dynamic environment with wide uses across many industries, the metaverse reflects a transforming digital (Agarwal & Alathur, 2023; Masmali *et al.*, 2025) [5, 61]. The metaverse is the result of many technologies coming together: IoT, blockchain, artificial intelligence, virtual reality glasses, augmented reality software, 5G/6G internet infrastructure, cryptocurrency, and robotics technology (Samala *et al.*, 2023) [85]. With the ability to change many sectors and social processes, the metaverse offers a radical paradigm in the digital sphere. To guarantee a fair and sustainable integration into our digital future, one must take into consideration technical components, social and economic consequences, and possible ethical issues regarding progress into serious thought. The metaverse aligns with various UN SDGs by promoting inclusivity, equity, and sustainability (Joshi *et al.*, 2024) [45]. It offers a platform for digital inclusivity and can enhance social well-being and equity (Mubarak *et al.*, 2024) [68]. Sustainable development can be advanced by the metaverse's use of bioinspired technology, which improves user interaction and encourages ethical considerations (Xu *et al.*, 2024) [101]. The influence of the metaverse on sustainability is multifaceted (Abdullah *et al.*, 2025; Vlăduțescu & Stănescu, 2023) [1, 97], impacting on issues of ethics (Yasuda, 2024) [103], economics, society (Cao, 2022) [15], and the environment. Although there are possible advantages to lowering carbon emissions and expanding economic prospects in the metaverse, there are also limitations, such as higher energy consumption (Nleya & Velepini, 2024) [71].

Immersive Virtual Business Simulation

Metaverse offers a transformative approach to immersive learning by enhancing engagement, personalization, and collaboration. It offers significant potential for immersive learning experiences in education, including enhanced engagement, personalized learning, and the creation of virtual environments (Chen, 2024; Shehawy *et al.*, 2024) [17, 87]. Innovative teaching tools called immersive business simulations combine technology and practical experience to improve corporate education. These simulations provide professionals and students with a dynamic environment where they may participate in actual business scenarios, helping them build strategic thinking and decision-making abilities (Dierdorff & Fisher, 2022; Shehawy, Khan, *et al.*, 2025) [22, 88]. Modern technologies including artificial intelligence, machine learning, IoT, augmented and virtual reality, and blockchain find common use in immersive business simulations (Rana *et al.*, 2025) [80]. These technologies generate dynamic and realistic settings that reflect actual corporate difficulties. Immersion visualisation tools let users interact with challenging data and business models, promoting a better knowledge of corporate dynamics and decision-making techniques (“MaxSIMhealth: An Interconnected Collective of Manufacturing, Design, and Simulation Labs to Advance Medical Simulation Training,” 2021). Participants can experience business roles and responsibilities in these simulations. This method bridges theoretical and practical knowledge. Using immersive visualisation tools, participants can interact with complicated data and enterprise models for deeper business dynamics and decision-making (Reiners & Wood, 2013; Shehawy, Faisal Ali Khan, *et al.*, 2025) [81, 88]. Immersive simulations simulate

business and supply chain scenarios for realistic learning. This prepares students for career problems and gives them practical skills. These simulations also have built-in assessment and feedback mechanisms for fast, diverse feedback. This helps participants develop and learn more (Ali M. Khalufi *et al.*, 2025; Morley *et al.*, 2019). Frequently, these simulations feature decision support systems that assess several paths of action using business information. This tool helps users to make optimal decisions based on data-driven analysis and acquire a numerical understanding of business operations (Dunke & Nickel, 2021; Helleno *et al.*, 2015; Polhill & Edmonds, 2023) [24, 35, 76]. Simulation-based learning has become an effective instrument in entrepreneurial education, especially in promoting dedication to sustainability. Using this technique, students may interact in a controlled, risk-free environment with difficult business dynamics and sustainability issues. However, the design and application of the simulation models determine how effective simulations are in improving entrepreneurial commitment to sustainability. Emphasizing the integration of education for sustainability (Efs) within entrepreneurial education, entrepreneurial learning for sustainable futures emphasizes active and interactive tools, simulations can inspire debates and critical thinking on sustainability, hence strengthening entrepreneurial dedication to sustainable solutions. Entrepreneurial simulations can help infuse sustainability into business education by driving learners to critically evaluate assumptions and examine environmental and financial sustainability (Kiani *et al.*, 2020; Shehawy & Ali Khan, 2024) [54, 87].

Interactive Sustainability Learning Modules

Interactive sustainability learning modules are becoming popular as effective tools for teaching Education for Sustainable Development (ESD). These modules incorporate sustainability topics into institutional programs, making learning engaging and multidisciplinary. Recent research shows that these modules significantly improve students' understanding and interest in sustainability issues (Altomonte *et al.*, 2016; Wijethilake & Upadhaya, 2020) [9, 99]. Interactive sustainability learning modules help adopt sustainable practices. These modules assist students develop relevant skills, awareness, and commitment to sustainable approaches by incorporating sustainability into entrepreneurship education. Sustainable education is vital to addressing global issues, and these educational opportunities help students develop this perspective and examine how these modules affect entrepreneurial sustainability (S. Khan & Khan, 2024). Among students, e-learning technologies (ELTs) have been demonstrated to raise awareness of sustainability and entrepreneurial skills. Though a direct correlation between entrepreneurial skills and sustainability consciousness was not established, a study carried out at a Hong Kong university indicated that ELTs greatly improve students' entrepreneurial success and sustainability efficacy (Liu *et al.*, 2023) [57]. The Sustainable Entrepreneurial Thinking (SET) program reinforces global responsibility skills by focusing on self, planet, and organisation sustainability. This subject encourages students to use entrepreneurial solutions to address SDG-related social issues. Student Training for Entrepreneurial Promotion (STEP) and other action-oriented training programs have incorporated sustainability into their pedagogy (Melyoki & Gielnik, 2023) [66]. Sustainable entrepreneurs are frequently driven by consumer concerns

and aspire to create innovative products and services that benefit both the economy and society.

Global Collaboration and Networking Opportunities

Globally, collaboration and networking have become vital in disciplines such as academic medicine, dental education, and healthcare allowing professionals all over to collaborate (Fallah & Bernstein, 2019) [28]. Through encouraging the sharing of sustainable ideas, improving resource integration, and supporting transformational leadership, global cooperation and networking greatly influence entrepreneurial commitment towards sustainability. These components contribute to the creation of ecosystems and sustainable business models (Hakami *et al.*, 2023) [34]. Global collaboration and networking significantly affect entrepreneurial commitment towards sustainability using stimulating the flow of sustainable ideas, bettering resource integration, and boosting transformational leadership. Taken together, these elements support sustainable business models and ecosystems (Patel, 2022) [75]. Social connections across countries increase the chance of eco-innovation partnerships, which are essential for environmental sustainability. Knowledge transference through interpersonal networks promotes eco-innovation collaboration in these partnerships to foster sustainable innovation and organizational sustainability. This relationship is moderated by the firm's environmental responsibility, emphasizing the necessity of sustainability in collaboration (Adomako, 2020) [4]. When faced with complicated sustainability concerns, it is vital to engage in collaborative entrepreneurship that involves collaboration across sustainability issues and the participation of cross-actors. This method promotes long-term sustainability by bringing together several forms of entrepreneurship, including social and policy entrepreneurship (Schaltegger *et al.*, 2018) [86].

Projects like Investors for Development (I4D) show how governments and NGOs may work together on a global scale to encourage sustainable economic practices. The success of sustainability initiatives, especially in underdeveloped areas, depends on the financial and political support of these players (Arevalo, 2014) [14]. Encouraging of global collaboration for entrepreneurial sustainability presents multiple challenges in technological, social, environmental, and financial spheres. While economic constraints concentrate on finite resources and the need for organised techniques to manage them, environmental issues emphasise the need for sustainable innovation and ethical corporate entrepreneurship. Technological constraints highlight the need of invention and digital tools in developing sustainable solutions, but also the challenges in properly using these resources. Socially, especially for startups, collaborations, and cooperation are sometimes limited by several elements (Suhluli & Ali Khan, 2022) [94]. While present studies provide some light on these problems, a better knowledge of the particular challenges in every field is required to promote worldwide cooperation for sustainability in entrepreneurship.

Gamified Learning for Sustainability

Gamification of sustainability is the application of gaming components in environments and actions connected to sustainability (Faisal Ali Khan & Ahmad, 2020) [27]. Games, scores, leader boards, incentives, and goals inspire individuals to act responsibly for their environment

(Whittaker *et al.*, 2021) ^[98]. Promising sustainability education, gamified learning may improve engagement (S. Park & Kim, 2021) ^[73], maintain learning effects, and equip vital skills (Despeisse, 2018) ^[19] needed to solve global environmental issues (Gatti *et al.*, 2019; Medabesh & Khan, 2020) ^[33, 65]. Studies have identified that incentives and rewards have a positive impact on sustainable commitments. Organizations that comply with sustainable practices receive benefits from governments (Saka *et al.*, 2021) ^[84]. While they provide major strategic, operational (Zaidi *et al.*, 2021) ^[106], and governance-related challenges that companies face to reach their sustainability goals (Beheiry *et al.*, 2006) ^[13], challenges and competitions can promote sustainability commitments by increasing reputation and inspiring improvements (Rubio-Andrés & Abril, 2024) ^[83]. By making the challenges more relevant (Pozzetto *et al.*, 2023) ^[77], interesting, and emotionally captivating (Bernier, 2020) ^[14], storytelling and narrative approaches are effective instruments in encouraging sustainability commitment by so generating behavioural change and trust (Fischer *et al.*, 2022) ^[30]. The psychological elements impacting sustainability commitment are several and include psychological well-being [29], environmental concern, and relationship with nature (Yu *et al.*, 2019) ^[105]. While technology, especially digital transformation and communication design, promote social contact and cooperation for sustainability commitment, organisational sustainability practices depend much on collaboration and present both possibilities and problems (S. S. A. Abidi & Khan, 2022; Najm *et al.*, 2023) ^[3, 69]. The insightful analysis of the psychological, organisational, and technological facets of sustainability commitment and cooperation, direct data addresses the particular difficulties and opportunities in advancing sustainability commitment through social interaction and collaboration (McGreavy *et al.*, 2015; Medabesh & Khan, 2019) ^[64]. The psychological processes underlying intrinsic motivation and autonomy are important in determining personal behaviour towards sustainable practices and have major organisational consequences for sustainability commitment (Kácha & Ruggeri, 2019; Zhou *et al.*, 2019) ^[47]. (S. Abidi & Faisal AU Khan, 2018) ^[2, 108].

Real-Time Analytics

Real-time analytics improves decision-making, operational efficiency, openness, and a data-driven culture inside businesses, supporting entrepreneurial sustainability (Oliveira & Handfield, 2023) ^[72]. Real-time analytics and creative teaching strategies can greatly increase entrepreneurial sustainability commitment by raising skills, promoting a green attitude, and supporting teamwork and pragmatic experiences (Wyness & Jones, 2019) ^[100]. Several factors affect the acceptance of real-time analytics in entrepreneurial sustainability commitment and education, including IoT (Malik *et al.*, 2018) ^[58], e-learning technologies, and top management support, therefore providing chances to increase decision-making, organisational behaviour, and sustainability awareness (S. M. F. A. Khan & Damanhouri, 2017; Rakicevic *et al.*, 2022) ^[79]. However, the integration of real-time analytics for entrepreneurial sustainability commitment should carefully address issues of cooperation between sustainability and entrepreneurship disciplines and ethical considerations (Jum'a *et al.*, 2022; Wyness & Jones, 2019) ^[46, 100]. Through encouraging critical thinking, creativity, and teamwork in higher education, the metaverse

has the potential to improve real-time analytics in the framework of entrepreneurial sustainability (Akbar & Mbonye, 2024) ^[6]. Including the metaverse in education provides immersive interactions and tailored learning opportunities that can inspire sustainable entrepreneurship using personal development. To properly include metaverse education into real-time analytics for entrepreneurial sustainability, nevertheless, issues including technology constraints, costs, ethical questions, and energy usage must be addressed (S. M. F. A. Khan, n.d.; Zhang *et al.*, 2022) ^[107].

Sustainability Knowledge Transfer

Sustainability knowledge transfer involves exchanging information and practices to promote sustainable development across various sectors. This process is crucial for bridging the gap between research and practical application, ensuring that sustainability initiatives are effectively implemented (M. Khan & Chawla, 2015; Sun & Hong, 2022) ^[95]. Sustainable knowledge transfer requires creative management systems, coordinated initiatives, and organised frameworks. Organisations can improve their sustainability performance and help contribute to global sustainable development by addressing HRM challenges, using leadership in SMEs, and supporting international partnerships (Lamperti *et al.*, 2023) ^[56]. The effective transfer of sustainability knowledge from academia to industry can be facilitated by the use of social networks and online platforms for knowledge transfer, as well as by consistent local access to scientific and technical knowledge (Chams *et al.*, 2024; Singh *et al.*, 2014) ^[16, 92]. Metaverse enhances sustainability knowledge transfer through immersive learning and effective tacit knowledge sharing. It also builds commitment towards sustainability by raising awareness, integrating sustainable practices, and requiring supportive policies and responsible digitalization frameworks (Mubarak *et al.*, 2024; Rajguru & Brüggemann, 2024) ^[68, 78]. Metaverse has the potential to both positively and negatively impact sustainability knowledge transfer, environmental implications, and commitment towards sustainability (Rajguru & Brüggemann, 2024) ^[78]. While it presents challenges, such as increased power consumption, it also offers opportunities for promoting environmentally sustainable development, integrating ethics and sustainability into education, and driving green knowledge sharing intention for enhancing supply chain resilience. However, it is important to consider the ethical implications and potential dangers associated with the (Fonseca & Borges-Tiago, 2024; Islam & Faisal Ali Khan, 2023) ^[31, 40].

Commitment to Sustainability

Commitment to sustainability refers to the dedication of individuals, organizations, and institutions to integrate sustainable practices into their operations, decision-making processes, and strategic goals (Jansson *et al.*, 2017) ^[43]. Modern enterprises are increasingly realizing the need for sustainability commitment, which includes social, environmental, and financial aspects into their operational and strategic systems. A strong sustainability commitment involves a multifaceted approach, integrating corporate culture (Srimulyani *et al.*, 2023) ^[93], strategic planning (Anlesinya & Abugre, 2022) ^[10], workforce development (Martí-Ballester, 2023) ^[60], and alignment with broader societal goals. Although encouraging commitment to sustainable practices depends on awareness and knowledge

of sustainability, the way information is delivered and the support of corporate and educational institutions will determine the effectiveness of this link (Sideri, 2023) ^[91]. Using creative assessment strategies and thorough stakeholder interviews will help one determine enterprises' degree of awareness and sustainability commitment. Maintaining sustainability commitment, however, presents difficulties like the necessity of consistent measuring systems and the impact of institutional constraints on sustainability (Arsawan *et al.*, 2024) ^[12]. Assessing whether individuals or enterprises include sustainable practices in their routines and long-term objectives helps us determine their degree of sustainability commitment. This can involve things like

employing environmentally friendly products, decreasing waste, lowering energy use, or helping social and environmental causes by way of projects. In an educational or entrepreneurial environment, particularly in the metaverse, it can evaluate sustainability commitment by observing how people make decisions in virtual simulations including real-world sustainability-related problems. It may also monitor their willingness to work with others on environmentally friendly innovations and how involved they are in learning activities emphasizing sustainability. Real-time data on their progress or sustainability difficulties can help to understand better how important firms regard sustainability.

Theoretical Framework of the Study

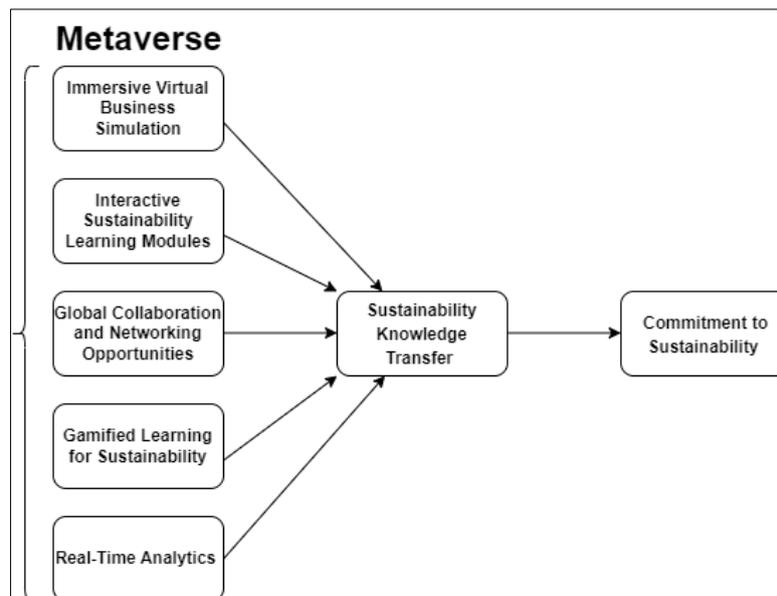


Fig 1: Conceptual Framework of the Study

Using the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh *et al.*, 2003) ^[96], we investigate student interaction with this creative learning environment in our research on metaverse-based entrepreneurial education. Important as they can improve students' learning experiences and simplify the content are the independent variables we have identified: immersive virtual business simulations and interactive sustainability learning modules. These fit the UTAUT ideas of effort expectation—how easy a student thinks it is to use the technology—and performance expectation—how much they believe the technology will enhance their learning. Furthermore, emphasised by Global Collaboration and Networking Opportunities are the influence of peers and the need to work together—qualities fundamental to the social influence element of UTAUT. Ultimately, by leveraging the motivating elements that inspire students to continue utilising the metaverse for their education, the gamified learning for sustainability element seeks to make learning enjoyable. Through the UTAUT perspective, we intend to investigate these factors and get an important understanding of what motivates students' dedication to learning in this new digital environment.

Research Methodology

Research Design

The primary objective of this paper is to investigate the metaverse-based learning upon the commitment to sustainability. An organised questionnaire was the primary tool used in this quantitative research for data collecting. Building from well-known questionnaires from earlier studies, the survey was developed. A first pilot test was conducted to ensure the validity and reliability of the questionnaire before beginning the main investigation.

Research Sampling

The present research employs a purposeful sample approach using stratified sampling techniques. Emphasizing those with strong academic backgrounds and diverse experiences, the study initially sought students enrolled at Indian Universities, therefore ensuring a high-quality sample. Students who were enrolled in higher degree programs were selected using a simple random sampling technique. This approach was chosen to include a wide range of opinions on sustainable commitment. Confirmatory Factor Analysis (CFA) and Structural Equation Modelling (SEM) were used to examine the data, verifying the measurement models and ensuring the

validity and dependability of the outcomes. SEM makes it feasible to investigate numerous factors and their interrelationships concurrently, therefore exposing how metaverse-based learning strategies influence commitment to sustainability. Using CFA, the convergent and discriminant validity of the measuring instruments was confirmed, therefore strengthening the validity of the research.

Sample Size

The study was conducted using survey responses from 501 students enrolled in Indian universities, representing diverse academic programs and backgrounds. These institutions are increasingly integrating digital learning platforms and sustainability education in response to national education reforms and global sustainability goals. The collected data were analysed using structural equation modelling to examine how metaverse-based learning features influence sustainability knowledge and commitment among university

students.

Data Analysis

The collected data were analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) to examine both the measurement and structural relationships in the proposed model. The analysis first assessed reliability and validity through Cronbach’s alpha, composite reliability, and average variance extracted, followed by discriminant validity using the Fornell–Larcker criterion. Collinearity was checked using VIF values, and model fit was evaluated through indices such as SRMR and NFI. After confirming the adequacy of the measurement model, the structural model was tested using bootstrapping to determine path significance, t-values, and p-values. Finally, the explanatory power of the model was evaluated through R² values to assess how well the metaverse learning features predicted sustainability knowledge transfer and commitment to sustainability.

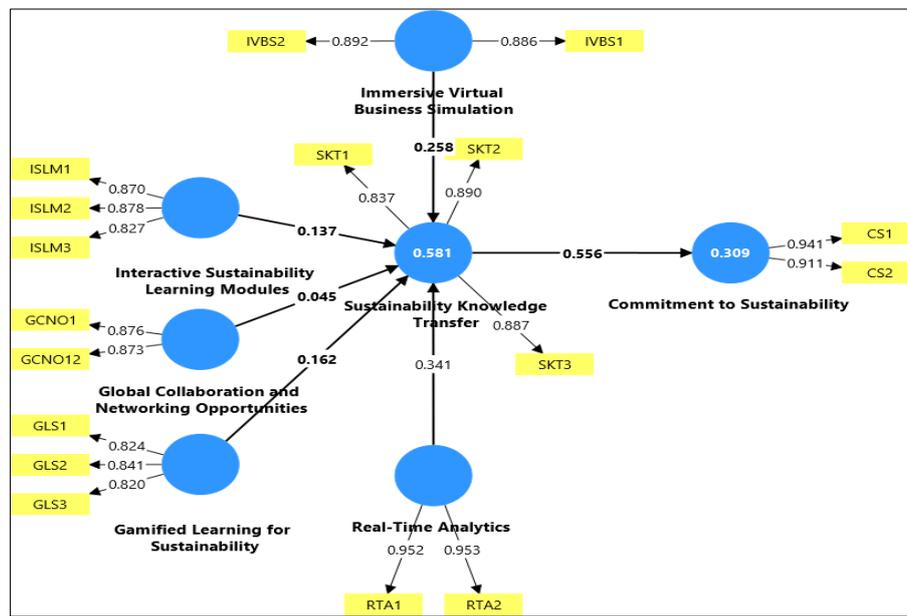


Fig 2: Measurement Model

Table 1: Convergent Validity

Constructs	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Commitment to Sustainability	0.837	0.861	0.924	0.858
Gamified Learning for Sustainability	0.776	0.796	0.868	0.686
Global Collaboration and Networking Opportunities	0.692	0.692	0.867	0.765
Immersive Virtual Business Simulation	0.734	0.735	0.883	0.790
Interactive Sustainability Learning Modules	0.822	0.825	0.894	0.737
Real-Time Analytics	0.898	0.898	0.951	0.907
Sustainability Knowledge Transfer	0.841	0.841	0.904	0.759

Table 1 and Figure 2 illustrates the reliability and validity results indicate that the measurement model performs well and the constructs are measured consistently and accurately. First, internal consistency reliability is satisfactory. All Cronbach’s alpha values range from 0.692 to 0.898, which meets the acceptable threshold for exploratory and behavioral research. Even Global Collaboration and Networking Opportunities (0.692), although slightly lower than others, remains acceptable because values close to 0.70 are considered adequate in social science studies. The composite

reliability values (rho_a and rho_c) are all above 0.70, confirming that the indicators consistently represent their respective constructs. Second, convergent validity is strongly supported. The Average Variance Extracted (AVE) values range from 0.686 to 0.907, exceeding the recommended threshold of 0.50 for all constructs. This means each construct explains more than half of the variance of its indicators, demonstrating that the items truly capture the intended concept. In particular, Real-Time Analytics and Commitment to Sustainability show very high AVE values, indicating very

strong measurement quality. Overall, these results confirm that the measurement scales are reliable and valid. The constructs are internally consistent,

the indicators measure the intended concepts effectively, and the model is suitable for further structural analysis and hypothesis testing.

Table 2: Discriminant Validity

	Commitment to Sustainability	Gamified Learning for Sustainability	Global Collaboration and Networking Opportunities	Immersive Virtual Business Simulation	Interactive Sustainability Learning Modules	Real-Time Analytics	Sustainability Knowledge Transfer
Commitment to Sustainability	0.926						
Gamified Learning for Sustainability	0.610	0.828					
Global Collaboration and Networking Opportunities	0.668	0.570	0.874				
Immersive Virtual Business Simulation	0.596	0.613	0.736	0.889			
Interactive Sustainability Learning Modules	0.400	0.478	0.505	0.506	0.859		
Real-Time Analytics	0.686	0.612	0.641	0.485	0.425	0.953	
Sustainability Knowledge Transfer	0.556	0.620	0.614	0.625	0.512	0.652	0.871

Table 2 represents the Fornell–Larcker results, which confirm that the constructs in the model are empirically distinct from one another. For each construct, the square root of the Average Variance Extracted (values shown on the diagonal) is higher than its correlations with all other constructs. This indicates that every construct shares more variance with its own indicators than with other variables in the model. For example, Commitment to Sustainability (0.926) is greater than its correlations with Gamified Learning (0.610), Global Collaboration (0.668), Real-Time Analytics (0.686), and Sustainability Knowledge Transfer (0.556). Similarly, Real-Time Analytics (0.953) and Immersive Virtual Business Simulation (0.889) also show much higher diagonal values than their inter-construct

correlations, confirming the strong uniqueness of these constructs. Although some relationships are moderately high — such as between Immersive Virtual Business Simulation and Global Collaboration (0.736), and between Real-Time Analytics and Sustainability Knowledge Transfer (0.652) — they remain clearly below the corresponding diagonal values. Therefore, these constructs are related but not overlapping, which is theoretically expected in an integrated learning environment. Overall, the results demonstrate satisfactory discriminant validity. Each construct measures a different concept, and the model does not suffer from construct redundancy or conceptual overlap. This supports the adequacy of the measurement model for subsequent structural path analysis.

Table 3: Structural Model Diagnostics and Model Fit Assessment

Category	Metric / Indicator	Value	Threshold	Interpretation
Collinearity (VIF)	Range	1.389 – 2.973	< 5.0	No multicollinearity
	Highest (RTA1/RTA2)	2.973	< 5.0	Acceptable
	CS1, CS2	2.07	< 5.0	Acceptable
	ISLM1	2.105	< 5.0	Acceptable
	ISLM2	2.031	< 5.0	Acceptable
	SKT2	2.337	< 5.0	Acceptable
	All remaining items	< 2.0	< 5.0	Excellent
Model Fit	SRMR (Saturated)	0.071	< 0.08 good	Good fit
	SRMR (Estimated)	0.109	< 0.12 acceptable	Acceptable fit
	d ULS	0.769 / 1.824	Lower better	Acceptable
	d G	0.591 / 0.71	Lower better	Acceptable
	NFI	0.683 / 0.643	> 0.60	Adequate fit
	Chi-square	1830.24 / 2062.842	Informational	PLS not sensitive
Predictive Power (R ²)	Sustainability Knowledge Transfer	0.581 (Adj. 0.577)	0.50 = moderate	Strong explanatory power
	Commitment to Sustainability	0.309 (Adj. 0.307)	0.25 = moderate	Moderate explanatory power

Table 3 represents the diagnostic results show that the model is statistically stable and reliable. First, the collinearity assessment indicates no overlap problem among predictors, as all VIF values fall between 1.389 and 2.973, well below

the critical threshold. This means each construct contributes unique information, and the relationships estimated in the model are not artificially inflated. Second, the model fit indices suggest that the proposed framework reasonably

represents the observed data. The SRMR value of the saturated model (0.071) indicates a good approximation, while the estimated model (0.109) remains within acceptable limits for PLS-SEM research. The NFI values above 0.60 and the relatively low discrepancy measures (d_{ULS} and d_G) further support that the structural relationships specified in the model are appropriate. Because PLS-SEM focuses on prediction rather than perfect covariance reproduction, these values confirm an adequate overall model fit. Finally, the predictive power of the model is meaningful. The model

explains 58.1% of the variance in Sustainability Knowledge Transfer, indicating strong explanatory capability. It also explains 30.9% of Commitment to Sustainability, which is considered moderate and realistic for behavioural outcomes that depend on personal values and contextual influences beyond the model. Overall, the results demonstrate that the measurement and structural model are sound, the relationships are reliable, and the framework has sufficient explanatory and predictive ability to examine sustainability-related behavioural mechanisms.

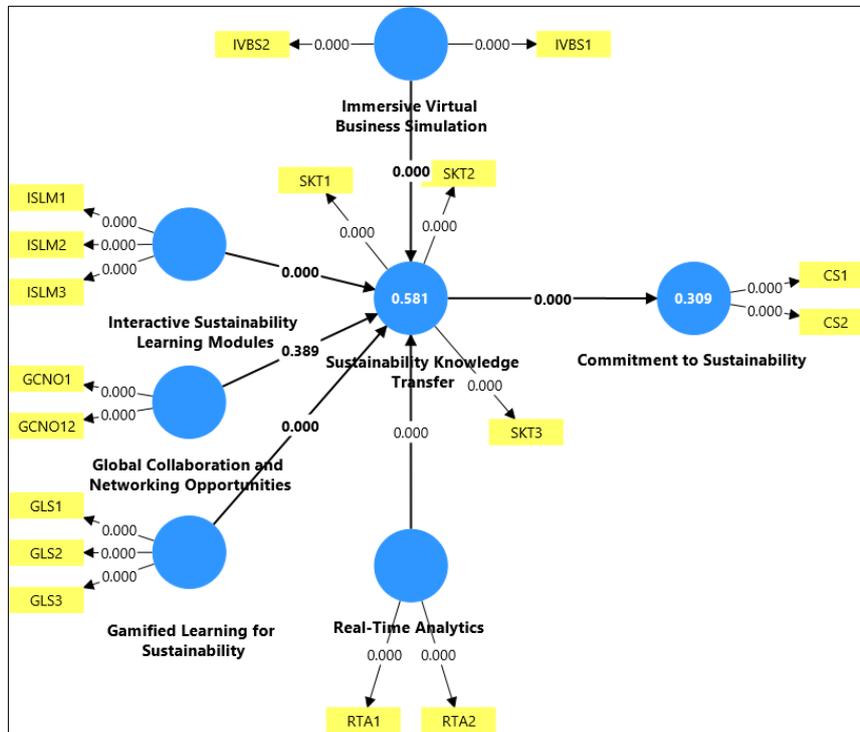


Fig 3: Structural Model

Table 4: Hypothesis Testing

Hypothesis	Path	β (O)	STDEV	t-value	p-value	Decision
H1	Immersive Virtual Business Simulation → Sustainability Knowledge Transfer	0.258	0.045	5.736	0.000	Supported
H2	Interactive Sustainability Learning Modules → Sustainability Knowledge Transfer	0.137	0.038	3.547	0.000	Supported
H3	Global Collaboration and Networking Opportunities → Sustainability Knowledge Transfer	0.045	0.052	0.861	0.389	Rejected
H4	Gamified Learning for Sustainability → Sustainability Knowledge Transfer	0.162	0.046	3.525	0.000	Supported
H5	Real-Time Analytics → Sustainability Knowledge Transfer	0.341	0.04	8.534	0.000	Supported
H6	Sustainability Knowledge Transfer → Commitment to Sustainability	0.556	0.035	15.984	0.000	Supported

Table 4 and Figure 3 show that most of the proposed learning mechanisms significantly enhance Sustainability Knowledge Transfer, which ultimately leads to Commitment to Sustainability. H5 is the strongest supported relationship: Real-Time Analytics → Sustainability Knowledge Transfer ($\beta = 0.341$, $t = 8.534$, $p < 0.001$). This indicates that immediate feedback and performance tracking play the most important role in improving sustainability understanding. H1 is also strongly supported: Immersive Virtual Business Simulation → Sustainability Knowledge Transfer ($\beta = 0.258$, $t = 5.736$, $p < 0.001$). This means students learn sustainability better when they experience realistic decision-making situations rather than only theoretical instruction. Both H4 (Gamified Learning for Sustainability → Sustainability Knowledge Transfer, $\beta = 0.162$, $t = 3.525$, $p < 0.001$) and H2

(Interactive Sustainability Learning Modules → Sustainability Knowledge Transfer, $\beta = 0.137$, $t = 3.547$, $p < 0.001$) are supported. These findings show that engagement, motivation, and interaction significantly improve learning effectiveness. However, H3 is not supported: Global Collaboration and Networking Opportunities → Sustainability Knowledge Transfer ($\beta = 0.045$, $t = 0.861$, $p = 0.389$). This suggests that collaboration alone does not automatically improve sustainability understanding without structured guidance or feedback. Finally, H6 is strongly supported: Sustainability Knowledge Transfer → Commitment to Sustainability ($\beta = 0.556$, $t = 15.984$, $p < 0.001$). This confirms the core mechanism of the model — once learners truly understand sustainability concepts, they become more committed to sustainable behaviour.

Overall, the findings indicate that feedback-driven learning and experiential learning methods are the primary drivers of sustainability commitment, while simple social interaction by itself is insufficient.

Discussion

The findings show that metaverse-based learning influences students' commitment to sustainability primarily through a cognitive learning mechanism rather than simple technological exposure (Islam & Khan, 2024; Roy *et al.*, 2025) [39, 82]. The strongest relationship in the model is between sustainability knowledge transfer and commitment to sustainability ($\beta = 0.556$, $p < 0.001$), confirming that learners become committed only after they understand sustainability concepts. Interpreted through UTAUT, this means technology acceptance alone does not produce behavioural change; performance expectancy must translate into improved learning outcomes. Features that enhanced understanding (Alruthaya *et al.*, 2025) [8]: — real-time analytics ($\beta = 0.341$), immersive virtual business simulation ($\beta = 0.258$) also highlighted by (Islam & Ali Khan, 2024a; Jolink & Niesten, 2021) [44], gamified learning ($\beta = 0.162$) as mentioned by (Jain *et al.*, 2022) [42], and interactive sustainability learning modules ($\beta = 0.137$) — significantly improved knowledge transfer because they either provided feedback, practical experience, motivation, or structured comprehension. These tools help learners visualize consequences and apply sustainability decisions, transforming abstract ideas into actionable understanding (Cristache *et al.*, 2025) [18]. In contrast, global collaboration and networking opportunities did not significantly influence knowledge transfer ($\beta = 0.045$, $p = 0.389$), indicating that social interaction alone encourages participation but does not guarantee cognitive learning (Herzallah *et al.*, 2025; Huang & Lajoie, 2023) [37]. This clarifies an important theoretical distinction within UTAUT: social influence explains technology use, while performance and effort expectancy explain meaningful learning outcomes (Gadi *et al.*, 2026; Islam & Ali Khan, 2024b; Nguyen *et al.*, 2024) [32, 38].

Overall, the metaverse functions not as a social digital space but as a cognitive learning infrastructure where experiential learning and feedback mechanisms generate knowledge, and knowledge subsequently produces sustainability commitment.

Conclusion

This study demonstrates that metaverse-based education promotes commitment to sustainability through a knowledge-formation pathway rather than through direct exposure to immersive technology. Students develop sustainable attitudes when the learning environment helps them understand the consequences of decisions, indicating that experiential learning, analytics-based feedback, structured modules, and engagement mechanisms are essential design elements. The study contributes theoretically by extending UTAUT beyond technology adoption toward behavioural outcomes, showing that performance and effort expectancy influence sustainability commitment only through knowledge transfer. Practically, the findings suggest universities and training institutions should design metaverse environments as interactive decision-learning laboratories rather than virtual meeting spaces, emphasizing simulations and feedback systems to achieve sustainability education goals. The study is limited by its cross-sectional design and reliance on self-

reported perceptions, which restrict causal interpretation and may not fully capture long-term behavioural change. Future research should employ longitudinal designs, behavioural experiments, and multi-context samples, and examine additional mediators such as values, environmental concern, or emotional engagement to better understand how digital immersive environments translate learning into real-world sustainable behaviour.

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