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Original Article

The Pedagogy of Play: Establishing UX Benchmarks for Efficacy and Learning Outcomes in VR Serious Games

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Abstract - *Virtual Reality (VR) serious games have come to be identify as learning environments, as immersive interaction, feedback and engagement of the learners can facilitate learning; the effectiveness of these games, however, relies on the alignment of User Experience (UX) design with play-based pedagogy. The purpose of this study is to establish UX benchmarks for the assessment of the efficacy of VR serious games and the relationships between UX design dimensions, pedagogical elements of play and learning outcomes. In Delhi NCR, a quantitative descriptive and analytical research design is used in purposive and stratified sampling. Primary data are gained by questionnaire administration, and analysis is done using descriptive statistics, correlation, regression and structural equation modelling using MS Excel, SPSS 27 and SmartPLS 4 programs among 200 VR serious-game learners. Results indicate that UX can predict the learning outcomes with $R = 0.719$, $R^2 = 0.517$, $\beta = 0.719$ and $p < 0.001$, and that the pedagogical elements of play have positive relationships with the UX design factors ($r = 0.760$, $p < 0.001$). The measurement model has a good fit with an SRMR value of 0.069 and an NFI value of 0.949. The study finds that successful VR learning needs to be pedagogically purposeful, integrated and user-centered in terms of UX.*

Keywords - *Learning outcomes, Play-based pedagogy, User Experience, UX benchmarks, Virtual reality serious games.*

1. Introduction

Digital educational games are one of the rapidly researched areas of educational technology over the last decade [1]. Educational games can be effective in learning (although overall evidence of their efficacy has been mixed) because they can provide such affordances as quick feedback, interactive problem solving, and learner control. They were also identified to enhance motivation and engagement [2]. Nevertheless, educational games have not been embraced in the classroom because of a number of obstacles. These are the absence of technological infrastructure, insufficient training of the teachers, administrative controls and the social stigma of modern digital game [3].

The way of adoption of the use of digital games in the learning process is significant in the role of teachers, yet the adoption of educational games by teachers has been low [4]. This has been mostly explained by four aspects; insufficient curricular resources to instructors, mismatch with curricular goals, insufficient knowledge of game-based learning by teachers and time and effort needed to incorporate digital games in lessons. One possible solution that could help to have a positive impact on the acceptance of games among the teachers could be availability and access to curricular material designed to facilitate the process of integrating a game into the classroom. In this respect, curriculum guides have been developed to assist teachers on the adoption of Commercial-off-the-Shelf (COTS) games [5, 6].

These manuals give a set of guidelines to educators to adapt digital commercial games to learning purposes. As an illustration, the United Nations, which is an international organization, established curriculum guides to help teachers adapt to the use of educational games. These manuals give lesson plans and teaching tools to teachers to incorporate serious games in their classes. Games for Change also prepared various guides and resources to facilitate the use of digital games in learning by teachers [7]. Nevertheless, the efficacy of these guides and how they affect teachers has not been researched. The attitude of teachers on the content of the curriculum, the utility of the given materials, and their role in enriching their knowledge of the game and the skills they develop during the process of learning Game-Based Learning (GBL) may become the major attributes affecting their decision to implement the game in their classes [8].

1.1. Educational 3D Virtual Worlds

Game-Based Learning (GBL) facilitates new types of learning that alter the learning process with simulated (real-life) activities in primary and secondary (K-12) education [9]. In designing and developing digital GBL interventions, instructional designers consider, at the same time, several

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instructional methods intended to enhance cognitive and practical skills of learners with the help of problem-solving [10].

A novel technique of developing prototypes of games is linked with the application of simulated realistic representational fidelity of visual objects/elements created using Three-Dimensional (3D) computer graphics. Specifically, the application of 3D Virtual Worlds (3DVWs) presented opportunities to sophisticated (and not so sophisticated) programmers to develop and create simulation games. A 3DVW is a virtual world of computer programs, where users have an opportunity to find the solutions to simulated problems and watch how their mistakes happen in real time, visually and acoustically, to realize what they do [9]. Examples of 3DVWs used to indicate some of them, like social Quest Atlantis, Second Life, and open source, like Open Simulator or Open Wonderland [11]. Every user is physically present in the form of an avatar (i.e. a representation in a digital form that has human or inanimate qualities) to communicate in real time, explore its functionality through visual objects, and engage in a great variety of simulated activities or tasks. There are asynchronous methods and tools that allow users to communicate with other peers and synchronous ones, through gestures, VoIP calls, to (co)-design and/or program visual objects with geometric figures by using the scripting language of 3DVWs or by using the visual palette of Scratch4SL [12].

A rich amount of study has presented much written evidence regarding the effect of 3DVWs on different education practices and activities [13]. Indicative examples are the behavior of gamified collaborative and cooperative learning and lesser financial expenditure of the behavior of simulations otherwise including hands-on experimentation with costly/special apparatus. When the latter is considered, other advantages are known under the terms of the alleviation of environmental issues (e.g., the decrease in the production of hazardous waste) as well as the eradication of laboratory injuries, determining the branches of education related to Science, Technology, Engineering and Mathematics (STEM) [10].

1.2. UX Metrics and Benchmarks for Learning Efficacy

User Experience (UX) measures are essential in assessing the learning effectiveness of VR serious games because they incorporate the perception and interaction of immersive environments, as well as cognitive processing of the learning environment by the learner. Usability, learnability, accessibility, and satisfaction are frequently used as normal recent UX measures, which can be quantified with the help of standardized tools like the System Usability Scale (SUS) or task-specific performance metrics [14]. These measurements take the form of interface efficiency within education VR to perceived control, feedback understandability, and user-friendliness in simulated situations. Researchers can use benchmarks based on these metrics to compare learning interventions to contrast various VR applications and pedagogical designs. A knowledge application with low cognitive friction and intuitively can be used to divert more mental resources towards problem solving and knowledge building, which in turn increases the learning efficacy and facilitates the pedagogical intentions of serious games [15].

In addition to usability, immersive-specific UX criteria like presence, engagement and flow are fundamental indicators of measuring the learning outcomes of VR serious games. Presence indicates the learner the feeling of being there in the virtual environment, whereas engagement and flow imply the maintenance of attention and intrinsic motivation in the game. The measurement of these constructs is usually done via self-report, behavioral data (e.g., time-on-task), and interaction logs [16]. The presence and engagement have been linked to a greater understanding of the concept and demonstrated better skill transfer, especially in simulation-based learning activities. Setting standards of these immersive measures allows the effective assessment of the effectiveness of VR experience in the context of experiential learning. These benchmarks also help designers in the process of balancing realism and interactivity so as not to overburden the cognitive system and make immersion oriented to the learning goal rather than to distractions of it [17].

The benchmarks of learning efficacy metrics in VR serious games are progressively based on both UX metrics and direct educational performance metrics, including knowledge acquisition, skill acquisition, and retention. This approach is combined to enable researchers see significant relationships between user experience quality and learning performance. As an example, benchmarks can be associated between optimum usability and engaging scores with statistically relevant enhancement in the post-test outcome or accuracy in the task. Besides, adaptive analytics and learning dashboards can also give real-time UX data which can be used to redesign in an iterative way [18]. The standardization of UX standards among studies aids in being comparatively and reproducibly, which are key to evidence-based educational design. Finally, clear UX measures and benchmarks serve as an interface between pedagogy and technology, so that VR serious games do not only look interesting but can actually be proved to be effective tools of learning [19].

The study is important as it connects the play-based pedagogy to the User Experience (UX) design, to improve learning in VR serious games. It provides useful advice to teachers and developers who should create immersive, engaging, and effective learning environments by setting UX benchmarks. The study proves the ability of pedagogical factors to enhance cognitive abilities, motivation, and knowledge retention in the presence of a well-designed UX. It can also be used to assess the efficacy of VR games using measurable criteria, which underlies evidence-based design

choices. Altogether, the study helps to optimize the use of VR serious games that can be a strong educational device to balance the levels of engagement and usability with meaningful learning outcomes.

The study is organized in the following way: the Introduction provides the background, significance, and research gap of play-based pedagogy and UX in VR serious games. This is then accompanied by a Review of Literature, which talks about theoretical underpinnings, empirical research, and gaps that have been identified. The section on Research Methodology describes the research design, sampling, data collection and data analysis tools. The Results section contains hypothesis test and statistical results. Discussion finds the interpretation of results as per the existing literature. Lastly, the Conclusion is a summation of important findings, then the implications, limitations and future study directions are provided.

2. Literature Review

2.1. Pedagogical Foundations of Play in VR Serious Games

Constructivist and experiential learning theories were highly influential pedagogical perspectives of VR serious games since they focused on building knowledge by actively engaging the environment [20]. As previous studies pointed out, VR serious games allowed learners to participate in situational problem-solving tasks in which knowledge was created by exploring, experimenting, and reflecting [21]. VR enabled experiential learning because of its immersiveness: e.g. to handle virtual objects, view the effects of actions, and repeat the solution in safe, simulated environments [22]. According to systematic reviews of the scientific material on educational technology, such play-based environments enhanced deeper conceptual and procedural knowledge, especially in STEM-related fields [23]. The pedagogical principles were operationalized through the means of embedding a learning objective into the mechanics of VR serious games, which made play align with an intentional instructional design [24].

VR serious games were also supported by problem-based learning and inquiry-based pedagogies [25]. There was reliable empirical evidence that game scenarios based on real-world, real-life challenges led to critical thinking, decision-making, and learning transfer [26]. In VR settings, the learners were put in the role of a participant, which required them to examine the situation, evaluate hypotheses, and react to the dynamically changing feedback of a system [27]. Another aspect of the study was the use of narrative and role-play to improve the engagement and motivation of learners because these activities placed tasks in contexts of meaningful stories [28]. The systematic reviews showed that pedagogical scaffolding, including hints, adaptive feedback, and progressive difficulty, could be introduced as part of a VR game to ensure, among other things, a higher level of task performance and a longer duration of engagement in the game [29]. The conclusions made in the study explained the need to support play mechanics and instructive approaches to learning [30]. Social constructivist views also added to the pedagogical premises of play in VR serious games, as they focused on collaboration, communication, and meaning-making [31]. The study on the use of multi-user VR environments demonstrated that cooperative gaming encouraged peer learning, as participants engaged in dialogue, negotiated, and solved problems together [32]. The study contained in the recent systematic reviews suggested that avatar-based communication and common virtual environments could support social presence and collaborative knowledge-building [30]. Also, debriefing and in-game feedback were listed as significant pedagogical elements that bridged the gap between play experiences and learning outcomes [33]. All of the studies taken together proved that successful VR serious games were based on the model of pedagogy integrating individual exploration, guided inquiry, and social interaction. These principles secured the fact that play was not just an engagement, but a guided learning process [28].

2.2. User Experience (UX) Design and Learning Efficacy Benchmarks in VR

VR-based learning environments were systematically reviewed in which the perspective on User Experience (UX) design was always among the key determinants of successful learning [34]. The analysis was based on the synthesis of the results concerning usability tests, experimental research, and design-based research, and immersion, presence, interaction fidelity, and cognitive load were identified as the key UX dimensions [35]. Studies stated that intuitive navigation, low-latency feedback, and ergonomic interaction methods greatly decreased any excess mental activity, allowing the learners to concentrate on learning material [36]. Multisensory feedback and visual realism were often associated with enhanced engagement, but the reviews warned of over fidelity that could distract the learners [35]. Such tools of evaluation were typically standardized UX tools, task-performance measures, and qualitative user feedback [12]. In multiple fields, the data indicated that user-oriented UX design, which aligned with pedagogical objectives, enhanced satisfaction, motivation, and attention, which created a precondition for a quantifiable learning outcome in VR settings [10].

The learning efficacy benchmarks in VR was a study that synthesized the results on knowledge retention, skill transfer, and higher-order cognitive development [37]. VR-based instruction was compared with traditional and screen-based modes in systematic reviews, which often reported moderate to high effectiveness in improving procedural learning, spatial conceptualization, and experiences [38]. Benchmarks were commonly operationalized by means of pre-after the fact testing, delayed retention measurement, performance accuracy, and transfer activity in real-life or simulated situations [16]. According to meta-analysis findings, VR experiences were scaffolded, goal-focused, and assessment-

aligned in order to achieve the highest learning efficacy [39]. However, inconsistent benchmarking criteria and brief intervention lengths were also found to bring variability in the effect sizes based on the reviews [21]. Recent reports demanded longitudinal references, learning standards, and more direct correlations between UX variables and learning outcomes in order to enhance the empirical premise of VR-based learning [34].

Though the idea of the pedagogical basis, play-based learning, UX design, and learning efficacy in VR serious games have been explored in previous studies, there is a critical gap in the study to comprehend their combined influence on the learning outcome. The available study mostly view pedagogical strategies, dimensions of UX, and efficacy benchmarks as independent constructs, and provide little information on the role of UX design as a mediator or moderator of the effectiveness of play-based pedagogies. Also, the discrepancy between benchmarks of learning efficacy and absence of longitudinal and standardized evaluation constructs prevent meaningful comparisons across studies. The active role of adaptive UX and pedagogical scaffolding in the process of sustaining varying learner profiles between the short term and the long term is also under-researched. Future studies need to take holistic and empirical methods that methodically match UX design measures with pedagogical intent and strong learning effectiveness levels in VR-based learning contexts.

3. Research Methodology

This study adopted a quantitative, cross-sectional, descriptive and analytical design to examine the relationships among User Experience (UX) design, play-based pedagogical elements, and learning outcomes in Virtual-Reality (VR) serious games. The study was conducted in Delhi NCR among learners who had experience using VR serious games. A total of 200 respondents were recruited using purposive sampling; the manuscript previously described the procedure as purposive and stratified sampling, and the exact implementation of any stratification should be specified by the authors. Primary data were collected through a structured questionnaire. The analyses reported in this manuscript were conducted using MS Excel, SPSS 27 and SmartPLS 4, including descriptive statistics, reliability analysis, KMO and Bartlett's tests, Pearson correlation, simple linear regression, and confirmatory measurement-model analysis. For consistency, UX design factors are treated as the predictor construct, learning outcomes as the outcome construct, and play-based pedagogical elements as a related pedagogical construct. The available results support a predictive association between UX and learning outcomes and a correlation between play-based pedagogical elements and UX; they do not, by themselves, establish a mediation effect. The conceptual framework and hypotheses have therefore been revised to match the analyses actually reported. The instrument measured three constructs: UX Design Factors, Learning Outcomes in VR Serious Games, and Play-Based Pedagogical Elements. Each construct was represented by five items, as indicated in the reliability analysis (Table 1). The reported Cronbach's alpha values were .789, .721 and .719, respectively. As Table 3 reports 69 participants below 18 years of age, the manuscript documents the safeguards used for participants who were minors. Figure 1 presents the conceptual framework of the study.

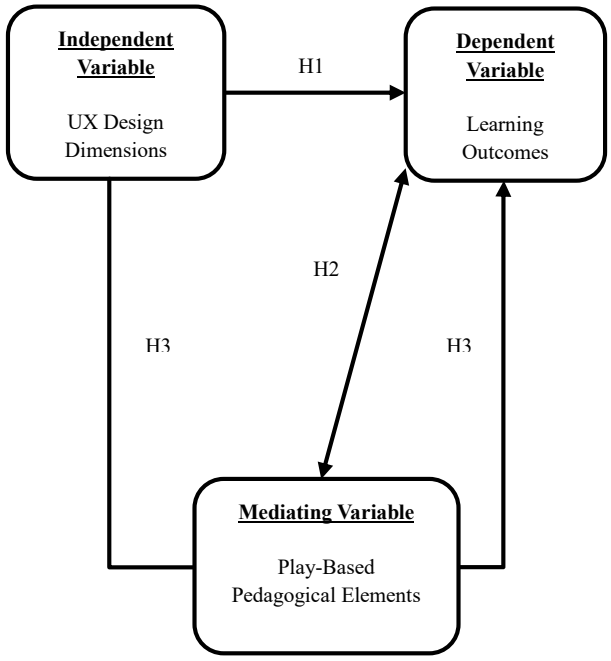

Fig. 1 Conceptual Framework-UX design factors predict learning outcomes; Play-Based Pedagogical Elements are modelled as a related pedagogical construct associated with UX design factors and learning outcomes. The available analyses do not test a mediation pathway.
Source: Author's own compilation

4. Results based on Objectives and Hypothesis

Table 1. Reliability analysis

Construct	N of Items	Cronbach's Alpha
UX Design Factors	5	.789
Learning Outcomes in VR Serious Games	5	.721
Play-Based Pedagogical Elements	5	.719

Source: By SPSS 27

The reliability analysis in Table 1 shows that both the Cronbach's alpha and the value of the three constructs indicate good internal consistency. The Cronbach's alpha of the UX Design Factors (5 items) is 0.789, which is considered as good reliability. The internal consistency of Learning Outcomes in VR Serious Games is acceptable, with an alpha value of 0.721, which is measured with five items. Likewise, Play-Based Pedagogical Elements, measured on 5 items, has a Cronbach's α of 0.719, which is also acceptable. All Cronbach's alpha values are above the accepted value of 0.70, which means that

the items in each construct are reliable enough for further statistical analysis. In general, the findings indicate that the instruments used for measuring the study have a satisfactory level of reliability. The results of the validity analysis in Table 2 indicate that the data are appropriate for analysis by factor analysis and provide evidence of construct validity. The Kaiser-Meyer-Olkin (KMO) Measures of Sampling Adequacy are 0.687 for UX Design Factors, 0.667 for Learning Outcomes in VR Serious Games and 0.629 for Play-Based Pedagogical Elements. 'All three constructs have acceptable levels of sampling adequacy, with these values. In addition, all constructs are significant on Bartlett's Test of Sphericity ($p < .001$), suggesting that the correlation matrices are significantly different from the identity matrices and that meaningful relationships exist between the items within each construct. Therefore, the results of the KMO and Bartlett's test indicate that the data is suitable for factor analysis and that the items could be used to represent their constructs.

Table 2. Validity analysis

Construct	No of Items	Kaiser-Meyer-Olkin Measure of Sampling Adequacy	Bartlett's Test of Sphericity
UX Design Factors	5	.687	.000
Learning Outcomes in VR Serious Games	5	.667	.000
Play-Based Pedagogical Elements	5	.629	.000

Source: By SPSS 27

Table 3. Demographic characteristics

S. NO.	Demographic Characteristics		N	%
1	Age	Below 18 years	69	34.5
		18-22 years	46	23
		23-27 years	42	21
		Above 27 years	43	21.5
2	Gender	Male	113	56.5
		Female	87	43.5
3	Education level	Higher secondary	49	24.5
		Undergraduate	47	23.5
		Postgraduate	50	25
		Doctoral	54	27
4	Field of study	Arts & humanities	40	20
		Engineering	46	23
		Management	62	31
		Science & technology	52	26
5	Experience with VR technologies	Less than 1 year	52	26
		1-3 years	47	23.5
		No prior experience	51	25.5
		More than 3 years	50	25
6	Purpose of VR serious game use	Academic learning	39	19.5
		Professional development	66	33
		Recreational learning	48	24
		Skill development	47	23.5

Source: Author's own compilation

The demographic grouping of the participants in Table 3 suggests the existence of a diversified sample about age, gender, education, area of study, VR experience, and mission of VR serious games application. Most of the participants are under the age of 18 years (34.5%), and the other older groups are fairly represented. There were a slight majority males (56.5) and females 43.5%. Doctoral and postgraduate students were the most educated types (27 percent and 25 percent, respectively) and represented the largest groups of the study population. The subjects represented diverse professions, the most of them being management (31%) and science and technology (26%). The data of VR technology experience is quite balanced, as there were no more than 50 percent and 50 percent not having experience, not more than one year, one to three years, and more than three years. Professional development (33%), recreational learning (24%), skill development (23.5%), and academic learning (19.5%), were the main topics of playing VR games.

Obj. 1: To identify the prediction of User Experience (UX) design dimensions on learning outcomes in VR serious games.

H1: User Experience (UX) design dimensions significantly predict learning outcomes in VR serious games.

Table 4. Model summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.719[a]	.517	.514	2.65076
a. Predictors: (Constant), User Experience (UX)				

Source: By SPSS 27

According to the model summary Table 4, the relationship between User Experience (UX) and the dependent variable under study is a strong positive association. The correlation coefficient (R) of 0.719 indicates that there is strong relationship, and R and square is 0.517, and this implies that UX can explain a large part of the variance in the dependent variable (0.517).

Its excellent Adjusted R Square of 0.514, found to be propagated by the sample size and the number of predictors, is a confirmation of the strength of the model. The average distance between the observed and predicted values is given by the standard error of the estimate, 2.65076, which indicates fairly accurate predictions. On the whole, UX is an influential forecast in this scheme.

Table 5. ANOVA

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1487.945	1	1487.945	211.761	.000[b]
	Residual	1391.250	198	7.027		
	Total	2879.195	199			
a. Dependent Variable: Learning Outcomes in VR Serious Games						
b. Predictors: (Constant), User Experience (UX)						

Source: By SPSS 27

The results of ANOVA Table 5 show that the regression equation of predicting Learning Outcomes in VR Serious Games with User Experience (UX) is significant. The regression sum of squares (1487.945) in comparison to residual sum of squares (1391.250) indicates that a significant amount of the variance in learning outcomes is attributed to UX. The F-value of 211.761, calculated with the $p < .001$, indicates that the predictive power of the model is very strong, which is far from much below the traditional 0.05. It implies that the differences in UX have a close connection with differences in learning outcomes. On the whole, the model shows that UX is a valuable predictor, and the correlation between UX and learning outcomes could not happen because it is not likely, and thus it should be regarded as a factor in the efficacy of VR serious games.

Table 6. Coefficients

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	5.014	.838		5.981	.000
	User Experience (UX)	.748	.051	.719	14.552	.000
a. Dependent Variable: Learning Outcomes in VR Serious Games						

Source: By SPSS 27

Table 6 of coefficients indicates that the effect of User Experience (UX) on Learning Outcomes has a significant positive influence in VR Serious Games. The coefficient (B) of UX is not standardized, so, on average, one-unit increase in UX increases the learning outcomes by about 0.748 units, other factors being equal.

The 5.014 constant term indicates the learning outcomes projected by the model in the event of a zero UX. The value of standardized Beta of 0.719 confirms that UX is a significant predictor based on a high relative contribution to the dependent variable.

This effect can be determined as highly significant because its t-value of 14.552 and $p < .001$ are statistically significant. On the whole, these findings verify that the improvement of UX positively affects learning in VR serious games.

Obj. 2: To determine the relationship between play-based pedagogical elements and UX design factors in VR serious games.

H2: There is a significant relationship between play-based pedagogical elements and UX design factors in VR serious games.

Table 7. Descriptive statistics

Descriptive Statistics			
	Mean	Std. Deviation	N
Play-Based Pedagogical Elements	17.8150	3.78051	200
UX Design Factors	17.2150	3.91348	200

Source: By SPSS 27

The descriptive statistics Table 7 shows that the participants rated the Play-Based Pedagogical Elements and UX Design Factors of VR serious games rather high. Play-Based Pedagogical Elements have a mean score of 17.815, which is a little bit higher than the mean of 17.215 of UX Design Factors, indicating that learners found pedagogical characteristics slightly better than UX ones.

The standard deviations of 3.78 and 3.91 show moderate variations in responses, which implies that there is some variance in perceptions of every individual, but the general variations show consistency among the 200 respondents. In general, the findings indicate that pedagogical design and UX are both visible elements of VR learning experience, and learners are equally aware of and engage with these elements to a similar degree.

Table 8. Correlations

Correlations			
		Play-Based Pedagogical Elements	UX Design Factors
Play-Based Pedagogical Elements	Pearson Correlation	1	.760**
	Sig. (2-tailed)		.000
	N	200	200
UX Design Factors	Pearson Correlation	.760**	1
	Sig. (2-tailed)	.000	
	N	200	200
**. Correlation is significant at the 0.01 level (2-tailed).			

Source: By SPSS 27

The correlation analysis Table 8 indicates that there is a positive and statistically significant high relationship between Play-Based Pedagogical Elements and UX Design Factors in VR serious games.

The correlation coefficient of 0.760 means that the greater the degree of play-based pedagogical design, the greater the degree of effective UX design and vice versa.

The significance ($p < .001$) indicates that it is nearly impossible that this relationship may have occurred due to chance, as it has reached the 0.01 significance level.

It indicates that, under VR serious games, the good pedagogic features are bound to correlate with a good UX feature, which is an important aspect of interaction between pedagogic and UX features in improving interest and the primary efficiency of VR-based learning spaces.

Obj. 3: To examine the mediating effect of play-based pedagogical elements in the relationships among UX design factors and learning outcomes in VR serious games.

H3: There is a significant mediating effect of play-based pedagogical elements in the relationships among UX design factors and learning outcomes in VR serious games.

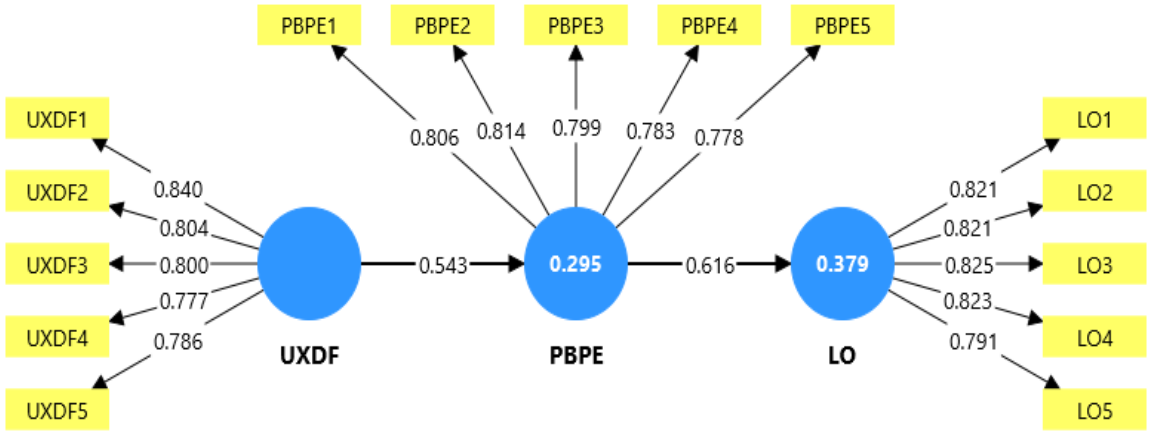

Fig. 2 SEM assessing the mediating effect of PBPE between UXDF and LO in VR serious games

Source: By SmartPLS 4

The structural model (Figure 2) used for this study is a model that considers the mediating role of Play-Based Pedagogical Elements (PBPE) between UX Design Factors (UXDF) and Learning Outcomes (LO) in VR serious games. The model results show that UXDF and PBPE are positively related, with a path coefficient of 0.543, which means that the enhancement of the design factors of UX were positively related with the integration of play-based pedagogical elements. In the same way, PBPE shows a positive association with the learning outcomes, with path coefficient 0.616. The PBPE elements play a positive role in achieving learning outcomes. The Coefficient of Determination (R^2) for PBPE is 0.295 and for LO is 0.379, which means that UXDF is able to explain 29.5% of the variance in PBPE and the model can explain 37.9% of the variance in LO. In addition, the loadings of the indicators ranged from 0.777 to 0.840 for UXDF, 0.778 to 0.814 for PBPE, and 0.791 to 0.825 for LO, which showed good relationships between the observed indicators and their constructs. In summary, the model depicts the proposed relationships between the UX design factors, pedagogical aspects and learning outcomes of VR serious games based on play.

Table 9. Assessment of measurement model, structural model, discriminant validity and model fit

Assessment	Indicator	Result
Structural Model	R^2 - LO	0.379
	Adjusted R^2 - LO	0.376
	R^2 - PBPE	0.295
	Adjusted R^2 - PBPE	0.292
	f^2 - UXDF → PBPE	0.419
	f^2 - PBPE → LO	0.611
Reliability and Convergent Validity	Cronbach's Alpha - LO / PBPE / UXDF	0.875 / 0.855 / 0.861
	Composite Reliability (rho_a) - LO / PBPE / UXDF	0.875 / 0.856 / 0.864
	Composite Reliability (rho_c) - LO / PBPE / UXDF	0.909 / 0.896 / 0.900
	AVE - LO / PBPE / UXDF	0.666 / 0.634 / 0.642
Discriminant Validity	HTMT - PBPE-LO / UXDF-LO / UXDF-PBPE	0.711 / 0.626 / 0.629
	Fornell-Larcker - LO / PBPE / UXDF (diagonal)	0.816 / 0.796 / 0.802
	Fornell-Larcker - PBPE-LO / UXDF-LO / UXDF-PBPE	0.616 / 0.545 / 0.543
Congruence Coefficient	LO-PBPE / LO-UXDF / PBPE-UXDF	0.956 / 0.923 / 0.926
Model Fit	SRMR (Saturated / Estimated)	0.030 / 0.069
	d_ULS (Saturated / Estimated)	0.106 / 0.577
	d_G (Saturated / Estimated)	0.055 / 0.078
	Chi-square (Saturated / Estimated)	56.399 / 77.711
	NFI (Saturated / Estimated)	0.963 / 0.949

Note: R^2 = Coefficient of Determination; f^2 = Effect size; AVE = Average Variance Extracted; HTMT = Heterotrait-Monotrait ratio; SRMR = Standardized Root Mean Square Residual; NFI = Normed Fit Index.

Source: Results by SmartPLS 4 and consolidation by Author

The results of the consolidated assessment of the measure model and the structure model are presented in Table 9, which includes construct reliability, convergent validity, discriminant validity, explanatory power, effect sizes, congruence coefficient and model fit. Cronbach's alpha values (0.855-0.875), composite reliability (rho_a) values (0.856-0.875), and composite reliability (rho_c) values (0.896-0.909) demonstrate good internal consistency for the three constructs. Likewise, Average Variance Extracted (AVE) falls between 0.634 and 0.666, which is higher than the recommended value of 0.50, and thus shows good convergent validity. HTMT values between 0.626 and 0.711 show good discriminant validity, and the Fornell-Larcker criterion demonstrates that the square roots of the AVE (0.796-0.816) are greater than the inter-construct correlations. The value of f-square for UXDF→ PBPE is 0.419, and the value of f-square for PBPE→ LO is 0.611, which shows that it has a significant effect. The value of R^2 for UXDF → PBPE is 0.31, and the value of R^2 for PBPE → LO is 0.37, which shows that the structural model has moderate explanation power. In addition, the congruence coefficients are between 0.923 and 0.956, which is a high degree of construct congruence. Concerning the model fit, the SRMR value estimated to be 0.069, and the NFI value estimated to be 0.949, were satisfactory. Overall, the results indicate the validity of the measurement model and support the postulated structural relationships. The mediation effect of H3, however, needs to be confirmed statistically with the bootstrapping analysis of the specific indirect effect.

5. Discussion

Wang (2025) [40] claims that VR serious games that incorporate play-based pedagogy greatly improves learning results because immersive environments promote active exploration, problem solving, and critical thinking [26]. Ofosu-Asare (2024) [41] concurs, but underlines that the mentioned pedagogical benefits are extremely conditional upon the User Experience (UX) design factors, including the interface usability, interactivity, and feedback mechanisms,

which define engagement and retention [36]. Buley & Natoli (2024) [42], however, warns that although great UX can enhance immediate engagement, it does not necessarily guarantee further learning or knowledge transfer unless pedagogical strategies are well planned and scaffolded. In reaction, Alomari et al. (2020) [35] uses an analysis of the study that indicates that in cases where play-based elements are carefully coupled with quality UX, learners not only enjoy the experience but also exhibit quantitative cognitive and skills-based benefits. Mittal et al. (2021) [28] extend the supply that the connection between UX and pedagogy is context-specific, contingent on the age, previous experience, and complexity of the subject matter of a learner, and benchmark standards are mandatory to assess and establish consistency in its design [24].

Putnam et al. (2023) [43] raise a point that too much emphasis on UX may lead to more emphasis on entertainment rather than learning, which may impose a dilution on education. Dube & Wen, (2022) [1] refute that contemporary VR design models combine both engagement and learning goals, enabling the UX to be used as a framework instead of a distraction. Anjum & Chowdhury (2024) [44] argues in favour of this, saying that it has been observed that learners are known to display peculiarities in terms of interaction which can be both pleasant and understandable, that is, effective UX can actually be complementary to pedagogy, not competing with it. Timileyin (2024) [45] admits though proposes that in the absence of close supervision, some learners can depend on the trial-and-error mode of playing which negatively affects learning objectives. Dede et al. (2017) [13] points out the importance of comparing UX features that include navigation, feedback, and immersion against the pedagogical objectives to determine the occurrence of gaps, and to make sure that VR serious games are both entertaining and efficient. On the whole, the study emphasizes that UX and play-based pedagogy are complementary to each other, but their combination needs a conscious design and evaluation to achieve the best learning results [12].

6. Conclusion

The findings indicate that UX design factors are positively associated with learning outcomes in VR serious games. The regression model reports $R = .719$, $R^2 = .517$, standardized $\beta = .719$, and $p < .001$, while the correlation analysis shows a positive association between play-based pedagogical elements and UX design factors ($r = .760$, $p < .001$). The reported measurement model also estimates positive relationships among UX design, play-based pedagogical elements, and learning outcomes. Because the analyses do not include a formal indirect-effect test, the study does not claim that play-based pedagogy mediates the UX-learning outcome relationship. The results instead support the importance of examining user-centred design and pedagogical alignment together when evaluating VR serious games. The findings should be interpreted as associations within this cross-sectional sample rather than proof of causality.

6.1. Implications of the Study

The findings have practical implications for educators, instructional designers, and VR developers. The observed association between UX design factors and learning outcomes suggests that usability, interaction, feedback, and other UX features deserve attention when evaluating VR serious games. The correlation between play-based pedagogical elements and UX design factors also suggests that pedagogical planning and interface design should be considered together. These results do not establish causality or a mediating effect; therefore, recommendations should be treated as design considerations to be evaluated in future studies rather than as proven causal effects.

6.2. Limitations of the Study

Although the study has its contributions, there are some limitations that it has. The study is constraint in terms of geography in the sense that the study is localized to the Delhi NCR area of India, which could influence the overall application of the results in other cultural or educational backgrounds. The cross-sectional design record the perceptions and the outcomes of the learners at a given time, which does not provide insights on the long-term retention and transfer of the skills learned. Self-reported measures can also result in response bias because of relying on data. Moreover, the study is more centered on the UX and pedagogical concepts, rather than on the individual differences in the subject matter or individual dissimilarities of learners, i.e., learning styles and cognitive skills. These shortcomings are indicative of care in making generalized inferences concerning the outcome.

6.3. Recommendation for Future Study

The longitusdinal designs must be used in future study efforts to explore the long-term effect of UX and play-based pedagogy on learning retention and transfer of skills into the real world in VR serious games. The external validity of the results would be improved by studies carried in different geographical areas and in educational institutions. Discipline-specific VR applications can also be studied in further research to evaluate the differences in UX benchmarks between different disciplines, including healthcare, engineering, and social science. Causal inferences would be reinforced by introducing objective learning analytics, behavioral tracking and experimental designs. Also, the adaptive and personalized UX, which is sensitive to learner profiles, should be explored in future study to narrow the benchmarks to enable inclusive, scaled and learner-centered VR-based educational systems.

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