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Article

Integrating Sustainable Educational Innovations and Spatial Cognition: A Study of Factors Affecting College Students' Sustainable Learning Behavior in Virtual Simulation Environments

Junsheng Zhou [1], Liyao Xiao [2,*] and Yunfu Li [3]

1 Virtual Simulation Design and Application, Xi'an University, Xi'an 710049, China; zhoujunsheng@xawl.edu.cn
2 Department of Media Content, Cheongju University, Cheongju 360-764, Republic of Korea
3 Education Digitalization Reform, Xi'an Jiaotong University, Xi'an 710049, China; liyunfu@xjtu.edu.cn
* Correspondence: gzxiaoliyao@gmail.com

Abstract: Objective: This study investigated the factors influencing college students' continuous utilization intention of virtual simulation software (Animation Character Virtual Simulation Software V1.0) in the context of current efforts to promote sustainable educational practices and explored design strategies to enhance this willingness in a sustainable manner. Method: Based on the Expectation Confirmation Model of Information System Continuance (ECM-ISC), this study developed a model to examine the impact of college students' spatial ability (SA) on their virtual simulation learning behavior. Upon administering a questionnaire to the selected participants (N = 164), the survey data were analyzed for reliability and validity. Subsequently, the relationships among the model's variables were explored. Result: For college students majoring in Digital Media Art, spatial ability significantly positively affects their sustainable utilization intention of virtual simulation software within 3D virtual scenarios. Meanwhile, it positively impacts perceived ease of use (PEU) and flow experience (FE), which are key factors in promoting the sustainable adoption of such technologies. The introduced spatial ability, perceived ease of use, and flow experience influence the endogeneity of the ECM-ISC. Moreover, gender differences in spatial ability are profound among these students. Conclusion: The primary influencing pathway is spatial ability → flow experience → expectation confirmation → perceived usefulness → continuous utilization intention. Enhancing spatial ability is one effective way to advance virtual simulation software, offering new insights for its design and long-term improvement in alignment with sustainable educational practices.

Keywords: sustainable educational innovations; spatial ability; virtual simulation software; multimedia; sustainable utilization intention

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1. Introduction

Under the guidance of the Chinese government's policy to "promote the digitization of education and build a learning society and a learning country with lifelong learning for all people", universities across China are actively exploring teaching reforms using virtual reality software [1]. This significant initiative signifies that the digital transformation of education has become a crucial task in educational reform and development. Currently, virtual simulation software has become a vital enabling tool in the digital transformation of higher education in China. Due to its effectiveness in reducing students' environmental cognitive load [2], virtual reality has been extensively adopted in educational practices aimed at creating immersive learning scenarios and fostering soft skills [3]. Despite its growing application, virtual simulation is still considered to be in an exploratory phase in higher education, and learners have not yet habituated to using it [4]. Thus, when formulating strategies to integrate virtual simulation into education, students' perceptions of virtual simulation experimental courses are an essential consideration [5].

Constructivist epistemology posits that knowledge is actively constructed by cognitive subjects [6], which is acquired by learners through activities and perceptions in specific contexts. Spatial ability enables learners to effectively handle spatial relationships in the task scenarios provided by virtual reality, completing operations and positioning tasks in virtual spaces. A review of the relevant literature indicates a lack of a unified definition of spatial ability. Spatial ability (SA) is also referred to as "spatial reasoning", which is interchangeable in research. Prior studies have highlighted spatial ability as a significant factor influencing academic achievement across various subjects [7]. Consequently, this study deemed it necessary to explore the impact of college students' spatial ability on their intention to use virtual simulation software. A model was constructed to investigate the impact of spatial ability on virtual simulation learning behavior, combining a nested model of spatial reasoning complexity and the Expectation Confirmation Model (ECM) [8]. In this model, perceived ease of use (PEU) and flow experience (FE) were incorporated into the ECM. Moreover, the relationships between spatial ability, perceived ease of use, and flow experience were examined.

Empirical research has revealed that spatial ability is significantly correlated with both perceived ease of use and flow experience. This study explored influencing pathways among spatial ability, perceived ease of use, flow experience, expectation confirmation, perceived usefulness, and satisfaction, laying a theoretical foundation for effectively enhancing information recall in the spatial presence and virtual simulation software usage behavior. The findings contribute to understanding the mechanisms by which spatial ability impacts learners' continuous utilization intention. The recommendations based on data analysis are practically significant for the design, update, and promotion of virtual simulation software in educational settings.

1.1. Literature Review

Spatial ability is the capacity to generate mental images through personal thought and problem-solving [9]. It belongs to fluid intelligence, a crucial component of the structure of human intelligence. Additionally, fluid intelligence has been identified as a causal factor in general learning as it supports the acquisition of knowledge and skills [10].

Existing research has demonstrated that spatial ability is highly malleable and responds positively to educational interventions [11]. In the field of design education, individuals in the design group exhibit superior spatial ability to those in the non-design group [12]. Spatial ability plays a pivotal role in creative thinking, conceptual problem-solving, and concept generation [13]. Furthermore, it is closely related to creativity [14]. Individuals with higher stereoscopic auditory-visual capability, spatial ability, and immersive tendency tend to experience heightened spatial presence [15].

Spatial ability is a user variable. User variables combined with media factors form the Spatial Situation Model (SSM), which is a necessary stage in generating spatial presence [16]. Consequently, spatial ability is considered a vital element in fostering spatial presence. Compared to traditional media, virtual simulation software magnifies spatial presence [17], which can enhance learning efficacy, including factual knowledge recall [18] and learning motivation [19]. However, some studies have suggested that virtual simulation software has no direct effect on information recall. While the spatial presence generated by such software can boost user engagement and enjoyment, it may also impede information recall due to the consumption of cognitive resources [20]. This arises from the finite cognitive capacity of humans for information processing. Spatial presence involves the allocation of psychological resources to process the mental representations used in media content for media space construction. Spatial ability, the most critical aspect of individuals' processing ability [21], remarkably influences their capacity to establish solid and vivid mental representations of spaces depicted by media products [16]. Additionally, individuals with higher spatial ability may find it easier to fill in missing spatial information from memory, thereby elevating the richness and/or internal consistency of SSM with insufficient spatial data in media products [22]. Spatial presence is a combination of technological and individual factors. The former provides environmental support, and the latter influences personal perception, rendering both aspects inseparable.

Virtual simulation software is widely recognized as an effective learning tool [23]. How to ensure that learners can fully benefit from spatial presence while effectively learning and recalling information warrants further investigation. Given the above analysis, it is essential to use spatial ability as an independent variable and analyze its impact on user experience and continuous utilization intention of virtual simulation software. This facilitates the integration of content design and information processing in virtual simulation software, ultimately advancing the deep fusion of digital technology and education.

1.2. The Proposed Framework

1.2.1. Nested Model of Spatial Reasoning Complexity

Davis posited that spatial reasoning (also known as spatial ability) was a process where "psychological understanding" and "physical transformation" were interwoven [24]. As shown in Figure 1, content related to "psychological understanding" is located on the left side of the graphic area, while that involving "physical transformation" is on the right side. During spatial cognition, the cognitive processes associated with "psychological understanding" dynamically interact with the physical actions or thoughts involved in "physical transformation". Ultimately, individuals will translate these processes into other skill categories through interpretation or performance.

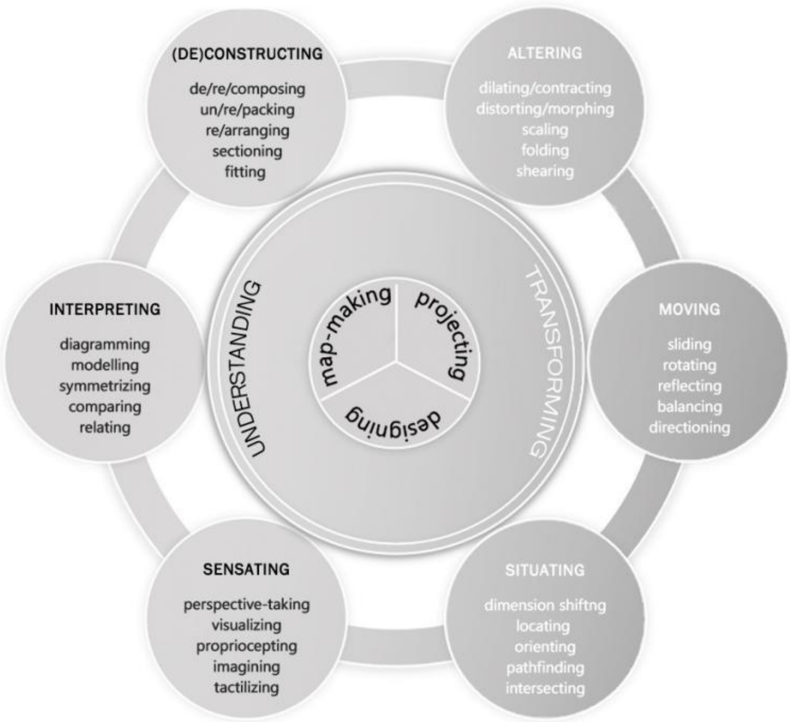

Figure 1. The emergent complexity of spatial reasoning elements, adapted from Davis et al.'s (2015) [24].

When using virtual simulation software, learners need to interact with the software to acquire spatial information. In spatial cognition, "physical transformation" requires learners to perform actions or thoughts related to "locating", "moving", and "modifying". This paper posits that spatial ability can assist learners in connecting external stimuli perceived with internal conceptual representations. For example, synchronizing mental and virtual spatial information when manipulating geometric shapes, such as moving, rotating, or scaling, can enhance the "perceived ease of use (PEU)" of the software. The easy interactivity perceived by learners can boost their operating efficiency. PEU is generally used to assess the degree to which a particular technology or system is considered as easy and convenient [25], serving as the foundation for successful learning activities. Accordingly, this study defines "PEU" as the learners' perception of the ease of use of virtual simulation technology. The following hypothesis is proposed:

H1. *Spatial ability has a significant positive effect on perceived ease of use.*

Virtual simulation software adopted in learning provides high-quality or abundant sensory information [26]. In this context, the "psychological understanding" domain involves initiating cognitive processes, encompassing "sensing", "interpreting", and "constructing (decomposing)". This article suggests that spatial ability can promote learners' perception of spatial information, facilitating the understanding of the relationships between stationary or moving target objects, their positions, and directions, as well as their contours, structures, constructions, and decompositions.

Csikszentmihalyi [27] defined "flow experience (FE)" as a state of complete immersion where individuals experienced peak engagement over a period. FE is related to the combination of skills individuals believe they possess, which is associated with challenges from activities. It can be inferred that spatial ability enhances learners' sensory experience, thereby improving "FE". In a flow state, individuals filter out irrelevant stimuli, focus only on goals and feedback, and maintain a sense of control over the environment. Flow plays a crucial role in shaping user experience and interactions with computer devices or programs [28]. Therefore, this article incorporates FE as a mediating variable and defines it as the psychological state of college students using virtual simulation technology, proposing the following hypothesis:

H2. *Spatial ability has a significant positive effect on flow experience.*

1.2.2. Expectation Confirmation Model

The Expectation Confirmation Model (ECM) is built upon Oliver's Expectation Confirmation Theory (ECT) [29] and Davis's Technology Acceptance Model (TAM) [30]. However, the ECM model addresses the post-confirmation stage. Omitting factors that influence perceived performance might yield an incomplete view of the research results. Perceived performance acts as a bridge between other influencing factors and the confirmation level, offering an additional perspective on raising the confirmation level [31]. The 3D virtual simulation software used in this study utilizes virtual simulation technology to better simulate real-world environments and enhance situational awareness. It also requires university students to have a high level of spatial ability to process spatial information and improve their perceived user experience. This may impact the level of expectation confirmation, necessitating an exploration of related influencing factors based on the ECM.

TAM theory suggests that technology can only meet users' initial expectations after being adopted. By comparison, ECT theory believes that users form expectations about a product or service before using it, and after usage, they compare their actual experience with their initial expectations, resulting in expectation confirmation. Positive confirmation occurs when actual performance meets or exceeds initial expectations [32]. Higher performance expectations generally lead to greater confirmation levels [33]. Given that virtual simulation software is an innovative technology in educational settings, pre-adoption expectations can influence post-adoption perceptions and behaviors. However, the Expectation Confirmation Model (ECM) places excessive emphasis on the final behavioral outcomes, while insufficiently considering process-related factors. Therefore, it is necessary to develop a new model that incorporates the influencing variables both before and after the use of virtual simulation software. By exploring the pathways through which university students' spatial abilities affect their intention to continue using the software, this model can provide valuable insights for improving educational interventions. Based on this, this article incorporates perceived ease of use and flow experience as pre-confirmation influencing factors. "Expectation confirmation (EC)" is defined as the psychological disparity between learners' expectations before using virtual simulation technology and their actual performance afterward. The following hypotheses are proposed:

H3. *Perceived ease of use has a significant positive effect on expectation confirmation.*

H4. *Flow experience has a significant positive effect on expectation confirmation.*

According to ECM proposed by Bhattacherjee [8], expectation confirmation directly affects users' perceptions of usefulness and satisfaction. Additionally, perceived usefulness has a direct impact on satisfaction and continuous utilization intention. Satisfaction, in turn, is a crucial factor affecting the intention to persist with the technology. Perceived usefulness significantly positively impacts satisfaction. It has been validated that the ECM hypotheses generally hold true in typical online education contexts [34]. In this study, "perceived usefulness" refers to the extent to which learners believe that virtual simulation technology enhances learning performance; "satisfaction" denotes the psychological state or emotional response of students to their learning experience with virtual simulation; "continuous utilization intention" represents the willingness to persist with virtual simulation technology for educational purposes. Therefore, this article proposes the following hypotheses for college students using virtual simulation technology:

H5. *Expectation confirmation has a significant positive effect on perceived usefulness.*

H6. *Expectation confirmation has a significant positive effect on satisfaction.*

H7. *Perceived usefulness has a significant positive effect on satisfaction.*

H8. *Perceived usefulness has a significant positive effect on continuous utilization intention.*

H9. *Satisfaction has a significant positive effect on continuous utilization intention.*

Based on these hypotheses, a model of the impact of spatial ability on virtual simulation learning behavior was constructed, as shown in Figure 2.

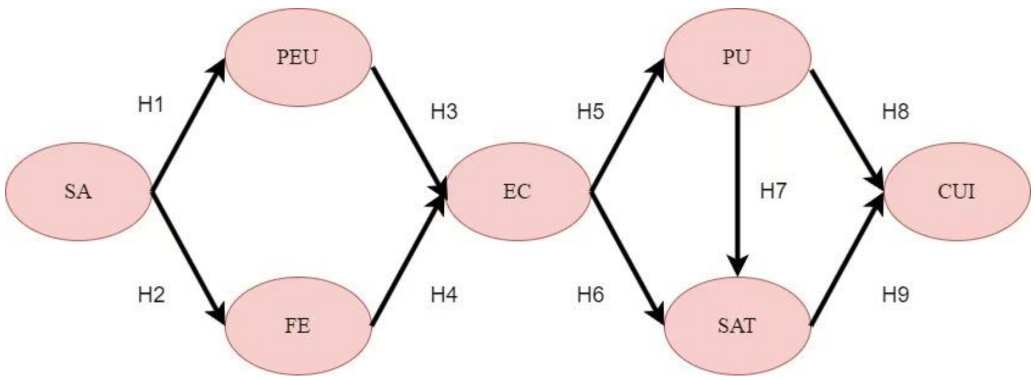

Figure 2. The research model of the influence of spatial cognition on virtual simulation learning behavior.

2. Research Methodology

2.1. Participants

This study is based on the course "Virtual Simulation Experiment Teaching for Animation Character Production" at a local undergraduate university in Shaanxi. The low-immersion virtual simulation software was developed by a company, with the teaching content designed by university instructors. The software is in Chinese and includes clearly defined tasks and assessment components. During classroom instruction, it is used by student groups, while after class, students can independently use the software at their own pace. During the eighth week of the course in the first semester of the 2023–2024 academic year, an offline survey was administered to Digital Media Art students enrolled in the course. A total of 185 paper questionnaires were distributed and collected. After excluding incomplete, uniformly answered, or systematically patterned questionnaires, 164 valid responses were retained. Among the respondents, 65.2% were female. The students were distributed across different grades as follows: sophomores (31.7%), juniors (35.4%), and seniors (32.9%). The students were aged between 18 and 24 years old, and prior to taking this course, they had no experience using virtual simulation software in other courses within their major.

2.2. Research Instruments

2.2.1. College Students' Spatial Ability Scale

Spatial ability is typically assessed using diagram-based tests and self-report scales, with the latter being more prevalent. This study adapted five spatial ability items from the General Aptitude Test Battery (GATB) [35] to fit the context of this research. Original items about solid geometry were modified to scenarios relevant to three-dimensional modeling in virtual simulation experimental teaching. This adaptation resulted in a one-dimensional scale of spatial ability for college students, including items such as "I can visualize the missing shape of an incomplete three-dimensional model" and "I can imagine shapes from other perspectives in three-dimensional space based on a geometric figure". The scale is a 5-point Likert scale, with 5 being the highest value, indicating the strongest spatial ability, and 1 being the lowest value, indicating the weakest spatial ability. Factor analysis and internal consistency results, presented in Table 1, demonstrate solid reliability and convergent validity of the scale.

Table 1. Reliability and validity testing of the spatial ability scale.

Item	Factor Loading	Cronbach α	CR	AVE
I have a strong ability to perceive three-dimensional space.	0.780	0.803	0.866	0.564
I can visualize the missing shape of an incomplete three-dimensional model.	0.796			
I can imagine shapes from other perspectives in three-dimensional space based on a geometric figure.	0.791			
I can easily imagine the unfolded plan when facing a box.	0.680			
As soon as a specific object is mentioned, you can immediately imagine its three-dimensional shape.	0.700			

2.2.2. College Students' Virtual Simulation Experimental Learning Experience Scale

The evaluation items were derived from the existing literature, with modifications made to suit the specific context of this study. The items for perceived ease of use and perceived usefulness were adapted from Davis [25] and Davis et al. [30]; those for FE were draw from Guerra-Tamez et al. [36]; and those for expectation confirmation, satisfaction, and continuous utilization intention were grounded on Ye et al. [37] and Bhattacherjee et al. [38]. Finally, a scale for college students' virtual simulation experimental learning experience was developed across six dimensions. The scale is a 5-point Likert scale, with 5 being the highest value and 1 being the lowest value.

In factor analysis, the fixed number of factors was set to "5". The varimax rotation method was adopted for rotation. Factors with loading below 0.4 (e.g., V14: "I enjoy using virtual simulation software to learn about character animation production") were excluded. The results of factor and internal consistency analyses are shown in Table 2, indicating the scale's robust reliability and convergent validity.

Discriminant validity assessment necessitates that the square root of AVE for each structure variable in the model be greater than the variable's correlation coefficient with other structure variables. As listed in Table 3, except for perceived usefulness, whose square root of AVE is slightly lower than its correlation coefficient with continuous utilization intention, other latent variables all have higher square roots of AVE than their correlation coefficients. This indicates that the measurement model has strong discriminant validity.

Table 2. Reliability and validity testing of the virtual simulation software learning experience scale.

Variable	Item	Factor Loading	Cronbach α	CR	AVE
PU	Using virtual simulation software has enhanced my mastery of animation production techniques.	0.763	0.813	0.771	0.461
	Using virtual simulation software has improved my understanding of model-related knowledge.	0.730			
	Using virtual simulation software has sparked my interest in animation character creation.	0.623			
	Using virtual simulation software has increased my learning efficiency.	0.582			
PEU	I can proficiently operate the virtual simulation software in the course independently.	0.793	0.775	0.812	0.522
	Using virtual simulation software does not require excessive mental effort.	0.769			
	Learning with virtual simulation software is easy for me.	0.701			
	The features of the virtual simulation software are clear and understandable.	0.612			
SAT	Learning modeling or animation production with virtual simulation software is a good choice.	0.796	0.800	0.756	0.513
	Learning modeling or animation production with virtual simulation software is an inevitable trend.	0.768			
	I support the use of virtual simulation software in character animation education.	0.562			
CUI	I plan to use virtual simulation software frequently in the future.	0.748	0.887	0.770	0.528
	I intend to continue using virtual simulation software.	0.739			
	I am willing to keep using virtual simulation software.	0.692			
FE	Learning with virtual simulation software makes me feel very comfortable.	0.765	0.890	0.810	0.517
	Learning with virtual simulation software makes me feel very satisfied.	0.730			
	Learning with virtual simulation software makes me feel very pleased.	0.722			
	Learning with virtual simulation software makes me feel very engaged.	0.654			
EC	The experience with virtual simulation software exceeded my expectations.	0.879	0.746	0.764	0.535
	The outcomes of using virtual simulation software exceeded my expectations.	0.787			
	My expectations for using virtual simulation software have been met.	0.461			

Table 3. Discriminant validity analysis.

	PU	PEU	SAT	CUI	FE	EC
PU	0.679					
PEU	0.454	0.722				
SAT	0.603	0.353	0.716			
CUI	0.681	0.464	0.646	0.727		
FE	0.670	0.515	0.617	0.697	0.719	
EC	0.481	0.380	0.486	0.545	0.547	0.731

3. Research Contents

3.1. Status Analysis

As detailed in Table 4, college students utilizing virtual simulation software to learn animation design generally have unsatisfactory scores across various dimensions. Specifically, the overall scores for flow experience, perceived usefulness, perceived ease of use, continuous utilization intention, expectation confirmation, and spatial ability are all below 4.0, and the satisfaction dimension is only 4.0630. This indicates that students' self-assessments across various dimensions are relatively low, with their overall evaluations at a moderate level.

Table 4. Status analysis.

Variable	SA	PUE	FL	EC	PU	SAT	CUI
Mean	3.700	3.482	3.732	3.679	3.968	4.063	3.807
SD	0.589	0.711	0.726	0.621	0.628	0.663	0.732

The *T*-test data indicate that male students score significantly higher than females in dimensions such as FE (T = 2.458 *), PEU (T = 3.725 *), CUI (T = 3.407 *), and SA (T = 6.363 *). Additionally, students with prior experience using 3D software show significantly better performance in SA (T = 3.100 ***) and PUE (T = 2.825 *) compared to those without 3D software experience.

3.2. Model Analysis

This study employed structural equation modeling (SEM) to analyze the proposed model. The model fit was assessed using AMOS 24.0. As detailed in Table 5, the criteria for model fit are all met, verifying that the proposed model has a good fit.

Table 5. Model fit indices.

Indicator	CMIN/DF	RMR	GFI	AGFI	NFI	RFI	IFI	TLI	CFI	RMSEA
Recommended value	1–3	<0.08	>0.90	>0.90	>0.90	>0.90	>0.90	>0.90	>0.90	<0.10
Measured value	1.488	0.062	0.839	0.804	0.828	0.806	0.936	0.927	0.935	0.055

The results of the hypothesis analysis are shown in Table 6, and the standardized paths are depicted in Figure 3. Hypotheses H3 and H7 are invalid; hypotheses H1, H2, H4, H5, H6, H8, and H9 are solid; and all hypotheses are highly significant at the level of $p < 0.001$, except for H4, which is significant at the level of $p < 0.05$.

Table 6. Hypothesis analysis results.

Hypothesis	Relationship	Estimate	S.E.	C.R.	*p*	Valid
H1	SA→PEU	0.760	0.145	5.253	*	Yes
H2	SA→FE	0.587	0.132	4.449	*	Yes
H3	PEU→EC	0.113	0.061	1.843	0.065	No
H4	FE→EC	0.661	0.086	7.642	*	Yes
H5	EC→PU	0.968	0.127	7.610	*	Yes
H6	EC→SAT	0.849	0.381	2.229	0.026 *	Yes
H7	PU→SAT	0.033	0.337	0.097	0.093	No
H8	PU→CUI	0.726	0.140	5.197	*	Yes
H9	SAT→CUI	0.440	0.132	3.340	*	Yes

Note: * represents $p < 0.05$.

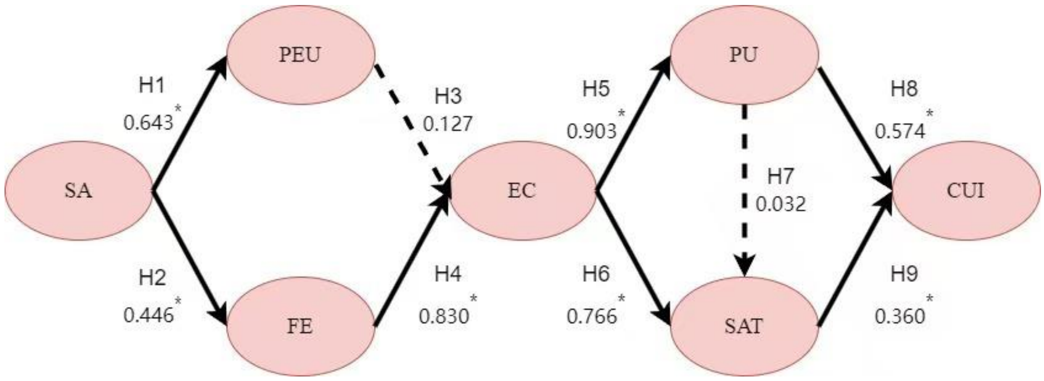

Figure 3. The standardized path diagram. Note: The solid lines represent significant correlations, and the dashed lines denote unconfirmed significant correlations. * represents $p < 0.05$.

4. Results and Discussion

Spatial ability significantly positively impacts both perceived ease of use and flow experience, with a more pronounced effect on perceived ease of use compared to flow experience. This suggests that spatial ability promotes learners' performance in physical transformations and mental understanding when they employ virtual simulation software. This is because spatial ability encompasses multiple spatial factors, such as visualization, mental rotation, perspective-taking, speed judgment, directional judgment, and memory [39]. These factors actively assist learners in understanding the contours, structures, and positional relationships of observed targets, as well as in multi-angle analysis. Spatial ability facilitates easier identification of spatial cues in virtual reality and enhances the cognitive significance of spatial structures. The findings of this study are consistent with the theories of Davis [24] and Wirth [16]. This also suggests that spatial ability influences the perceived experience when completing learning tasks using virtual simulation software, particularly the immersion experience. However, according to immersion theory, the emergence of immersion experience requires a corresponding level of spatial ability. This is especially important for STEM disciplines, which are highly correlated with spatial ability [39], and attention should be given to students' spatial ability levels during use.

Perceived ease of use does not significantly influence expectation confirmation, whereas FE does. This implies that digital media art students' perceived ease of use with virtual simulation software deviates from their initial performance expectations. In contrast, their higher expectation for flow experience is confirmed. This denotes that learners are more concerned with how well the virtual simulation software matches their professional skills and challenges rather than its ease of use. The lack of predictive power of perceived ease of use for software usage in this study aligns with the findings of Noble et al. [40].

Expectation confirmation significantly positively affects both perceived usefulness and satisfaction, with a greater effect on perceived usefulness (0.903 *) than on satisfaction (0.766 *). This conclusion demonstrates that the degree of alignment with expectations influences subsequent expectations. Meanwhile, it validates the relationships between expectation confirmation and perceived usefulness and satisfaction in the ECM. However, in this study, perceived usefulness fails to predict satisfaction. This implies that college students' satisfaction with virtual simulation software primarily stems from the expectation confirmation of the alignment with flow experience rather than the perceived usefulness alone. Previous research highlights that despite online learning being a pivotal tool, the greatest challenges lie in inappropriate learning environments and software content below educational requirements [41].

Both perceived usefulness and satisfaction significantly positively influence continuous utilization intention, and perceived usefulness has a greater effect than satisfaction. This finding extends the applicability of the ECM to investigate the continued use of virtual simulation software. It suggests that, in expectations afterward, knowledge acquisition is a primary goal for adult learners [42]. College students who have positive experiences with virtual simulation software view it as beneficial for knowledge acquisition, which encourages their continued utilization. In other words, although perceived ease of use does not significantly impact the learning process, perceived usefulness helps students overcome system-related inconveniences and motivates them to persist in using virtual simulation software.

Male students consistently score evidently higher than female ones across all dimensions, reflecting substantial gender differences in spatial ability. Based on the data analysis from this study, the difference in spatial abilities may be attributed to the varying experience with 3D software and learning outcomes between male and female students. Additionally, existing research suggests that this disparity is largely attributed to differences in responses to virtual reality between genders. Females generally exhibit inferior performance in spatial cognition [43]. However, the overall impact of gender on virtual reality usage is minimal [44]. Remarkable differences are primarily observed among individuals with lower spatial abilities. Mental rotation is a predominant factor contributing to these differences [45]. It is necessary to train female students before classes to mitigate this gender disparity in spatial ability.

5. Conclusions

This study focuses on the pre-adoption and post-adoption stages, primarily exploring the processual impact of spatial ability on the intention to continue use. Through a quantitative research approach, the relationship between spatial ability, perceived ease of use, and flow experience was validated. In expanding the applicability of the ECM, the study also identified the primary pathways through which spatial ability influences continuous utilization intention. Additionally, strategies need to be developed to reduce gender differences. Based on the research findings, the following strategies are recommended to enhance learning outcomes:

This study identifies a significant impact between college students' spatial ability and their continuous utilization intention for virtual simulation software, with male students showing notably higher spatial ability than female students. Therefore, it is essential to train students in spatial solution strategies and narrow gender gaps in spatial ability. It is recommended that holistic strategies be used when employing virtual simulation software to help students form comprehensive images of 3D models in their minds. If needed, targeted training should be provided to students with lower spatial ability, focusing particularly on improving their mental rotation skills.

The primary influencing pathway is spatial ability → flow experience → expectation confirmation → perceived usefulness → continuous utilization intention. On the one hand, emphasize the learning content challenge and flow experience. Flow experience is a key mediator affecting the intention to continue using. By enhancing flow experience, user engagement and spatial presence can be heightened. integrate learning content into meaningful contexts to deepen understanding and memory retention. Design adjustable difficulties for software tasks. By anticipating learners' needs, the alignment with their psychological understanding can be improved, thus promoting their engagement during use. Additionally, streamline the user interface, reduce distractions, and optimize information density to minimize unnecessary cognitive loads. College students' positive experiences exceeding their anticipation will elevate their expectation confirmation of virtual simulation software. On the other hand, enrich data feedback mechanisms and improve the perceived usefulness of software performance. Data visualization can be utilized to present relevant information to college students, enabling them to directly perceive the benefits of using virtual simulation software and augmenting user viscosity. Focus on the reflection of group learning feedback, such as function design and data representation of teacher evaluations, peer learning progress, and collaborative learning. This not only favors teachers' effective 'context-specific' implementation to enhance empathy with students but also heightens college students' continuous utilization intention of virtual simulation software.

6. Limitations and Future Research Directions

This article establishes a framework for understanding the impact of spatial cognition on user experience and behavioral intentions in virtual simulation software. However, several limitations should be noted.

Firstly, the study's participants were university students from China specializing in digital media arts, who were aged 18 to 24, who may have higher spatial cognition abilities due to their academic background. Future research could segment participants based on varying levels of spatial cognition and include samples from diverse global populations to further validate the theoretical framework.

Secondly, the virtual simulation software evaluated in this study is a low-immersion system. User experiences may differ in high-immersion systems, particularly regarding perceived ease of use and flow experience. The selected variables related to virtual simulation experiences were not exhaustive. Future research should incorporate additional variables such as interactivity, system features, and user enjoyment to achieve a more comprehensive investigation. Consequently, the findings may not be generalizable across all types of virtual simulation software. However, this study demonstrates the potential applicability of the extended ECM in low-immersion systems, suggesting that further exploration in high-immersion systems is warranted in future research.

Finally, spatial cognition encompasses numerous factors, while this study only involved limited investigation. Subsequent research should expand to specific elements—such as spatial perception, mental rotation, and spatial visualization—to delve into their effects on user experience with virtual simulation software.

Author Contributions: J.Z. contributed to the conceptualization, methodology, analysis, data curation, and writing. L.X. supervised all stages of the project and was responsible for the final editing of the manuscript. Y.L. was responsible for the collation and analysis of data. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Our study does not require further approval from the ethics committee, as it does not involve animal or human clinical trials, nor is it unethical. In accordance with the ethical principles outlined in the Declaration of Helsinki, all participants provided informed consent prior to their involvement in the research. The anonymity and confidentiality of the participants are ensured, and participation was entirely voluntary.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to the interviewees' request for the conversation content to be kept private.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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