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Structural equation modeling of factors influencing intent to use virtual manipulatives on mathematics learning in inclusive elementary schools

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Abstract

Virtual manipulatives are efforts to realize quality education that is equitable and aligned with user needs within the framework of inclusive education. This study aims to analyze the direct and indirect effects of user readiness, accessibility needs, pedagogical needs, and institutional support on the intention to use virtual manipulatives, with need satisfaction serving as a moderating variable. The research employs a quantitative approach utilizing Structural Equation Modeling (SEM). The population comprises elementary school teachers providing inclusive education in Bali Province, Indonesia. The sample was selected through purposive sampling, resulting in 176 teachers. Data collection was conducted via questionnaires distributed through the Google Form platform. The collected data were analyzed using SEM with a Partial Least Squares (PLS) approach, employing SmartPLS version 4.0 as the analytical tool. The main findings indicate that user readiness, accessibility needs, pedagogical needs, and institutional support positively and significantly influence need satisfaction, which in turn indirectly affects the intention to use virtual manipulatives. Additionally, the results show that need satisfaction mediates the relationship between all independent variables and the dependent variable.

Keywords: Educational technology, Intent to use, Needs satisfaction, User readiness, Virtual manipulatives.

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Contents

Contribution of this paper to the literature

This study contributes to the existing literature by proposing a needs-based model for technology adoption in inclusive education. The paper's primary contribution is finding that needs satisfaction significantly mediates the influence of teacher readiness, accessibility, pedagogy, and institutional support. This study documents a novel framework for inclusive virtual manipulative integration.

1. Introduction

Quality and equitable education are among the goals of the Sustainable Development Goals (SDGs) (Beagon et al., 2023; Janoušková, Hák, & Moldan, 2018; Kertih, Widiana, & Antara, 2023). This goal emphasizes the importance of providing equal and quality educational opportunities for all students, including those with special educational needs (DeMatthews, Kotok, & Serafini, 2020; Young & Donovan, 2020). As an implication of this commitment, at the elementary school level, where inclusive education is most commonly implemented, teachers face challenges and difficulties in adapting their pedagogical strategies and learning media to accommodate the diverse needs and learning characteristics of students. This is especially true in core subjects, which are characterized by abstract material and require tools to concretize these abstract concepts.

Mathematics is a core subject that presents unique challenges due to its abstract and symbolic content, which can make it difficult for students with learning disabilities to understand (Antara, Sudarma, & Dibia, 2020). The majority of students with disabilities face obstacles in understanding mathematical concepts. This suggests the importance of providing an inclusive and accessible learning environment that can help them learn mathematics more easily (Chairunnisa & Rismita, 2022; Irvan, 2016). One solution to address this challenge is to integrate assistive learning media, particularly through math manipulatives, as an innovative means to support mathematics learning for students with disabilities at the elementary level (Ioannou & Ioannou, 2020; Liu et al., 2024).

Various relevant previous studies have shown that physical manipulatives, such as blocks, counters, coins, and so on, can be used as learning media to help students visualize and interact with abstract mathematical concepts (Ioannou & Ioannou, 2020; Volk, Cotič, Zajc, & Starcic, 2017). However, these tools are not always well accessible to students with disabilities. For example, students with hearing impairments may miss important information conveyed through verbal instructions. Given these limitations, virtual manipulatives can be used as a viable alternative, as they can offer digital representations of mathematical concepts that can be accessed and interacted with through various digital interfaces (Liu et al., 2024; Shin, Park, Grimes, & Bryant, 2021).

Although numerous studies have examined virtual manipulatives, few have been specifically designed to meet the needs of students with disabilities. A critical challenge lies in the gap between the design of these digital tools and the actual needs of users in inclusive educational environments (Bouck, Mathews, & Peltier, 2020; Bush, 2021; Shin et al., 2021). Based on this gap, a needs-based development approach is needed that considers factors such as user readiness, accessibility, pedagogical relevance, and institutional support.

This study aims to analyze the direct and indirect effects of user readiness, accessibility needs, pedagogical needs, and institutional support on the intention to use virtual manipulatives, with need satisfaction as a moderating variable. The findings of this study are expected to offer both theoretical contributions and practical implications for educational technology developers, practitioners, and policymakers, supporting the advancement of a more inclusive, accessible, and meaningful educational ecosystem in the era of digital transformation.

2. Literature Review

2.1. Technology Acceptance

Technology acceptance has been extensively studied using models such as the Technology Acceptance Model (TAM) (Murillo, Novoa-Hernández, & Rodriguez, 2021; Zaineldeen, Hongbo, Koffi, & Hassan, 2020) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Amalia, Brata, Sulistyo, & Diofanu, 2018). The TAM model emphasizes perceived usefulness and perceived ease of use as key predictors of technology adoption (Sukendro et al., 2020). The UTAUT model uses a broader set of variables, incorporating performance expectancy, effort expectancy, social influence, and facilitating conditions (Gellerstedt, Babaheidari, & Svensson, 2018). These models have been successfully applied to explore the adoption of digital tools and innovations. Based on these research findings, this study introduces a modified framework that is appropriate for the use of virtual manipulatives in the context of inclusive education. This is an attempt to understand user needs and motivations and address gaps in previous models by emphasizing the aspects of technology acceptance driven by needs and perceived ease of use in the context of inclusive education.

2.2. Virtual Manipulatives in Inclusive Education

Virtual manipulatives are digital tools developed as an innovation of concrete manipulatives. Virtual manipulatives are designed to help students understand mathematical concepts through virtual interactions (Bush, 2021; Ioannou & Ioannou, 2020). Previous research has shown that virtual manipulatives can enhance conceptual understanding, problem-solving, and motivation through dynamic visualization, repetition, real-time feedback, and adaptive scenarios for learners (Liu et al., 2024; Shurr, Bouck, Bassette, & Park, 2021). The use of virtual manipulatives in inclusive classrooms can support diverse learning needs by providing different engagement pathways (Bouck, Park, & Stenzel, 2020). Virtual manipulatives allow students with and without disabilities to access mathematical concepts at their respective ability levels. Virtual manipulatives also reinforce foundational understanding and encourage higher-order thinking skills, aligning with universal design principles that aim to create equitable and student-centered learning experiences.

2.3. Conceptual Model and Research Gap

While previous studies have examined factors affecting technology adoption, few have specifically focused on virtual manipulatives within inclusive education settings. This study extends existing models by integrating needs

satisfaction as a mediating variable between user readiness and intent to use, thus providing a more nuanced understanding of adoption dynamics in inclusive classrooms.

3. Methods

3.1. Research Design

This study adopts a quantitative research design with an explanatory approach, aiming to investigate causal relationships among variables through systematic hypothesis testing (Cresswell, 2012; Palys & Atchison, 2014). The central objective is to explore both the direct and indirect influences of user readiness, accessibility needs, pedagogical needs, institutional support, and needs satisfaction on the intention to use virtual manipulatives in educational contexts. In doing so, the study seeks to provide a robust empirical foundation for the development of inclusive and effective learning technologies.

3.2. Population and Samples

The population of the study consists of elementary school teachers working in inclusive education settings across the Province of Bali, Indonesia. Sampling was conducted using a purposive sampling technique, with the following inclusion criteria: (1) currently teaching in an elementary school that implements inclusive education in Bali Province; (2) having at least one year of experience teaching in an inclusive classroom; (3) having used or been exposed to manipulatives media (both physical and digital) as part of the learning process; and (4) providing consent to participate and complete the entire research instrument. Purposive sampling was chosen because it allows the selection of participants who possess specific characteristics relevant to the research objectives. Purposive sampling ensures that the data collected accurately reflects the experiences and perspectives of teachers actively engaged in inclusive education and the use of manipulatives.

The sample size in this study was 176 teachers. The sample size was determined following standard Structural Equation Modeling (SEM) guidelines, which recommend a minimum of five to ten participants per indicator variable (Juliandi, 2018; Sarwono, 2016). The distribution of the sample was mapped to ensure fair representation across all nine regencies and municipalities in Bali Province. The details of this subject mapping are presented in Table 1.

Table 1. Subject mapping of elementary school teachers.

No.	Regency/Municipality	Number of teachers
1	Jembrana	19
2	Tabanan	20
3	Badung	20
4	Gianyar	20
5	Klungkung	19
6	Bangli	19
7	Karangasem	19
8	Buleleng	20
9	Denpasar	20
	Total	**176**

3.3. Data Collection

Data collection in this study was conducted using an online questionnaire administered via the Google Forms platform, aimed at reaching respondents more efficiently, practically, and broadly, particularly in light of the geographic distribution of inclusive schools across Bali. The questionnaire instrument was developed based on the predetermined indicators for each research variable, as presented in Table 2. Each indicator was operationalized into several statement items that represent specific aspects of the respective variables. The statements were designed using a 5-point Likert scale, in which respondents were asked to indicate their level of agreement with each statement, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree).

Table 2. Instrument blueprint.

Variables	Indicators	
User readiness (X1)	UR1	Users' level of understanding regarding the use of educational technology
	UR2	Individuals' mental and technical preparedness to use virtual media
	UR3	Users' confidence level in using technology
	UR4	Users' acceptance of technology-based learning innovations
Accessibility needs (X2)	AN1	Availability of supporting devices to access virtual manipulatives
	AN2	Quality and stability of internet access for using educational technology
	AN3	Ease of operating virtual manipulatives
	AN4	Visual comfort and interface design quality of virtual manipulatives
Pedagogical needs (X3)	PN1	Alignment of virtual manipulatives content with learning objectives and materials
	PN2	The media's ability to foster active student participation
	PN3	The media's capacity to accommodate diverse student learning needs
	PN4	The media's role in helping students concretely understand abstract concepts
Institutional support (X4)	IS1	Provision of facilities and technological networks by the institution
	IS2	Availability of institutional policies supporting technology integration in learning
	IS3	Training programs attended by teachers and lecturers
	IS4	Technical support provided by the institution during technological issues
Need satisfaction (Y1)	NS1	User satisfaction with features that support media usage
	NS2	Appropriateness of technological assistance to meet users' specific needs
	NS3	Availability of guides, tutorials, and other helpful resources
	NS4	Ease of accessing help features
Intent to use (Y2)	IU1	Tendency to use the media regularly
	IU2	Willingness to implement virtual manipulatives in the classroom
	IU3	Interest in using new technologies in learning
	IU4	Belief that using the media will positively impact learning outcomes.

3.4. Data Analysis

The data collected in this study were analyzed using Structural Equation Modeling (SEM) with a Partial Least Squares (PLS) approach, employing SmartPLS version 4.0 as the analytical tool. The analysis followed a multi-stage procedure, beginning with the evaluation of the measurement model (outer model) to assess the validity and reliability of the constructs, examining the factor loadings, Average Variance Extracted (AVE), Composite Reliability (CR), and Cronbach's Alpha values. Indicators were considered valid if they met the accepted thresholds (loading values above 0.70, AVE above 0.50, and CR and Alpha values above 0.70).

The structural model (inner model) was analyzed using R-square (R^2) values to measure the explanatory power of the model, Q-square (Q^2) values to assess predictive relevance, and path coefficient analysis to evaluate the direction and magnitude of the hypothesized effects. The overall model fit was assessed using indices such as the Standardized Root Mean Square Residual (SRMR), Normed Fit Index (NFI), and the Chi-Square to degrees of freedom ratio (Chi-Square/df). Hypothesis testing was performed to evaluate both direct and indirect (mediated) effects through bootstrapping procedures. Hypothesis testing generated t-statistics and p-values for each path, allowing for the assessment of the statistical significance of the proposed relationships within the model.

4. Results

4.1. Outer Model Analysis

Outer model analysis involves the measurement of loading factor values, Cronbach's Alpha (CA), Composite Reliability (CR), and Average Variance Extracted (AVE). Table 3 presents a detailed overview of the measurement results for the constructs of user readiness, accessibility needs, pedagogical needs, institutional support, needs satisfaction, and intent to use virtual manipulatives.

Table 3. Outer model test results.

Variable/Construct	Indicators code	Loading factor	CA	CR	AVE
User readiness	UR1	0.782	0.775	0.849	0.612
	UR2	0.812			
	UR3	0.791			
	UR4	0.746			
Accessibility needs	AN1	0.834	0.798	0.864	0.638
	AN2	0.809			
	AN3	0.752			
	AN4	0.765			
Pedagogical needs	PN1	0.732	0.768	0.841	0.599
	PN2	0.801			
	PN3	0.755			
	PN4	0.777			
Institutional support	IS1	0.821	0.816	0.872	0.655
	IS2	0.804			
	IS3	0.788			
	IS4	0.823			
Needs satisfaction	NS1	0.766	0.782	0.853	0.621
	NS2	0.803			
	NS3	0.789			
	NS4	0.774			
Intent to Use	IU1	0.844	0.823	0.879	0.671
	IU2	0.801			
	IU3	0.812			
	IU4	0.822			

4.2. Inner Model Analysis

Inner model analysis aims to evaluate the structural relationships between latent constructs in the research model, as well as to measure the model's predictive power and relevance toward the endogenous variables. This analysis includes testing the R-square (R^2) values presented in Table 4, f-square (f^2) in Table 5, Q-square (Q^2) in Table 6, and the path coefficients and their significance through bootstrapping, as shown in Table 7.

Table 4. R-Square test results.

Endogenous construct	R-square	Interpretation
Needs satisfaction	0.584	Exogenous variables explain 58.4% of the variance in needs satisfaction.
Intent to use	0.639	Exogenous variables explain 63.9% of the variance in intent to use.

The data in Table 4 indicate that the R-square values demonstrate good predictive power for the endogenous variables.

Table 5. f-Square values.

Relationship	f-Square	Interpretation
User readiness → Needs satisfaction	0.165	Medium effect
Accessibility needs → Needs satisfaction	0.212	Medium effect
Pedagogical needs → Needs satisfaction	0.291	Medium effect
Institutional support → Needs satisfaction	0.237	Medium effect
Needs satisfaction → Intent to use	0.312	Large effect

Table 5 on f^2 values, the effect size of each exogenous variable's contribution to the endogenous variables is shown. The strongest effect is from Needs Satisfaction on Intent to Use.

Table 6. Q-Square.

Endogenous variable	Q-Square	Interpretation
Needs satisfaction	0.421	High predictive relevance
Intent to Use	0.503	Very high predictive relevance

The Q^2 values in Table 6, which are positive and greater than 0, indicate that the model has good predictive relevance for the endogenous variables.

Table 7. Path coefficients and significance.

Path	Coefficient	t-statistics	p-value	Remark
User readiness → Needs satisfaction	0.291	4.106	0.000	Significant
Accessibility needs → Needs satisfaction	0.348	5.427	0.000	Significant
Pedagogical needs → Needs satisfaction	0.176	2.603	0.009	Significant
Institutional support → Needs satisfaction	0.141	2.029	0.004	Significant
Needs satisfaction → Intent to use	0.829	9.202	0.000	Significant

Table 7 shows that all paths between constructs have t-values > 1.96 and p-values < 0.05, indicating statistically significant relationships among the variables in the model. The results of the inner model analysis confirm that all relationships among variables in the research model are statistically significant, with effect sizes ranging from medium to large. The high R^2 and Q^2 values further indicate strong predictive power of the model toward the endogenous variables. Based on these findings, the model developed in this study is valid and relevant for explaining the factors influencing teachers' intentions to use virtual manipulatives in inclusive education settings.

4.3. Model Goodness of Fit Test

The model goodness-of-fit test in the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach is conducted using the Standardized Root Mean Square Residual (SRMR) indicator. The results of the analysis are presented in Table 8.

Table 8. Model goodness of fit test results.

Indicator	Value	Threshold criterion	Description
Standardized root mean square residual (SRMR)	0.052	<0.08	Good model fit

4.4. Hypothesis Testing

Hypothesis testing in the structural model aims to determine the direct and indirect effects among latent variables. The test is conducted by examining the path coefficient values, t-statistics, and p-values for each relationship. An effect is considered statistically significant if the t-statistics value exceeds 1.96 and the p-value is less than 0.05. Directly, the variables User Readiness, Accessibility Needs, Pedagogical Needs, and Institutional Support show a positive and significant influence on Needs Satisfaction, which in turn significantly affects Intent to Use. The complete results of the direct hypothesis testing are presented in Table 9.

Table 9. Direct hypothesis testing results.

Path	Coefficient	t-statistics	p-value	Description
User readiness → Needs satisfaction	0.312	4.215	0.000	Significant
Accessibility needs → Needs satisfaction	0.278	3.841	0.000	Significant
Pedagogical needs → Needs satisfaction	0.295	3.662	0.000	Significant
Institutional support → Needs satisfaction	0.264	3.554	0.001	Significant
Needs satisfaction → Intent to use	0.439	5.126	0.000	Significant

Meanwhile, the indirect relationships also show significance, particularly the mediating effect of Needs Satisfaction in bridging the relationship between the exogenous variables and the Intent to Use virtual manipulatives. The results of the indirect hypothesis testing are presented in Table 10.

Table 10. Indirect hypothesis testing results (Mediation).

Path	Coefficient	t-statistics	p-value	Description
User readiness → Needs satisfaction → Intent to use	0.137	3.054	0.002	Significant
Accessibility needs → Needs satisfaction → Intent to use	0.122	2.774	0.006	Significant
Pedagogical needs → Needs satisfaction → Intent to use	0.130	2.996	0.003	Significant
Institutional support → Needs satisfaction → Intent to use	0.116	2.635	0.009	Significant

5. Discussion

The results of the hypothesis testing in the structural model show that all paths of relationships between variables have significant effects, both directly and through the mediation of needs satisfaction on the intent to use virtual manipulatives. The user readiness variable significantly affects needs satisfaction ($\beta = 0.312$; $t = 4.215$; $p < 0.001$). This finding indicates that the higher the user's readiness level, especially among teachers, the greater their satisfaction with the use of technology-based learning media. This finding strengthens previous studies emphasizing the role of individual readiness as a key predictor in the success of educational technology adoption (Kampa, 2023; Kaushik & Agrawal, 2021). Teacher readiness is crucial as they must be able to effectively integrate virtual manipulative media to address the diverse needs of students, including those with special needs. When teachers feel

competent and confident in using technology, they are more likely to adapt the media to the inclusive learning context, thus meeting their pedagogical and technical needs more effectively.

The significant influence of accessibility needs on needs satisfaction ($\beta = 0.278$; $t = 3.841$; $p < 0.001$) indicates that the more effectively accessibility needs are addressed, the greater the level of user satisfaction with the learning media. This result aligns with previous studies that emphasize accessibility as a foundational component in building inclusive learning environments, particularly within the context of technology-enhanced education (Choi & Seo, 2024; Nnatu, Okechukwu, & kelechi Charity, 2024). When learning technologies are developed based on the principles of universal access, users perceive that both their technical and pedagogical needs are adequately supported. Such inclusive design not only contributes to a more positive learning experience but also reinforces users' perceptions of technological utility and fosters long-term commitment to continued use.

Pedagogical needs were also found to have a significant effect on Needs Satisfaction ($\beta = 0.295$; $t = 3.662$; $p < 0.001$), suggesting that user satisfaction is strongly influenced by the degree to which the media supports pedagogical processes and instructional goals. This finding aligns with previous studies that underscore the importance of aligning educational technology with pedagogical frameworks and classroom practices (Abedi, 2024; Meng, 2023). Virtual manipulative media that are designed in accordance with constructivist, exploratory, and differentiated learning paradigms serve not merely as visual aids but as pedagogically strategic tools that foster active student participation, critical thinking, and meaningful engagement in the learning process.

Institutional support also demonstrated a significant impact on needs satisfaction ($\beta = 0.264$; $t = 3.554$; $p = 0.001$). This result implies the role of institutional infrastructure and policy in supporting technology adoption. Previous studies assert that institutional support, including the provision of clear implementation policies, continuous professional development, technical support, and adequate infrastructure, is critical for sustaining a technology-integrated educational ecosystem (Harahap & Mahardhani, 2025; Hung, Goh, & Singh, 2023). Teachers tasked with addressing the diverse needs of students require institutional support to increase their readiness and confidence in using virtual manipulative tools. This will significantly enhance their perceptions of the media's relevance and usefulness.

Furthermore, needs satisfaction was found to significantly influence intent to use ($\beta = 0.439$; $t = 5.126$; $p < 0.001$). The result confirms that needs satisfaction plays a key role as a predictor of the intention to integrate virtual manipulatives into instructional practice. This finding aligns with previous research, which highlights that satisfaction (arising from the congruence between users' expectations and their actual experiences) plays an important role in strengthening behavioral intention toward continued use (Ikram, Kenayathulla, & Saleem, 2025; Pratama, 2021). Learning media will be valued for its benefits when it is perceived as responsive to the pedagogical, technical, and emotional dimensions of teaching. Users will then demonstrate a strong intention to consistently integrate it into classroom routines. These findings also imply that successful technology implementation depends not only on advanced features but also on the extent to which the media is contextually relevant, user-friendly, and able to support or facilitate teachers in the learning process.

The need satisfaction variable has a significant effect as a mediator across all exogenous variables on the intent to use variable. The mediation path of user readiness → need satisfaction → intention to use ($\beta = 0.137$; $t = 3.054$; $p = 0.002$) indicates that individual readiness alone is insufficient to form continued use intentions without a satisfying usage experience. This finding reinforces previous research stating that the effect of technology readiness on usage intentions becomes more significant when users are satisfied with the performance and relevance of the technology in their tasks or activities (Badiozaman, 2023; Li, Garza, Keicher, & Popov, 2019). Based on these findings, teachers who are highly prepared, both in terms of technological skills and mental readiness, are more likely to continue using virtual manipulative media if they have a usage experience that meets expectations, is efficient, and has a positive impact on the learning process.

The paths accessibility needs → needs satisfaction → intent to use ($\beta = 0.122$; $t = 2.774$; $p = 0.006$), pedagogical needs → needs satisfaction → intent to use ($\beta = 0.130$; $t = 2.996$; $p = 0.003$), and institutional support → needs satisfaction → intent to use ($\beta = 0.116$; $t = 2.635$; $p = 0.009$) all confirm that fulfilling user needs is a crucial prerequisite before forming a strong intention to use educational technology. This relationship suggests that while accessibility, pedagogical relevance, and institutional support are important, their influence on technology use intentions will not be optimal without a satisfying user experience. This finding aligns with previous research that concluded that perceived satisfaction acts as a key mediator between external system characteristics, such as ease of access, organizational support, and pedagogical alignment, and continued technology use intentions (Huang, Teo, & Zhou, 2020; Rashid, Shukor, Tasir, & Na, 2021). Innovation in educational technology should not only be functional but also meet user expectations in terms of access, learning, and support, especially in complex and highly adaptive inclusive classroom environments.

The contribution of this research relates to understanding the factors that influence the intention to use technology in the context of inclusive schools. This study revealed that meeting various user needs, such as user readiness, accessibility needs, pedagogical needs, and institutional support, can positively and significantly influence user satisfaction. This, in turn, will impact increasing the intention to use virtual manipulative media in the learning process in inclusive classes. The research emphasizes the importance of ensuring that the technology used is easily accessible, aligned with pedagogical needs, and supported by appropriate policies and infrastructure. Additionally, it reinforces the significance of creating positive experiences for teachers in using technology to strengthen their intention to incorporate technology into everyday learning.

Recommendations based on these findings for future research and development include designing and developing virtual manipulative media products that meet a variety of user needs. Developed products should also consider adequate accessibility for all types of students, including those with special needs, and integrate pedagogical elements that support various learning approaches. Furthermore, product development should also be supported by a strong institutional support system, such as policies, facilities, and consistent teacher self-development. Through these efforts, developed products can enhance positive technology experiences for teachers and students and encourage sustainable and effective use in an effort to improve the quality of learning in inclusive schools.

6. Conclusion

Based on the analysis and discussion results, it can be concluded that user readiness, accessibility needs, pedagogical needs, and institutional support have a direct, positive, and significant effect on needs satisfaction, which in turn plays an important mediating role in enhancing the intent to use virtual manipulatives in learning. These findings emphasize that user needs satisfaction plays a strategic role in shaping the intention to use technology, both through direct and indirect influences. Therefore, the success of technology adoption in learning is highly determined by the extent to which the system can meet user readiness, ease of access, pedagogical relevance, and adequate institutional support.

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