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PAPER

Perceived Cultural Relevance as a Cognitive-Affective Mechanism in TAM: Acceptance of PhET Simulations in Mathematics Learning

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ABSTRACT

The dynamic ethno-situation (DES) approach integrates ethnomathematics exploration with PhET Simulations to provide an interactive and culturally meaningful mathematics learning experience. This study aims to analyze students' acceptance of DES using the technology acceptance model (TAM) framework, which is expanded with perceived cultural relevance (PCR). A total of 278 junior high school students from four provinces in Indonesia participated through surveys and thematic interviews. Structural equation modeling (SEM) analysis showed that PCR serves as a link between perceived ease of use (PEOU) and perceived usefulness (PU) of technology, strengthening the effect of PU on students' intention to use it. These results confirm that the acceptance of learning technology depends not only on ease of use and usefulness but also on the cultural relevance perceived by students. When simulations reflect their cultural context, learning becomes more meaningful, emotionally engaging, and deeply motivating. This study structurally expands TAM by incorporating PCR as a cognitive-affective mechanism, offering a cross-nationally transferable conceptual framework for designing culturally responsive mobile, AI, and interactive simulation-based digital learning.

KEYWORDS

dynamic ethno situation (DES), PhET simulations, ethnomathematics, technology acceptance model (TAM), perceived cultural relevance (PCR)

1 INTRODUCTION

Digital transformation has revolutionized the way mathematics is taught and learned around the world, with interactive technology and digital simulations recognized as effective means of increasing student engagement and conceptual understanding [1], [2]. However, teaching practices in many countries still focus on symbolic and procedural representations [3], which often fail to connect abstract

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concepts with students' real-world experiences [4], [5]. To bridge this gap, the dynamic ethno-situation (DES) approach integrates ethnomathematics into PhET simulations, creating contextual and culturally responsive learning [6], [7]. In line with the principles of realistic mathematics education (RME), DES places meaningful context at the foundation of constructing mathematical concepts relevant to students' daily lives [8], [9], [10]. Globally, DES principles can be adapted to various cultural contexts, such as agricultural culture in Indonesia, European geometric art [11], [12], [13], First Nations crafts in Canada [14], [15], or traditional Latin American design [16], [17]. Thus, DES serves as a transferable framework for developing adaptive, inclusive, and cross-cultural digital learning.

Furthermore, the success of innovations such as DES-based PhET Simulations depends not only on engaging instructional design but also on how students receive, understand, and assess the cultural alignment of the technology they use [18], [19]. In this context, students' acceptance of culture-based technology is a crucial aspect to ensure that digital technology functions not only as a learning tool but also as a space for cultural representation and personal meaning-making [20], [21]. Therefore, this study focuses on analyzing the mechanisms of student acceptance of digital simulations integrated with cultural contexts. It aims to understand how cultural factors shape perceptions of ease, usefulness, and intention to use mathematics learning technology more comprehensively.

To systematically examine this mechanism, this study employs the technology acceptance model (TAM) [22] as its primary theoretical framework. TAM has been widely used to explain user acceptance of technology in various contexts, including education, because it can map the relationship between cognitive factors such as perceived ease of use (PEOU) and perceived usefulness (PU) with attitude toward use (ATU) and behavioral intention (BI) [23], [24]. This positive attitude then drives BI to use the technology, which is ultimately manifested in actual use (AU) or actual usage behavior. This model offers a robust conceptual framework for understanding how individuals' perceptions of the ease and usefulness of technology impact their attitudes and intentions to use it. However, while effective in explaining cognitive aspects, TAM does not fully capture the affective and sociocultural dimensions that play an important role in multicultural learning contexts, where cultural experiences and identities can influence students' perceptions of technology.

To address these limitations, this study expands TAM by adding the construct of perceived cultural relevance (PCR) as a cultural mechanism that modifies the relationship between variables in the model. Several studies show that when digital features are tailored to user characteristics and experiences, motivation and technology acceptance increase significantly [25], [26], confirming that PCR can be an important cognitive-affective mechanism in the acceptance of PhET simulations in mathematics learning. PCR describes the extent to which students perceive technology-based content or activities as being in line with their cultural identity, experiences, and values. Theoretically, PCR acts as a dual mechanism within the TAM framework. First, PCR acts as a mediator that explains how PEOU can transform into PU when technology is perceived as culturally relevant to students. Second, PCR acts as a moderator that strengthens or weakens the relationship between PU and BI depending on the extent to which cultural alignment is perceived.

Thus, PCR not only serves as an additional variable but also conceptually modifies the TAM structure by placing culture as the core mechanism that influences cognitive, affective, and behavioral pathways in technology acceptance [27], [28]. This study expands TAM from a model that focuses on technological factors to a culturally responsive framework. This conceptualization is relevant to the acceptance of mobile and interactive technologies in various global educational contexts. In an era of increasingly personalized digital learning [29], these findings have the potential to contribute to the development of AI-based technologies [30], augmented and virtual reality (AR and VR) [31], [32], and adaptive interactive simulations that can tailor the learning experience to the user's cultural background. By placing culture as a structural component in the technology acceptance model, this study offers a conceptual framework that can be transferred across countries and across education systems to realize more inclusive and meaningful digital learning.

Cross-cultural studies have shown that PU, PEOU, and cultural relevance influence technology acceptance [33], [34]. However, empirical research testing the dual role of PCR as a mediator and moderator in TAM within the context of ethnomathematics at the junior high school level remains limited. To address this gap, this study aims to analyze the role of PCR in expanding TAM in digital simulation-based mathematics learning, thereby producing a more comprehensive understanding of how factors such as ease, usefulness, attitude, and cultural mechanisms interact in shaping technology acceptance. The findings of this study are expected to contribute theoretically and practically to the development of a culturally adaptive and globally relevant TAM in the context of increasingly mobile and interactive digital learning.

2 LITERATURE REVIEW

2.1 Ethnomathematics simulation using PhET simulations

Ethnomathematics examines how mathematical practices and ideas emerge, develop, and are used in specific cultural contexts. This approach emphasizes that mathematical knowledge grows from social and cultural activities such as traditional games, weaving, architecture, symbols, or number systems that can serve as bridges to formal abstraction [35], [36]. Globally, ethnomathematics is viewed as a pedagogical strategy that links cultural identity with mathematical practice [21] while strengthening student motivation and sense of belonging in a multicultural learning environment.

In line with technological advances, several studies show that ethnomathematics can be integrated into interactive digital learning environments. One important innovation is culturally situated design tools (CSDTs), which are web-based tools that allow students to simulate cultural patterns (e.g., Native American weaving, cornrow braiding, or graffiti) using mathematical and computational principles [37], [38]. This approach demonstrates that digital technology can serve as a vehicle for cultural representation and a means of exploring formal concepts through hands-on and virtual activities.

The integration of ethnomathematics and technology is also reflected in the use of PhET Simulations, which have been proven effective in visualizing abstract mathematical and scientific concepts through dynamic models that encourage active exploration [20], [39]. Recent research shows that PhET improves students' conceptual and numeracy skills, as well as their engagement in STEM learning when integrated into contextual instructional design [40]. Thus, combining an ethnomathematical approach with interactive digital simulations has the potential to create meaningful and culturally relevant learning experiences. The following image displays a digital simulation of the concept of linear inequalities, which can be recontextualized within cultural contexts.

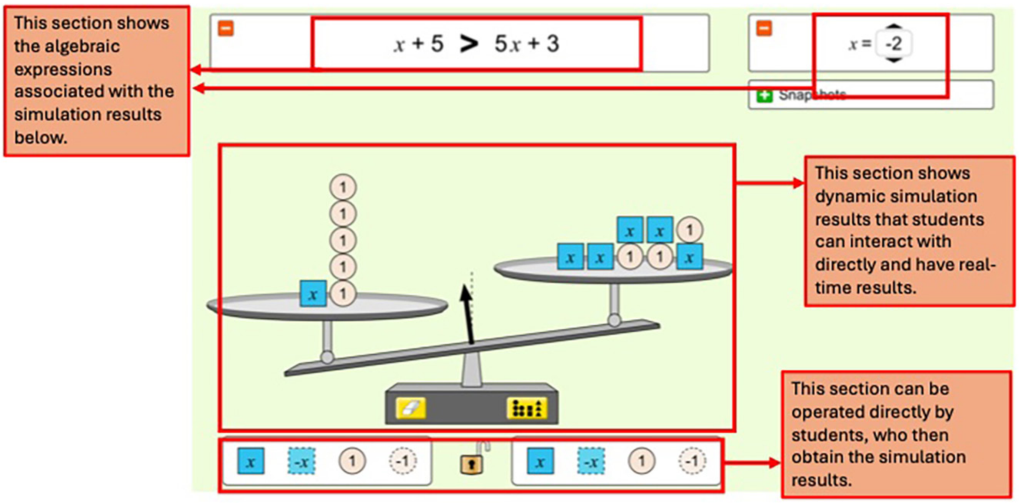

Fig. 1. Example of PhET simulations in the linear inequality concept

In Figure 1, conceptually illustrates that interactive simulations of linear inequalities can be recontextualized using the metaphor of balance, such as the two-armed scales commonly found in various cultures. The principle of balance represents the concepts of equality and imbalance in mathematics while also emphasizing that mathematical ideas can arise from different cultural symbols and practices [41], [42]. The integration of cross-regional cultural contexts demonstrates that cultural representations can act as a global conceptual bridge, connecting students' real-world experiences with mathematical abstractions in interactive learning environments.

2.2 Technology acceptance model

The TAM explains how individuals' beliefs about technology shape their attitudes, intentions, and ultimately their actual usage behavior. Its two main constructs are PU, which is the belief that using technology can improve performance or learning outcomes, and PEOU, which is the belief that technology is easy to learn and operate [35], [43]. In the main pathway of the model, PEOU influences PU, and both form ATU, which then influences BI to use the technology, ultimately leading to AU. Several studies also show a direct relationship between PU and BI [23], [30], because high perceived benefits often encourage usage intentions even though attitudes toward technology are not yet fully positive.

In the context of interactive and mobile digital learning, including PhET Interactive Simulations in mathematics, TAM is a highly relevant framework for explaining how students evaluate and adopt learning technologies. Digital simulations provide visual and manipulative representations that reduce interface barriers (increasing PEOU) and facilitate the understanding of abstract concepts (increasing PU). At the secondary education level, where the transition from concrete to abstract thinking is crucial [44], [45], positive perceptions of the ease and usefulness of digital simulations have been shown to shape more positive attitudes (ATU), intentions to reuse (BI), and ultimately actual adoption (AU) in learning activities. Thus, TAM provides a strong conceptual foundation for understanding the acceptance of interactive technology in the context of digital-based mathematics learning that is increasingly mobile, adaptive, and user-experience-centered.

2.3 Perceived cultural relevance

Perceived cultural relevance is a concept that emphasizes the importance of aligning learning experiences with students' identities, values, and cultural contexts. Conceptually, PCR is rooted in the ideas of culturally responsive pedagogy [46] and culturally relevant teaching [47], which hold that learning is more meaningful and effective when students find connections between academic knowledge and their cultural lives. In the context of contemporary education, which is increasingly digital and global, PCR is an important framework for bridging the gap between learning technology and the cultural diversity of users.

Perceived cultural relevance views culture not merely as a static background but as a cognitive and affective resource that influences how individuals understand, interpret, and construct meaning from learning experiences. This concept highlights that cultural connectedness influences students' engagement, intrinsic motivation, and conceptual understanding [48]. Thus, learning experiences that are considered culturally relevant enable students to navigate between the symbolic world of academia and their real-life experiences.

2.4 Extending TAM with cultural acceptance mechanisms

This study introduces PCR as a key component that expands the TAM structure and repositions culture as a cognitive-affective mechanism in technology acceptance. PCR is positioned not only as an antecedent but also as a mediator and moderator, altering the main relationship pathways in the model. As a mediator, PCR explains how perceptions of ease of use can transform into perceptions of usefulness when learning experiences are culturally relevant [34], [49]. As a moderator, PCR strengthens the relationship between PU and BI, especially when technology reflects the cultural values and identity of users, as illustrated in Figure 2.

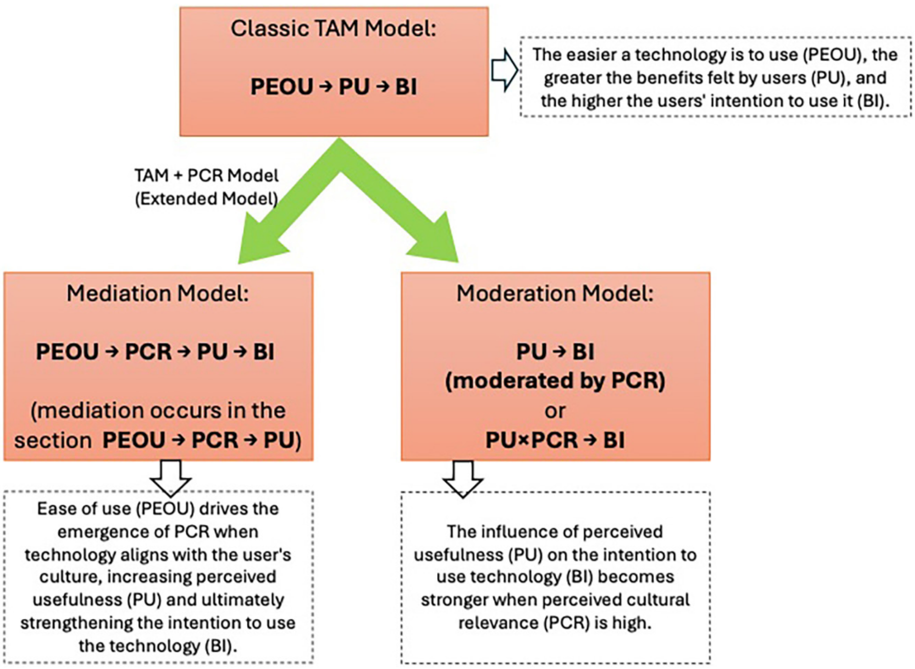

Fig. 2. Conceptual framework of extended TAM with cultural mechanisms

Based on Figure 2, this modification changes TAM from a technology-centered model to a culturally responsive framework, which has the potential to be applied in various educational and technological contexts. The integration of PCR in TAM also considers the influence of social context and cultural identity on the user experience of technology. This reconceptualization has global relevance, as it can be applied in various interactive educational and technological contexts such as AI-based learning tools, AR and VR [50], [51], [52], and mobile digital simulations. By placing culture as a structural element in the technology acceptance model, this framework provides a new theoretical contribution that can be tested across cultures to realize more adaptive, inclusive, and meaningful digital learning.

3 RESEARCH HYPOTHESES

Based on the literature review above, a strong relationship exists between cultural receptivity (PCR) and each dimension in TAM. Specifically, PCR is expected to be positively associated with PEOU and PU; increases in these two constructs then mediate the influence of PCR on ATU, which strengthens BI and ultimately correlates with AU. In other words, the higher the perception of cultural relevance, the easier the technology is to use (PEOU) and the more useful it is perceived to be (PU), resulting in a more positive attitude toward its use (ATU), an increased intention to use it (BI), and higher AU. Based on this, the hypotheses in this study are as follows.

Hypothesis 1: *PCR mediates the relationship between PEOU and PU.*

The above hypothesis assumes that ease of use alone is not enough to make technology useful. PEOU reduces students' cognitive load, but technology will only be considered truly useful when the content presented is relevant to their identity and cultural experiences. In this context, PCR is a bridge that transforms technical ease into conceptual meaningfulness [46]. This means that when students feel that digital simulations are not only easy to operate but also in line with the culture they are familiar with, their PU will increase significantly. Thus, PCR is a key mechanism explaining why the relationship between PEOU and PU can be strengthened within the TAM framework.

Hypothesis 2: *PCR moderates the relationship between PU and BI*

The above hypothesis assumes that the PU of technology does not automatically encourage the intention to use it. This relationship will strengthen if students feel the technology aligns with their cultural identity and experience [29]. In other words, even if a simulation is useful, students' intention to use it will only increase significantly when they feel its cultural relevance. Conversely, if cultural relevance is low, the influence of PU on BI tends to weaken. Therefore, PCR acts as a reinforcing factor that ensures that the benefits of technology are translated into behavioral intentions to use it.

4 METHODS

4.1 Research design

This study uses mixed methods, beginning with quantitative data collection and analysis to reveal the relationship between PCR and each dimension of student acceptance, followed by exploration to deepen understanding of the findings. Specifically, the extended TAM with the PCR framework was used to evaluate student acceptance of PhET simulations [53] based on DES in mathematics learning [35], [54]. The study began by introducing the PhET Simulations to students for 60 minutes. Students were explained the specifications and use of these digital simulations in learning linear inequality concepts. Then, students were given a questionnaire to assess their acceptance of these digital simulations.

4.2 Participants

The participants in this study were 278 eighth-grade students from four provinces in Indonesia (West Java, East Kalimantan, West Nusa Tenggara, and South Sulawesi). The sample was selected purposively based on the following criteria: (1) having access to digital devices, (2) having participated in PhET simulation-based mathematics learning, and (3) coming from different local cultural backgrounds. These students also used smartphones as one of their learning media, which made it easier to introduce the previously developed PhET simulations. As a result, 278 students voluntarily agreed to participate in the research project.

4.3 Instruments

Quantitative data was collected using a closed-ended questionnaire based on the modified and contextualized TAM within the PCR framework. This instrument consists of 15 statements, which are categorized into seven dimensions.

Table 1. TAM questionnaire grid with PCR

No.	Measured Aspects	Indicator	Many Items
1.	Perceived Usefulness (PU)	The extent to which students believe that technology can improve student performance or work outcomes.	2
2.	Perceived Ease of Use (PEOU)	The extent to which students believe that technology is easy to learn, use, and understand.	2
3.	Attitude Towards Using (ATU)	Attitudes reflect a person's feelings and opinions about technology.	2
4.	Behavioral Intention to Use (BI)	The desire or plan to use technology in a particular situation.	2
5.	Actual System Use (AU)	A person's actual actions in using technology, such as frequency of use, intensity of use, and type of use.	2
6.	Perceived Cultural Relevance (PCR)	The extent to which students perceive technology-mediated content and activities as consistent with their identity, experiences, and cultural values	5

As detailed in Table 1, each item uses a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Three experts in educational technology, mathematics, and culture reviewed the instrument's content validity, while reliability was tested using Cronbach's alpha analysis [55], with results > 0.83 for all dimensions. Qualitative data was also collected through semi-structured interviews with 24 students selected for maximum variation based on their TAM scores. The interview questions were designed to explore students' experiences using simulations, their perceptions of local cultural content in DES, and how the simulations helped them develop mathematical abstraction processes.

4.4 Data analysis

The main analysis was conducted using SEM with the maximum likelihood estimation (MLE) method. SEM was chosen for its ability to simultaneously estimate complex causal relationships, including testing mediation and moderation effects, as well as validating the measurement model within a single analytical framework [56]. This approach is considered superior to conventional multiple regression because it allows for direct evaluation of construct validity and model fit as a whole.

This analysis tests two main hypotheses: (1) PCR is positively associated with PEOU and PU and mediates the relationship between PEOU and PU; and (2) PCR moderates the relationship between PU and BI, where cultural alignment strengthens the influence of PU on usage intention. Mediation testing was conducted using bootstrapping with 5,000 resamples to obtain bias-corrected confidence intervals for indirect effects [57]. The moderation test was conducted through interaction term analysis with mean-centering on the PU and PCR variables to reduce multicollinearity. Robustness checks included testing the variance inflation factor (VIF) values, all of which were below 5, indicating no multicollinearity issues.

To reinforce the quantitative results, a thematic qualitative analysis was conducted through in-depth interviews with several students. These interviews focused on six main dimensions: PEOU, PU, ATU, BI, AU, and PCR to explore participants' perceptions and experiences of culture-based digital simulations. The data were analyzed using a thematic analysis approach to identify patterns of meaning, cultural representations, and student learning experiences. The interview results were presented as thematic tables summarizing the TAM dimensions, along with representative student quotes and conceptual interpretations that reinforced the SEM findings.

The mixed methods approach allows for data triangulation, where qualitative findings reinforce quantitative results. Qualitative analysis provides a richer context for explaining the relationship pathways found in the SEM model. Thus, data analysis not only answers hypotheses about the relationship between PCR and TAM dimensions but also broadens understanding of how cultural relevance acts as a mediator and moderator in the process of technology acceptance in secondary schools.

5 RESULTS

5.1 PCR mediates the relationship between PEOU and PU

To test the first hypothesis regarding the role of PCR as a mediator in the relationship between PEOU and PU, a path analysis was conducted using the SEM approach.

This analysis evaluated the direct relationship between variables and assessed the indirect effect through perceived cultural relevance.

Table 2. Path coefficients and indirect effects in the mediation model

Path Tested	Coefficient (β)	p-Value	Interpretation
PEOU → PCR	0.543	<0.001	Higher PEOU increases cultural relevance
PCR → PU	0.476	<0.001	Higher cultural relevance enhances perceived usefulness
PEOU → PU (direct)	0.291	<0.001	Direct effect remains besides mediation
Indirect effect (a×b)	0.259	CI95% [0.191; 0.336]	Partial mediation of PEOU → PU via PCR

Table 2 illustrates the results of mediation analysis in the SEM model that tests the role of PCR in the relationship between PEOU and PU. The results show that the PEOU → PCR path ($\beta = 0.543$; $p < 0.001$) and the PCR → PU path ($\beta = 0.476$; $p < 0.001$) are significant. In addition, the direct effect of PEOU on PU also remains significant ($\beta = 0.291$; $p < 0.001$), indicating partial mediation. The indirect impact calculated through the PEOU → PCR → PU path is also significant ($\beta = 0.259$; CI95% [0.191; 0.336]). Thus, it can be concluded that PCR plays an important role as a mechanism that bridges ease of use with perceived usefulness, where learning technology is not only easy to operate but also more useful when perceived as relevant to students' cultural identity.

5.2 PCR as a moderator in the relationship between PU and BI

Next, to test the second hypothesis regarding the role of PCR as a moderator, an interaction analysis was conducted between PU and PCR on BI. This analysis aimed to determine whether the level of PCR could strengthen or weaken the influence of PU on usage intention. The detailed outcomes of the moderation path analysis are presented in Table 3.

Table 3. Moderation analysis results: PCR as a moderator between PU and BI

Path Tested	Coefficient (β)	p-Value	Interpretation
PU → BI	0.308	<0.001	PU drives behavioral intention
PCR → BI	0.241	<0.001	Cultural relevance contributes to behavioral intention
PU×PCR → BI (interaction)	0.233	<0.001	Moderation: PCR strengthens the effect of PU → BI

The moderation analysis evaluates how PCR shapes the relationship between PU and BI. The test results show that the PU → BI path is significant ($\beta = 0.308$; $p < 0.001$), which means that the higher the perceived usefulness, the stronger the students' intention to use the technology. The PCR → BI path is also significant ($\beta = 0.241$; $p < 0.001$), confirming that cultural relevance directly increases the intention to use. In addition, the interaction PU×PCR → BI is significant ($\beta = 0.233$; $p < 0.001$), proving that PCR functions as a moderator. In other words, the effect of PU on usage intention will be stronger if students feel that the technology used is relevant to their cultural identity and experience.

5.3 Model fit evaluation of the SEM analysis

To ensure the model's suitability with the data, model goodness-of-fit indices were tested on three main models: the mediation, moderation, and full TAM models. This evaluation included the χ^2/df ratio, comparative fit index (CFI), Tucker–Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR).

Table 4. Model fit indices of SEM

Tested Model	χ^2/df	CFI	TLI	RMSEA	SRMR
Mediation Model (PEOU → PCR → PU)	1.85	0.96	0.95	0.056	0.041
Moderation Model (BI ~ PU + PCR + PU × PCR)	1.92	0.95	0.94	0.058	0.046
Full TAM Model (PEOU, PU, ATU, BI, AU)	2.01	0.94	0.93	0.061	0.048

Table 4 presents the model fit evaluation based on the goodness-of-fit indices assessed across the three estimated models. The mediation model (PEOU → PCR →PU) meets the criteria for good fit with values of CFI = 0.96, TLI = 0.95, RMSEA = 0.056, and SRMR = 0.041. This confirms that PCR is a valid mediator in the relationship between ease of use and perceived usefulness. The moderation model (BI ~ PU + PCR + PU × PCR) also shows a good fit (CFI = 0.95; RMSEA = 0.058; SRMR = 0.046), which reinforces the role of PCR as a moderator in the relationship between PU and intention to use. Meanwhile, the full TAM model (PEOU, PU, ATU, BI, AU) has a fit that is still in the acceptable category (CFI = 0.94; RMSEA = 0.061; SRMR = 0.048), so that the basic structure of TAM can still be used as a framework for technology acceptance. Overall, these results support the idea that the integration of PCR into TAM is acceptable both empirically and theoretically.

5.4 Results of interviews

In addition to quantitative analysis through SEM, this study was also supplemented with thematic interviews to enrich and confirm the findings. Interviews were conducted with several students to explore their direct experiences using DES-based PhET Simulations. The interviews focused on the main aspects of TAM, which were expanded with PCR. Qualitative data were analyzed thematically using NVivo software to identify recurring patterns and categories corresponding to the core constructs of the TAM model expanded with PCR. The coding process was carried out in three stages: open coding, axial coding, and selective coding. This approach allowed the emergence of main themes representing students' perceptions of DES-based mathematics learning. An overview of the qualitative analysis findings is provided in Table 5.

Table 5. Thematic interview findings based on TAM with PCR aspects

TAM with PCR Aspect	Thematic Findings (From Qualitative Coding)	Interpretation
Perceived Usefulness (PU)	Most students indicated that the simulations enhanced their comprehension of difficult and abstract algebraic concepts. They reported a clearer understanding of symbolic representations through interactive visualizations.	Simulations are perceived as highly useful in clarifying complex mathematical ideas, confirming the role of PU as a cognitive driver of acceptance.
Perceived Ease of Use (PEOU)	Students described the simulation interface as intuitive and easy to navigate, requiring minimal guidance. They emphasized smooth interaction and effortless control.	The technology is viewed as user-friendly, reducing cognitive load and enhancing engagement without imposing technical barriers.
Attitude Toward Using (ATU)	Participants expressed enjoyment and emotional engagement while using the simulation, associating it with playful and game-like learning experiences.	Positive affective responses indicate that enjoyment strengthens students' attitudes toward sustained technology use.
Behavioral Intention to Use (BI)	Students showed a strong willingness to continue using simulations and to recommend them to peers, reflecting perceived relevance and satisfaction.	High BI reflects a strong internalization of usefulness and enjoyment; cultural familiarity further amplifies this intention.
Actual Use (AU)	Several students reported voluntarily reusing simulations outside classroom hours for independent review and experimentation.	Evidence of autonomous and self-regulated learning behavior, indicating genuine technology adoption beyond formal instruction.
Perceived Cultural Relevance (PCR)	Students highlighted that cultural elements made mathematical ideas more relatable and easier to understand.	Cultural relevance serves as a cognitive-affective bridge, transforming ease of use into PU.

Qualitative findings were obtained from in-depth interviews with 24 students who had used DES-based PhET simulations. The data were analyzed thematically using NVivo 12 Plus, in which the codes generated were grouped based on the TAM construct expanded with perceived cultural relevance.

5.5 Integration of findings

The quantitative and qualitative results in this study show strong consistency and complementarity in explaining the mechanism of student acceptance of ethnomathematics-based digital simulations (DES). SEM analysis provides empirical evidence that PCR plays a dual role as a mediator and moderator in expanding the TAM framework. The significant mediation path in the PEOU → PCR → PU relationship indicates that ease of use does not automatically lead to perceived usefulness; instead, it is mediated by students' perception of the cultural relevance of the simulation content. This means that the learning experience becomes more meaningful when students feel that the technology they use reflects familiar cultural values, symbols, or practices.

Qualitative data from respondent interviews support these findings. Most respondents stated that the simulation was easy to use (PEOU), helped them understand abstract concepts (PU), and increased their desire to continue using the technology (BI). In addition, the cultural context recognized by students was reported to make learning easier to understand and more interesting. The interview findings confirm two main patterns: (1) ease of use is associated with increased cultural relevance and perceived usefulness, and (2) cultural relevance strengthens the relationship between PU and intention to use the technology. Overall, the integration results show that PCR empirically mediates and moderates the relationship between the main TAM constructs, supporting the validity of the expanded TAM model with PCR as a more comprehensive framework for explaining the acceptance of culture-based interactive learning technology.

6 DISCUSSION

6.1 Reconceptualizing the expanded TAM with PCR

The results of this study confirm that the integration of PCR fundamentally changes the way TAM works in explaining the acceptance of educational technology. The findings indicate that culture can no longer be viewed as an external factor but rather as a structural element that influences users' cognitive and affective processes in evaluating technology. By incorporating PCR into the model, the classic relationship between ease of use, usefulness, and intention to use becomes a more meaningful concept, both conceptually and contextually. This expands on the results of previous studies in the context of mobile learning and interactive learning. Reviews from [19], [30], and [54] indicate that meaningful user experiences influence the success of digital learning, but they have not explained how these experiences are culturally shaped. The findings of this study fill that gap by showing that cultural perceptions play a direct role in shaping the relationship between ease of use, usefulness, and intention to use.

Additionally, cultural relevance has been shown to strengthen the link between PU and intention to use. When students feel that technology represents or values their culture, their belief in the benefits of technology transforms into an affective drive to continue using it. This mechanism expands the affective pathway in TAM, where the intention to use technology is driven not only by rational perceptions of benefits, as in several previous studies [58], [59], but also by a sense of emotional and cultural connection.

This finding contributes to the global literature by showing that technology acceptance models must consider social and cultural contexts as an integral part of the adoption process. In the context of mobile learning and interactive learning [60], [61], meaningful user experiences are determined not only by interface design or functionality but also by the extent to which technology reflects the identity, values, and cultural practices of its users. Thus, this study reconceptualizes TAM as a culturally responsive framework that is better able to explain the acceptance of educational technology in culturally diverse environments.

6.2 Implications for cross-cultural educational design

Comparatively, these findings are consistent with previous research on the effectiveness of PhET simulations, which confirms that manipulative visual representations can improve understanding of abstract mathematical concepts [62], [63]. However, this study goes beyond instructional research by revealing a deeper mechanism of acceptance: technology is seen as beneficial not only because of its visualizations but also due to its cultural relevance, which makes these benefits more meaningful to students. These findings are also consistent with the literature on ethnomathematics and culturally based design, such as CSDTs that integrate Native American art or cornrow patterns to teach mathematical and computational concepts [49]. The difference is that this study provides a more explicit theoretical contribution by placing cultural relevance within the structural pathway of TAM, rather than merely as an external contextual factor.

Furthermore, this model can be applied to the development of AI-based learning tools, AR and VR, and mobile simulations with diverse cultural contexts [64], [65]. The DES principle, which integrates ethnomathematics elements with digital simulations, can be used to design learning experiences that foster cultural identification while strengthening scientific concept construction. This approach is consistent with cross-cultural design trends in global research [66], [67], [68], [69] that call for balancing technological sophistication with cultural authenticity. Thus, this study opens opportunities to design culturally adaptive simulations that are responsive to the diversity of student identities in different countries. This addresses the criticism that ethnomathematics-based studies are often local in nature. Instead, this study presents a conceptual framework that can be universalized in the global discourse on integrating interactive technology and culture in mathematics education.

6.3 Limitations and future research directions

This study has several limitations. First, the use of purposive sampling techniques limits the generalization of findings because respondents were selected from a specific context. Second, this study was conducted only in one country (Indonesia) and focused on a single mathematics topic, namely linear inequalities, so the results may not represent other fields or levels of education. Third, the cross-sectional research design does not allow for analysis of changes in perception over time [70]. Therefore, further research is recommended to use a longitudinal design, involve more cultural contexts and countries, and test the expanded TAM model with PCR on new AI, AR, or VR-based learning technologies.

7 CONCLUSION

This study provides empirical evidence that PCR is a fundamental component in the expansion of the TAM in the context of digital simulation-based mathematics learning. The findings show that PCR mediates the relationship between PEOU and PU, indicating that ease of use acquires a stronger pedagogical meaning when the technology is perceived to be in line with students' cultural identities. Furthermore, PCR acts as a moderator that strengthens the influence of PU on BI, so that the intention to use technology increases significantly when the benefits of technology are considered culturally relevant.

Theoretically, this study expands the TAM construct by placing PCR not only as a contextual factor but as a structural mechanism that can function dualistically as a mediator and moderator in the technology acceptance process. Practically, these findings confirm that integrating cultural sensitivity into digital simulation design can enhance student engagement, motivation, and meaningful learning. Furthermore, this contribution is cross-cultural and has the potential to be applied in various global contexts through the development of culturally adaptive simulations that are responsive to user identity diversity.

Finally, it should be emphasized that this expanded TAM framework is not only relevant to educators but can also be directly transferred to developers of AI and mobile learning applications. By understanding the strategic role of PCR in mediating and moderating technology acceptance, developers can design more adaptive, inclusive, and effective digital learning systems and AI-based applications that reach users from diverse cultural backgrounds. Thus, this research confirms that cultural relevance is a core element in educational technology innovation, as well as an important foundation for more human-centered and universal technology design.

8 ETHICS AND COMPLIANCE

This study was approved by the Research and Community Service Unit of Universitas Sindang Kasih Majalengka, Indonesia. All participants (and parents/guardians for minors) provided written consent. Data were anonymized and securely stored following institutional policies. No generative AI tools were used in preparing this manuscript, in line with iJIM's publication policy.

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