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Visual and interface design mechanisms: Systematic review of ethnomathematics media bridging culture and mathematics

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Abstract

Mathematics education continues to face representational challenges because abstract concepts are often disconnected from students lived and cultural experiences. Although ethnomathematics offers a way to contextualize learning, limited research has examined how visual and interface design may support the links between cultural contexts and formal mathematical understanding. This study presents a systematic literature review of 17 empirical studies from Scopus published between 2020 and 2025, following the PRISMA guidelines. The analysis identified recurring visual and interface design elements used to represent mathematical concepts in culturally meaningful and interactive ways. These elements are associated with three mediational processes: concretization, embodied engagement, and structured cognitive scaffolding, which may support learners in moving from cultural experiences to formal mathematical understanding. The novelty of this review lies in proposing these three constructs as analytical interpretations developed through cross-study thematic synthesis, rather than as mechanisms directly identified or tested within the primary studies. This review offers a design-oriented perspective on ethnomathematics learning and proposes an analytical framework to guide future research and practice, while highlighting the need for further empirical validation across diverse contexts.

Keywords: cultural mathematics; design mechanisms; ethnomathematics; media design; visual interface

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Introduction

Mathematics is a system of symbols used to represent patterns and relationships in both natural and social contexts. However, it is frequently perceived by students as something abstract and disconnected from lived experience, and culturally distant (Acharya, 2017; Nahdi, 2019). This challenge is not solely cognitive but also representational, relating to how mathematical ideas are visually presented, structured, and organized within learning environments (Norman, 2013). Research in multimedia learning demonstrates that clear and simple visual displays can reduce cognitive load and support students' processing of difficult and abstract ideas (Mayer & Moreno, 1998; Clark & Mayer, 2016). This cognitive account addresses how visual information is processed rather than how it becomes culturally and socially meaningful. Therefore, it offers a partial rather than complete explanation of why visual design matters in ethnomathematical contexts. To account for the cultural and meaning-making dimension, this study draws on semiotic perspectives, which explain how visual and symbolic forms carry culturally situated meaning beyond their cognitive processing function. Together, these perspectives suggest that visual design operates simultaneously as a cognitive support mechanism and as a bearer of cultural meaning, particularly in digital learning environments (Mayer, 2014).

However, difficulties in mathematics learning arise from multiple interacting factors, including pedagogy, teacher competence, and instructional context, and existing literature does not establish that design deficiencies are the primary or sole source of these difficulties. Rather than claiming a direct causal role, this study analytically positions visual and interface design as one potential mediating layer among several, whose specific contribution relative to pedagogical and contextual factors remains empirically unresolved in the current literature. This framing is adopted because design constitutes the representational and interpretative layer through which learners' access and organize mathematical concepts within cultural contexts. This makes design an analytically tractable entry point for systematic review, though it is not presented here as the dominant explanatory factor. Building on the cognitive-cultural distinction established above, ethnomathematics further emphasizes the cultural embeddedness of mathematical knowledge itself, not merely its visual representation (D'Ambrosio, 1985; Rosa et al., 2016). These three perspectives are treated as complementary rather than theoretically unified: multimedia learning theory explains the perceptual and cognitive mechanisms by which visual information is processed, while ethnomathematical and semiotic perspectives explain the cultural and symbolic conditions under which that information acquires mathematical and cultural meaning. This study does not claim that these frameworks share a common theoretical foundation; rather, it uses them jointly as complementary lenses, applied at different levels of analysis to examine design elements that operate across both dimensions. Taken together, multimedia learning theory accounts for how visual information is cognitively processed, semiotic perspectives explain how that same information carries culturally situated meaning, and ethnomathematics anchors both processes within specific cultural practices; the proposed analytical framework in this review is positioned at the intersection of these three perspectives rather than as an extension of any single one.

Building on this framework, ethnomathematics addresses the disconnection between mathematics and students' cultural experiences more specifically by conceptualizing mathematics as a form of knowledge embedded within cultural practices, where ideas such as symmetry, proportion, and spatial transformation are expressed through artifacts, activities, and traditions (Gerdes, 1998; Verner et al., 2019). Prior research shows that integrating cultural contexts can enhance student engagement, conceptual understanding, and affective responses toward mathematics (Rosa et al., 2016; Turmuzi et al., 2023). It can also reduce students' anxiety and strengthen their sense of cultural identity, particularly among learners from underrepresented groups (Bishop, 1988; Orey & Rosa, 2021). However, despite these benefits most studies focus on learning outcomes rather than examining how design elements within learning media facilitate these processes.

This indicates a descriptive rather than causal gap: while cultural learning media consistently report positive affective and cognitive outcomes, the specific contribution of visual and interface design features relative to other pedagogical factors remains under-analyzed and undifferentiated in the literature. Existing studies often combine cultural content with learning media without clearly identifying which design elements are described as supporting the transition from cultural experience to abstract mathematical thinking. For example, studies may report that cultural artifacts improve engagement or understanding, yet provide limited explanation of the specific design features, visual structures, or interaction mechanisms involved (Adnan et al., 2019). This does not establish that design is the cause of the reported outcomes, only that its role has not been isolated or examined explicitly. Moreover, prior systematic reviews in ethnomathematics have primarily examined effectiveness in terms of motivation and achievement, with limited attention to how design specifically is described as functioning within these outcomes. Unlike earlier reviews, which are organized primarily around learning outcomes and treat learning media as a single undifferentiated construct, this review is scoped specifically around visual and interface design features, distinguishing it from prior work not merely by topical emphasis but by unit of analysis. As a result, practitioners and researchers lack a clear, design-focused account of ethnomathematical media, independent of claims about design's causal weight relative to pedagogy or teacher competence. It is important to note that this study does not treat design as the sole or primary source of limitations in mathematical learning; rather it is examined as one representational component that interacts with, but does not replace pedagogical, contextual, and teacher related factors in shaping learning outcomes.

In response to this gap, the present study employs a systematic literature review to analyze visual and interface design in ethnomathematics learning media. A systematic review approach is appropriate as it enables the identification of recurring design patterns and supports analytical synthesis of how design elements function across diverse contexts. Therefore, this study positions itself as a design focused systematic review to provide a more specific and actionable contribution. This study aims to move beyond outcome-based evaluation toward understanding how and why ethnomathematics learning works, particularly through visual and interface design. Accordingly, this study addresses three research questions. First, what visual and interface design elements are predominantly employed in ethnomathematics media to represent

mathematical concepts. Second, how do these design elements mediate the transition from cultural experience to formal mathematical understanding. Third, what emerging trends, challenges, and future directions characterize the development of culturally responsive mathematics learning media. By addressing these questions, this study contributes a design-oriented perspective that provides more precise and actionable guidance for educators, designers, and researchers.

Methods

This study employed a Systematic Literature Review (SLR) guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Page et al., 2021). The SLR approach was selected to enable a structured, transparent, and reproducible synthesis of empirical findings across interdisciplinary domains, particularly those intersecting ethnomathematics, educational technology, and visual/interface design. Given the fragmented nature of existing studies, this approach is appropriate for identifying recurring design elements and examining how these elements are described as functioning within learning processes. Rather than establishing causal relationships, this study aims to provide analytical generalization by addressing "what" and "how" questions through thematic synthesis. Interpretations related to underlying mechanisms are therefore treated as theory-informed explanations rather than empirically verified causal claims.

The literature search was conducted in Scopus, selected for its rigorous indexing of peer-reviewed international journals in education and social sciences. While these database ensure high-quality sources, limiting the search to a single platform, combined with a relatively narrow set of search terms (elaborated below), may exclude relevant studies indexed elsewhere or described using alternative terminology (e.g. 'instructional design', 'learning environments'). These combined constraints are acknowledged as potential sources of selection bias and are addressed further in the discussion as a boundary condition on the generalizability of the findings. In particular, restricting the search exclusively to Scopus, without complementary searches in Web of Science or ERIC, may have excluded relevant studies indexed only in those databases, and this single-database restriction should be read as a specific limitation on the comprehensiveness of the search rather than a general caveat.

The search strategy was developed iteratively, expanding keywords beyond core terms to capture conceptual variations across disciplines. During this scoping process, terms such as visualization, representation, instructional design, and interactive or learning environments were considered. Of these, visualization and representation were retained in the final Boolean stings, while instructional design and interactive or learning environments were excluded to preserve search precision and avoid excessive result dilution. This narrower scope, while manageable for systematic screening, may not fully capture studies using alternative terminology such as 'instructional design' or 'learning environments', representing a limitation on the comprehensiveness of the search. The final Boolean search strings were as follows: (1) "Ethnomathematics" OR "Cultural Mathematics" AND "Visual Design" OR "Interface Design" OR "Visualization" OR "Representation"; (2) "Cultural Representation" OR

"Indigenous Pattern" OR "Traditional Motif" AND "Mathematical Structure" OR "Formal Concept"; and (3) "Ethnomathematics" AND "Media Design" OR "Digital Media" OR "Learning Interface". These search strings were designed to retrieve studies that explicitly bridge cultural or ethnomathematics content with media or design considerations. The search was restricted to publications from 2020 to 2025 to capture recent developments in digital learning environments and interface design practices.

Studies were included if they met the following criteria: (1) being peer-reviewed, being in the form of original empirical research published in English; (2) explicitly combining ethnomathematics or cultural mathematical contexts with learning media (digital or non-digital); (3) including substantive analysis of visual design, interface features, or interactivity; and (4) measuring variables in the affective domain (engagement, motivation, anxiety, attitudes) OR explicitly reporting how design elements facilitate mathematical understanding. Studies were excluded if they were: (1) dissertations, non-English publications or review articles without primary empirical data; (2) studies focused solely on cultural exploration without pedagogical media application (3) studies measuring only cognitive outcomes without design feature analysis.

The inclusion and exclusion criteria that were applied during the study selection process and organized across key dimensions including publication type, language and availability, publication timeline, content focus, variables measured, and pedagogical application are systematically presented in Table 1.

Table 1. Inclusion and exclusion criteria

Dimension	Inclusion criteria	Exclusion criteria
Publication Type	Peer-reviewed articles	Dissertations, master theses, book chapters, conference abstracts (unless full paper indexed), editorials, or gray literature without formal peer review
Language and Availability	Published in English and available as full-text	Published in a non-English language (full-text is not widely accessible even via institutional access/interlibrary loan)
Publication Timeline	Published between 2020 and 2025	Published outside the defined timeframe
Content Focus	Studies combining: (1) Ethnomathematics/Cultural Context AND (2) Learning Media/Tools (Digital or Non-Digital); AND (3) Analysis of Visual Design, Interface Design, or Interactivity features	Studies focusing only on pure cultural exploration without pedagogical media application, using media but not analyzing the design features, or focusing solely on the delivery method (e.g., using Zoom)

Dimension	Inclusion criteria	Exclusion criteria
Variable Measured	Studies measuring variables of the Affective Domain (e.g., Math Anxiety, Student Engagement, Motivation, Attitude) AND/OR explicitly reporting the relationship between design elements and mathematical concept understanding	Studies only focusing on Cognitive Outcomes (e.g., test scores, achievement, or purely conceptual understanding) without design feature analysis
Pedagogical Application	Studies explicitly analyzing the pedagogical application of ethnomathematics media and reporting measurements of affective aspects	Studies being purely theoretical or lacking empirical data on outcomes

Table 1 describes the multiple indicators for screening and deciding the eligibility articles to be included in the review. This study specifically prioritizes articles that report both the design features of ethnomathematics media and outcomes related to affective domain variables (engagement, motivation, anxiety, attitudes) or explicit discussions of how design elements bridge cultural contexts to formal mathematics.

The study selection followed PRISMA procedures. The initial search yielded 488 records, with 474 remaining after duplicate removal. Title and abstract screening resulted in the exclusion of 418 articles based on: 272 with irrelevant topics, 9 without available full text, 94 not indexed as peer-reviewed, 20 book chapters, and 23 review articles without primary empirical data, leaving 56 articles for full-text review. Following full-text assessment, 39 articles were excluded due to lack of explicit design analysis (16 studies) and insufficient linkage to mathematical concepts (23 studies) , resulting in a final sample of 17 studies. To enhance transparency and reduce subjectivity, the study selection process was conducted by two independent reviewers. Discrepancies were resolved through discussion until consensus was reached. Inter-reviewer agreement prior to consensus discussion was not formally quantified (e.g., using Cohen's kappa or percentage agreement) in this review; reporting such a measure is recommended for future iterations of this synthesis to strengthen the transparency and reproducibility of the screening process.

Although the final sample size is relatively small (n = 17), this reflects the specificity of the inclusion criteria, particularly the requirement for explicit analysis of visual and interface design elements. This limited sample size carries different implications across the three research questions. For RQ1, which concerns the identification of recurring design elements, the dataset offers reasonably consistent patterns across studies. However, for RQ2 and RQ3, which involve interpretive claims about mediating mechanism and emerging design principles, the limited number of studies constrains the strength of evidence: these interpretations are derived through cross-study synthesis rather than direct empirical testing, and should therefore be read as tentative, theory-informed propositions rather than robust or generalizable conclusions.

Accordingly, findings related to mechanisms and design principles are best understood as a preliminary analytical framework intended to guide future empirical validation, rather than as confirmed patterns applicable across contexts. The complete systematic selection process, from initial database searches through final study inclusion, is visualized in Figure 1 following PRISMA 2020 flow diagram below.

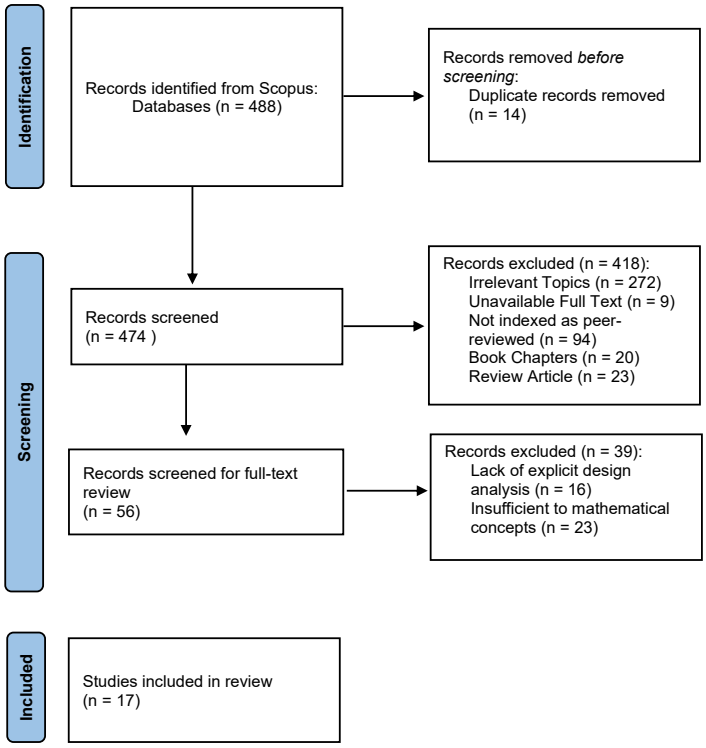

Figure 1. PRISMA 2020 flow diagram illustrating the study selection process from initial identification to final inclusion

Data were extracted from included studies regarding: (1) research design and methodology, (2) participant demographics and educational context, (3) media platform characteristics (technology type, interactivity level), (4) cultural context represented, (5) specific visual and interface design elements employed, (6) mathematical content domains, (7) reported outcomes (affective and learning-related), and (8) stated limitations.

The analysis employed a thematic synthesis approach conducted in three iterative phases: (1) all texts were reviewed to identify and familiarize the analyst with key design features and mediation mechanisms; (2) systematic coding captured visual elements and proposed mechanisms; (3) analytical themes were inductively generated from coded segments, organized around the three research questions. This thematic synthesis approach allowed for identification of patterns, recurrent design elements, and evidence-based insights into how visual interfaces mediate cultural-to-formal mathematical transition. To illustrate the coding procedure, a raw finding such as a report that batik motifs helped students visualize symmetry (Kholid & Husodo, 2025) was first coded descriptively as "cultural artifact used as visual reference for a mathematical property," and codes sharing this pattern across studies were then grouped

inductively under the higher-order construct of concretization; comparable coding steps were applied to generate the embodied engagement and structured cognitive scaffolding constructs.

Results

Seventeen articles meeting the inclusion criteria were analyzed to identify patterns in design practices, pedagogical roles, and development of culturally responsive mathematics media. The analysis focuses on three dimensions: key visual and interface design elements, their potential mediating roles in linking cultural experience to formal mathematics, and emerging trends, challenges, and future directions.

Rather than emphasizing outcomes alone, this section takes a design-oriented perspective by examining how media such as digital modules, games, AR, videos, and comics combine cultural representation with interactivity to support learning. This approach provides insight into how design may influence cognitive and affective processes.

Table 2 summarizes the key findings of the seventeen studies and forms the basis for the subsequent analysis.

Table 2. Synthesis of key findings

Author	Year	Key Findings
Rohaeti et al.	2020	An ethnomathematics-based VBA Excel model is valid, practical, and improves students' mathematical reasoning.
Sutarto et al.	2022	An ethnomathematics-based e-module is valid, practical, and enhances students' metacognitive skills in geometry.
Gembong et al.	2022	Mathematics learning based on the Javanese vegetable salad context significantly improves students' higher-order thinking skills
Richardo et al.	2023	The media is valid and practical, and may support improvements in creative thinking, motivation, and understanding of geometry through visualization
Suparman et al.	2024	Ucing Sumput digital educational game is valid, practical, and effective in stabilizing students' achievement emotions in mathematics learning
Jariyah et al.	2024	Learning video using the Palembang songket context is valid, practical, and effectively improves students' mathematical reasoning skills in reflection topics
Ramadhani et al.	2024	An ethno-flipped classroom integrating Lemang Batok is associated with improved students' numeracy, especially in descriptive statistics
Meeran et al.	2024	Ethnomathematical games support active learning and strategic thinking, with adaptations to fit learning goals
Supriyadi et al.	2024	Culturally integrated digital modules are linked to improved understanding, motivation, engagement, and responsiveness.
Betrand et al.	2024	Integrating AR and VR in culturally responsive

Author	Year	Key Findings
		learning is linked to higher engagement, motivation, spatial reasoning, and conceptual understanding.
Pramulia et al.	2024	AR-based ethnomathematics comics effectively enhance elementary students' numeracy and literacy through interactive cultural learning
Selepe	2025	Cultural play with technology may support neurodiverse learners, though effective use requires teacher training
Kholid & Husodo	2025	Batik Sidomukti reflects arithmetic and discrete mathematics concepts, offering a meaningful learning context
Abdullah et al.	2025	Zapin and Kuda dance activities are associated with improved achievement, motivation, and appreciation of mathematical aesthetics
Susanto et al.	2025	AR-based ethnomathematics learning is practical and engaging, and may enhance creative thinking skills
Zito & Albanese	2025	Integrating juggling into ethnomathematics may support understanding and creativity while linking concepts to real practice
Trubus et al.	2025	Culturally integrated e-comics show potential to support students' numeracy, engagement, and contextual understanding

Predominant visual and interface design elements in ethnomathematics media

The analysis of the seventeen selected studies suggests that ethnomathematics learning media tend to combine culturally grounded visual representations with interactive interface features to convey mathematical concepts. One prominent pattern observed across the studies is the use of cultural contexts as the primary visual basis for representing mathematical ideas. Cultural artifacts such as batik patterns, traditional foods including Javanese vegetable salad and Lemang Batok, and textile designs such as Palembang songket are used to situate mathematical concepts within familiar contexts (Kholid & Husodo, 2025; Gembong et al., 2022; Ramadhani et al., 2024; Jariyah et al., 2024). In addition, cultural performances and practices, including Zapin and Kuda dances as well as juggling activities, provide dynamic representations of mathematical relationships and transformations (Abdullah et al., 2025; Zito and Albanese, 2025). Some studies also report that integrating cultural elements into learning modules is associated with improved student understanding, engagement, and motivation (Sutarto et al., 2022; Supriyadi et al., 2024).

Alongside these visual elements, interactive and technology supported interface design appears as another important feature. Educational games, including Ucing Sumput and other ethnomathematics based games, are associated with increased engagement, strategic thinking, and emotional involvement (Suparman et al., 2024; Meeran et al., 2024). Digital learning environments such as e modules and flipped classroom models help structure learning processes and encourage independent exploration (Sutarto et al., 2022; Ramadhani et al., 2024).

Interactive tools, including VBA based applications, are also reported to support students' mathematical reasoning (Rohaeti et al., 2020). Moreover, advanced technologies, particularly augmented reality and virtual reality, are increasingly incorporated to create more immersive learning experiences that may support spatial reasoning and conceptual understanding (Susanto et al., 2025; Betrand et al., 2024; Pramulia et al., 2024). The use of these technologies is also described as potentially beneficial for diverse learners, including neurodiverse students, although effective implementation appears to depend on teacher readiness (Selepe, 2025).

Beyond visual and interactive features, multimodal and narrative-based representations are also commonly used. Learning videos present mathematical concepts through culturally situated storytelling (Jariyah et al., 2024), while e comics and augmented reality-based comics combine visual narratives with textual explanations to support both numeracy and literacy (Trubus et al., 2025; Pramulia et al., 2024). Several studies further emphasize the role of visualization in transforming abstract concepts into more concrete forms, which may contribute to students' creative thinking and conceptual understanding (Richardo et al., 2023). Through the integration of visual, textual, and narrative elements, these multimodal approaches allow learners to engage with mathematical ideas through multiple cognitive pathways.

Overall, the findings indicate that ethnomathematics learning media are characterized by the integration of culturally meaningful visual elements, interactive technological interfaces, and multimodal narrative representations. Together, these design elements appear to support the presentation of mathematical concepts in ways that are engaging, contextually relevant, and cognitively accessible, while also providing a basis for the mediational processes discussed in the subsequent section.

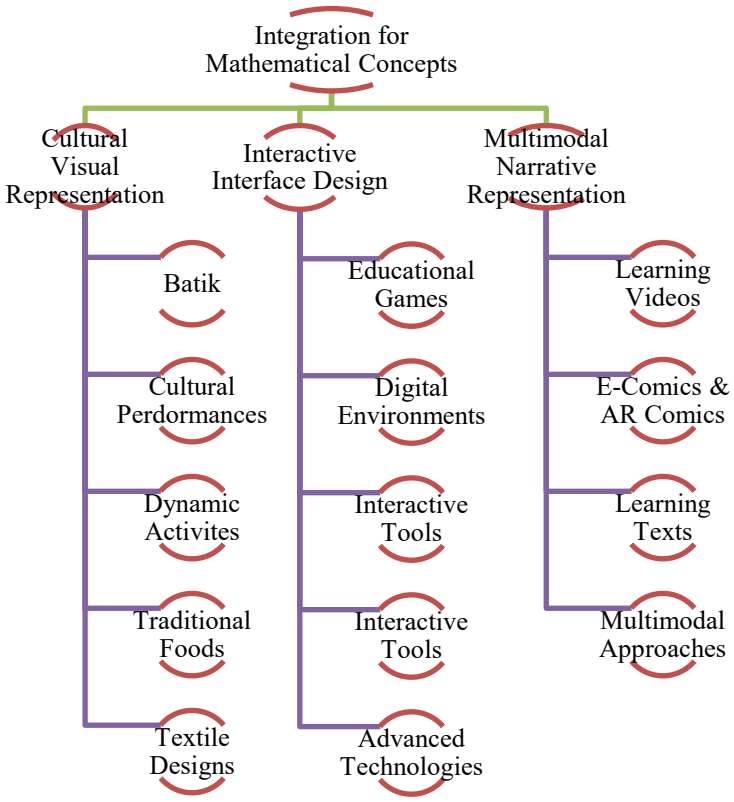

Figure 2. Three dominant design elements of ethnomathematics learning media (conceptual illustration derived from thematic synthesis, not an empirically validated model)

Figure 2 illustrates the three dominant design elements identified across the seventeen reviewed studies, namely cultural visual representation, interactive interface design, and multimodal narrative representation. These elements are interconnected and collectively contribute to how mathematical concepts are represented in ethnomathematics learning media. Building on this integrated perspective, the following section explores how this design elements may function as mediational mechanisms that support the transition from learners' cultural experiences to formal mathematical understanding.

Design elements mediate the transition from cultural experience to formal mathematical understanding

The analysis of the studies suggests that design elements in ethnomathematics media can be understood not only as representations but also as potential mediating components that may support the transition from cultural experiences to formal mathematical understanding. This role is suggested by how cultural contexts, interface features, and representational forms are organized to guide learners from informal knowledge toward more abstract reasoning. Importantly, this transition was not explicitly labeled or theorized as such within the primary studies; rather, the authors inductively identified recurring patterns across the reviewed literature and organized them into three analytical constructs, namely concretization, embodied engagement, and structured cognitive scaffolding. These constructs represent the authors' interpretative synthesis, framed through relevant theoretical lenses, rather than terminology or mechanisms directly reported by the original researchers. They are therefore presented as theory-informed analytical categories intended to organize observed patterns, not as empirically confirmed mechanisms.

The first construct, concretization, is used here to describe patterns observed across studies in which abstract mathematical ideas appear to become more accessible through culturally grounded representations. Cultural artifacts such as batik, songket, and traditional foods provide visual and contextual references that can help clarify mathematical relationships and may support higher order thinking (Kholid & Husodo, 2025; Jariyah et al., 2024; Gembong et al., 2022; Ramadhani et al., 2024). Visualizations are similarly reported to transform abstract concepts into more concrete forms, with the original author linking this to improved conceptual understanding and creative thinking (Richardo et al., 2023). This pattern is also observed in digital modules and videos that incorporate cultural contexts into structured learning environments (Sutarto et al., 2022; Supriyadi et al., 2024; Jariyah et al., 2024). However, none of these studies explicitly frame their findings using the term concretization, which is applied here as an interpretative label for the recurring pattern.

The second construct, embodied and experiential engagement, is used to characterize a pattern in which learners are involved in physical and social activities as part of the learning process. Cultural practices such as dance and juggling are reported to allow students to experience mathematical ideas through movement and interaction (Abdullah et al., 2025; Zito & Albanese, 2025). Game based learning environments are similarly associated with increased engagement and strategic thinking (Suparman et al., 2024; Meeran et al., 2024). In addition, the

integration of cultural play with technology may offer flexible and multimodal learning experiences that can support diverse learners (Selepe, 2025). As with concretization, this construct reflects an analytical grouping applied by the authors rather than a category used by the original researchers.

The third construct, structured cognitive scaffolding, is used to describe patterns in which learning appears to progress from intuitive understanding toward more formal reasoning through sequenced or staged design features. Digital modules and flipped classroom approaches provide sequenced learning experiences that can facilitate reflection and conceptual development (Sutarto et al., 2022; Supriyadi et al., 2024; Ramadhani et al., 2024). Interactive tools such as VBA applications and immersive technologies, including augmented and virtual reality, enable step by step exploration and iterative learning, which may be associated with improvements in reasoning and spatial understanding (Rohaeti et al., 2020; Susanto et al., 2025; Betrand et al., 2024; Pramulia et al., 2024). Narrative media such as comics and videos also contribute by organizing learning into coherent and structured sequences (Trubus et al., 2025; Jariyah et al., 2024). This construct, like the previous two, is an analytical label introduced by the authors to organize observed design patterns, not a mechanism explicitly tested or named in the primary studies.

To provide stronger evidence for how these three constructs were developed, Table 3 maps each analytical construct to the specific studies whose findings collectively informed it, making the basis of the synthesis more transparent.

Table 3. Mapping of reviewed studies to the three analytical constructs

Analytical Construct	Contributing Studies
Concretization	Rohaeti et al. (2020); Sutarto et al. (2022); Gembong et al. (2022); Richardo et al. (2023); Jariyah et al. (2024); Ramadhani et al. (2024); Supriyadi et al. (2024); Kholid & Husodo (2025)
Embodied Engagement	Suparman et al. (2024); Meeran et al. (2024); Selepe (2025); Abdullah et al. (2025); Zito & Albanese (2025)
Structured Cognitive Scaffolding	Rohaeti et al. (2020); Sutarto et al. (2022); Supriyadi et al. (2024); Betrand et al. (2024); Ramadhani et al. (2024); Pramulia et al. (2024); Susanto et al. (2025); Trubus et al. (2025); Jariyah et al. (2024)

To synthesize these analytically derived constructs, Figure 3 presents a conceptual model illustrating how learners may move from culturally situated experiences toward formal mathematical understanding through the interconnected constructs of concretization, embodied engagement, and structured cognitive scaffolding. This model should be read as a proposed analytical framework generated through cross-study interpretation, rather than a validated causal or empirical model.

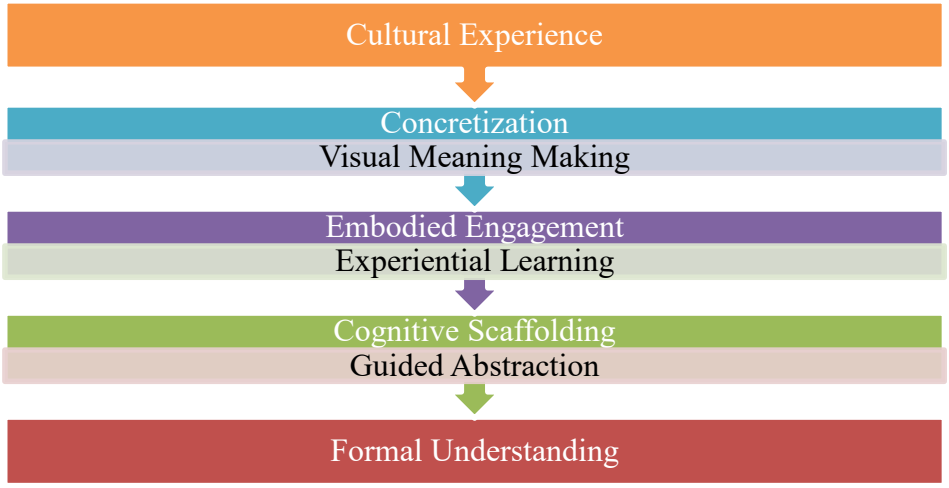

Figure 3. Mediational processes in ethnomathematics learning media (conceptual illustration derived from thematic synthesis, not an empirically validated model)

Overall, these constructs suggest that the transition from cultural experience to formal mathematical understanding may be analytically framed as a mediated process shaped by the integration of representation, interaction, and structured guidance. This framework points to the potential importance of design in supporting how learners interpret and formalize mathematical knowledge, though it remains a theory-informed proposition requiring further empirical validation rather than a confirmed explanatory account. Building on this view, the following section explores emerging trends, challenges, and possible future directions in the development of ethnomathematics learning media.

Emerging trends, challenges, and future directions

The analysis of the reviewed studies points to several emerging patterns in the development of ethnomathematics learning media, which the authors interpret as broader trends. One such pattern is the growing use of digital technologies, particularly augmented reality, virtual reality, and interactive platforms, which the original studies are associated with increased engagement, spatial reasoning, and conceptual understanding (Susanto et al., 2025; Betrand et al., 2024; Pramulia et al., 2024). In addition, narrative-based media such as videos and comics are reported to be increasingly utilized to contextualize mathematical concepts and to support both literacy and numeracy development (Jariyah et al., 2024; Trubus et al., 2025). A further pattern observed across studies is the stronger emphasis on culturally responsive and inclusive design, including efforts to address diverse learner needs through multimodal and technology supported approaches (Selepe, 2025; Supriyadi et al., 2024). These three patterns are drawn directly from findings reported in the reviewed studies, through their characterization as ‘trends’ reflects the authors’ cross-study synthesis rather than a claim made by the primary studies themselves.

Despite these developments, several challenges are reported or can be inferred from the reviewed studies. A key concern, explicitly reported, is the limited preparedness of teachers to implement culturally integrated and technology supported media effectively, particularly in relation to pedagogical and technical competencies (Selepe, 2025). Furthermore, translating

cultural contexts into mathematically meaningful and curriculum aligned learning experiences requires careful consideration, as cultural practices often need to be adapted to meet educational goals (Meeran et al., 2024). Beyond these explicitly reported concerns, the authors also infer, based on patterns across the dataset rather than direct statements in any single study, that issues related to scalability and consistency may arise, particularly in maintaining a balance between cultural authenticity and pedagogical rigor. This latter observation represents an analytical inference rather than a directly reported finding

Based on the patterns and limitation identified above, the authors propose several directions for further research and development. It could focus on establishing design- oriented frameworks that more systematically connect cultural elements, interface design, and mathematical cognition. There is also a need to explore immersive and adaptive technologies that can support more personalized learning experiences, as well as to encourage interdisciplinary collaboration among educators, designers, and cultural experts. These recommendations are forward looking proposals derived from the authors' synthesis and interpretation of gaps in the reviewed literature, and should not be read as conclusions supported by empirical evidence from the dataset itself.

Discussion

This review adopts a design-oriented perspective on ethnomathematics by examining how visual and interface elements are described within learning processes. While prior studies report improvements in motivation, engagement, and conceptual understanding, they generally treat learning media as a unified construct rather than analyzing specific design features. In this synthesis, specific design elements are identified and discussed descriptively, based on patterns of co-occurrence with reported outcomes across studies; this descriptive association should not be read as evidence of functional or causal contribution, as none of the reviewed studies isolated design variables from pedagogical or contextual factors. This pattern echoes earlier observations that ethnomathematics scholarship published in Indonesian mathematics education journals tends to report affective and cognitive outcomes without differentiating the design mechanisms responsible for them (Turmuzi et al., 2023), and that studies combining cultural content with learning media rarely isolate which visual or interface features are doing the explanatory work (Adnan et al., 2019).

The findings indicate that visual and interface design features frequently co-occur with reports of representational clarity, interactive engagement, and structured guidance, though this co-occurrence does not establish that design features produced these outcomes. Culturally grounded visual representations are described in the primary studies alongside reports of learners relating abstract mathematical ideas to familiar contexts, while interactive and multimodal features are described alongside reports of increased engagement. These parallel patterns appear broadly consistent with perspectives from multimedia learning (Mayer & Moreno, 1998; Clark & Mayer, 2016) and culturally responsive education (Bishop, 1988; Gay, 2018); however, because the reviewed studies did not isolate or systematically compare individual design elements against alternative explanations (e.g., teacher quality, curriculum

design), these parallels remain suggestive associations rather than evidence of underlying theoretical mechanisms. A more balanced reading must also consider that pedagogical strategies, teacher expertise, and instructional sequencing may plausibly account for a substantial share of the reported gains, and none of the reviewed studies were designed to adjudicate between these competing explanations and a design-based account. Positioned against existing instructional design models, the proposed framework shares with Mayer's multimedia principles (Mayer, 2014; Mayer & Moreno, 1998) an emphasis on reducing extraneous cognitive load through coherent visual organization (Norman, 2013), but departs from it by foregrounding cultural meaning-making rather than cognitive efficiency alone; it likewise overlaps with culturally responsive instructional frameworks (Gay, 2018; Bishop, 1988) in centering learners' cultural assets, while adding a design-specific layer that these frameworks do not typically articulate in detail. This positioning clarifies the distinctive, though still tentative, contribution of the present framework relative to established models.

The identification of recurring design elements and their organization into three analytical constructs, concretization, embodied engagement, and structured cognitive scaffolding, represents an interpretative contribution of this review rather than an empirical finding. These constructs were not reported or labeled as such in the primary studies; they were inductively derived by the authors through cross-study thematic synthesis. Given that the underlying dataset consists of only 17 studies, none of which employed designs capable of isolating the causal contribution of specific design features, these constructs should be treated strictly as a proposed analytical framework for future testing, not as validated mechanisms. Presenting them with greater confidence would misrepresent the evidentiary basis of this review. Even so, each construct resonates with an established line of theory situated outside the reviewed corpus: concretization parallels the concreteness-fading principle documented in mathematics and science instruction (Fyfe et al., 2014), embodied engagement aligns with embodied-design accounts of grounding mathematical meaning in physical action and gesture (Abrahamson, 2009), and structured cognitive scaffolding echoes sociocultural descriptions of guided progression through a learner's zone of proximal development (Vygotsky, 1978; Wood et al., 1976). These parallels lend the constructs some theoretical plausibility, but they remain external to, rather than derived from, the primary studies themselves, and therefore still require direct empirical testing within ethnomathematics contexts specifically.

The discussion of trends identified in the review, including the increased use of interactive and immersive technologies and growing attention to cultural and affective dimensions, must be read in direct light of the dataset's composition: the reviewed studies are concentrated in a small number of geographic and cultural contexts (predominantly Indonesia and a limited set of other regions), drawn from a single database (Scopus), and represent a small and uneven sample (n = 17). These characteristics mean that the identified trends reflect patterns within this specific, narrow corpus rather than broader developments in the field of ethnomathematics learning media as a whole. This concentration is consistent with earlier documentation of the geographic clustering of ethnomathematics scholarship within Indonesian mathematics education journals specifically (Turmuzi et al., 2023), reinforcing the need for caution in generalizing the identified trends beyond this corpus.

These constraints collectively mean that the contribution of this review lies in organizing and interpreting existing patterns, not in establishing generalizable or causal claims about how design functions in ethnomathematics learning. Within these boundaries, this review offers a structured way to consider how design elements might be implicated in ethnomathematics learning media, understood as one component within a broader system that includes pedagogy, context, and cultural representation (D'Ambrosio & Rosa, 2017; Orey & Rosa, 2021), whose relative weight this review does not and cannot determine. Further empirical research, particularly studies that experimentally or longitudinally isolate design variables from pedagogical and contextual factors, is needed before the constructs proposed here can be treated as more than a preliminary analytical framework.

Conclusion

This systematic review examines the role of visual and interface design as a mediating component in ethnomathematics learning media. The findings indicate that design may contribute to learning by enhancing representational clarity, supporting engagement, and guiding learners through structured interactions with mathematical concepts. However, these contributions are better understood as analytical generalizations rather than causal relationships, considering the limited number of studies and the reliance on secondary data.

This study offers a design-oriented framework that provides a more specific perspective on how ethnomathematics learning media may function beyond outcome-based evaluation. It also points to emerging trends involving interactive and immersive technologies, along with increasing attention to cultural and affective aspects in learning design.

Despite these contributions, several limitations should be acknowledged, including the restricted sample size, the scope of the databases used, and variability in reporting across studies. Future research is needed to examine the identified design elements through empirical approaches, particularly using experimental, longitudinal, and cross-cultural methods, as well as to explore their applicability across diverse educational contexts.

Overall, this review indicates that visual and interface design can be considered an important component in the development of culturally responsive mathematics learning media, while further evidence is required to clarify its effectiveness and broader applicability.

Beyond calling for further empirical research in general terms, this review offers several concrete implications for practice. Instructional designers can use the three constructs as a preliminary checklist when developing ethnomathematics media, for example pairing a culturally grounded visual (concretization) with an interactive or embodied task (embodied engagement) and a sequenced progression toward formal notation (structured cognitive scaffolding). Curriculum developers can use the construct-to-study mapping in Table 3 as a starting point for selecting design exemplars suited to specific cultural contexts and mathematical topics. Educational technology researchers are encouraged to design controlled or longitudinal studies that isolate the contribution of specific design features from pedagogical and contextual factors, building directly on the analytical framework proposed here rather than starting from an outcome-only baseline.

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Declarations

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