



## Integration of Ethnochemistry in Digital Comics Based on Tetrahedral Representation of Colloidal Material

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**Abstract:** This study aims to develop and test the effectiveness of a digital comic integrating tetrahedral representations (human, microscopic, macroscopic, and symbolic) and ethnochemistry within the context of Sasirangan fabric dyeing. A convergent parallel mixed-methods design was employed, involving students from SMA Negeri 4 and SMA Negeri 12 Banjarmasin. Data collection utilized validation questionnaires for content and media experts, student response questionnaires, tests for conceptual understanding and misconceptions, and an ethnochemistry literacy questionnaire. Effectiveness was assessed using a non-equivalent pretest-posttest design with a control group, involving 120 students divided into control and experimental groups. Validity results from media and content experts indicated that the developed digital comic was highly valid, while student responses demonstrated high practicality with a positive reception. Effectiveness testing revealed that the digital comic improved conceptual understanding and reduced misconceptions in the experimental group compared to the control group. The Mann-Whitney U test results indicated a significant difference between the groups. Overall, the findings suggest that the proposed ethnochemistry-integrated tetrahedral digital comic is valid, practical, and effective for culture-based chemistry learning on colloidal materials.

**Keywords:** colloids; digital comics; ethnochemistry; sasirangan; tetrahedral representation

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## INTRODUCTION

Chemistry learning is a complex discipline because students need to understand macroscopic, microscopic, and symbolic representations to build a comprehensive conceptual understanding (Dewi et al., 2021; Rahmawati et al., 2021). This complexity often hinders students' ability to connect the levels of representation, resulting in a shallow understanding, which is exacerbated by classroom practices that prioritize symbolic information without linking it to macroscopic and microscopic levels (Fatah et al., 2021; Fernández et al., 2025; Takim, 2021). The limited availability of learning media that can integrate all three representations (Fombona-Pascual et al., 2022; Handayani et al., 2022) leads to a less meaningful learning process, as students do not obtain a complete picture of the concepts being studied.

Developing media that explicitly incorporates all three representations is a crucial step in improving students' conceptual understanding. Several studies have shown that the use of representations in chemistry learning improves students' understanding. Talanquer (2022) emphasizes the importance of developing cross-representational thinking skills to strengthen conceptual understanding. Popova and Jones (2021) found that visual-based media helped students more effectively link macroscopic, microscopic, and symbolic representations. Hu et al. (2022) showed that chemistry misconceptions are often rooted in students' failure to connect different types of representations. These three studies reinforce the importance of designing learning experiences that integrate chemical representations.

Several of the studies still focus on the three elements of representation in Johnstone's triangle model: macroscopic, microscopic, and symbolic. Mahaffy added a new element, namely the human element, which is known as the tetrahedral representation (da Silva Júnior, 2023; Mahaffy et al., 2019; Reid, 2021). The addition of this human element can enrich the study of chemistry learning with a more complete representation that can be linked to the socio-cultural context. This plays an important role in helping students relate concepts to everyday life and encouraging students to think critically (Mahaffy et al., 2019; Yamtinah et al., 2023). Expanding the representation model to four elements opens new opportunities for developing more contextual learning media. The human element in this tetrahedral representation can be enhanced through an ethnochemical approach, which connects chemical concepts with local cultural practices as a tangible manifestation of science in everyday life (Chibuye & Singh, 2024; Heliawati et al., 2022). The Sasirangan cloth-dyeing tradition in South Kalimantan provides a highly relevant context for colloidal systems, as it involves

dispersed colorants, interactions between dispersed particles and fabric fibers, and solution-based processes that can be explained across multiple representational levels. However, there is still no comic-based digital learning media that integrates these four representations simultaneously within the ethnochemical context of Sasirangan cloth dyeing. Embedding this cultural practice in learning can make chemical concepts more tangible while supporting awareness of cultural heritage through a humanistic scientific lens (Abumchukwu et al., 2021; Anggreni, 2023).

Despite the potential of these approaches, learning media that simultaneously integrate tetrahedral representation with ethnochemistry in a digital comic format, specifically within the Sasirangan dyeing context for colloidal materials with emphasis on colloidal systems, remain limited (Mahaffy et al., 2019; Heliawati et al., 2022; Fombona-Pascual et al., 2022). Therefore, this study develops and evaluates a tetrahedral-representation-based digital comic integrated with the ethnochemistry of Sasirangan dyeing for learning colloidal systems, addressing the following objective: to determine the validity, practicality, and effectiveness of the developed digital comic in improving students' representational conceptual understanding and ethnochemical literacy.

## METHODS

This research employed a Convergent Parallel Design, a mixed-methods approach in which quantitative and qualitative data were collected simultaneously in a single phase, analyzed independently, and then merged to provide a more comprehensive understanding of the research problem (Cresswell & Clark, 2011; Cresswell & Cresswell, 2018). This design was selected because the study required objective evidence of the developed digital comic's validity, practicality, and effectiveness (quantitative strand), as well as in-depth explanations of how and why the comic supported students' representational understanding and ethnochemical literacy within the Sasirangan context (qualitative strand). These two aspects can be integrated to enable triangulation between learning experiences and statistical results, thereby strengthening the analysis of the findings. (Cresswell & Cresswell, 2018). This study was conducted with Grade 12 students at SMA Negeri 4 and SMA Negeri 12 Banjarmasin. Purposive sampling was employed, recognizing that both schools represent Banjarmasin culture and are relevant to the ethnochemistry of sasirangan fabric dyeing. Classes were selected via random sampling: the experimental group comprised 60 students from Class 12-IPA-3 at SMA 4 Banjarmasin and Class 12-IPA-3 at SMA 12 Banjarmasin, while the control group consisted of 60 students from Class 12-IPA-2 at SMA Negeri 4 Banjarmasin and Class 12-IPA-2 at SMA Negeri 12 Banjarmasin. Effectiveness was assessed using a non-equivalent pretest-posttest control group design, in which the experimental group received instruction using digital comics that integrated tetrahedral representations and the ethnochemistry of sasirangan dyeing, whereas the control group received conventional instruction.

Data collection was conducted using validation instruments for content and media experts, a student response questionnaire, an ethnochemistry literacy questionnaire, and a test assessing conceptual understanding and misconceptions. The validation instruments were used to determine the suitability of the digital comic before its classroom implementation (Tanjung & Faiza, 2019). Three expert validators conducted content and media validation. The content aspect comprised 19 statements distributed across three indicators (content, construction, and language), while the media aspect consisted of 17 statements distributed across three indicators (text display, images, and the function of the digital comic in learning). Validator scores were subsequently converted into percentages and interpreted based on the following criteria: highly valid (>80%), valid (71–80%), adequate (61–70%), inadequate (51–60%), and invalid (<50%). The practicality of the digital comic was assessed using a student response questionnaire administered after the comic was used in instruction. The questionnaire comprised 12 items evaluating aspects such as ease of understanding the comic's content, visual appeal, narrative clarity, and the extent to which the comic aided comprehension of the topic of colloids. The obtained student response scores were converted into percentages and interpreted based on the following criteria: highly practical (>90%), practical (81–90%), moderately practical (71–80%), impractical (61–70%), and highly impractical (<61%) (Raisa et al., 2018).

The effectiveness of digital comics in learning was evaluated using a four-tier diagnostic test instrument to assess conceptual understanding and misconceptions about colloids. The test instrument consisted of 8 four-tiered multiple-choice questions that integrated tetrahedral representations (human, microscopic, macroscopic, and symbolic). Each item was structured in four tiers: an answer choice (Tier 1), confidence in the answer (Tier 2), a reasoning choice (Tier 3), and confidence in the reason (Tier 4). Student responses were categorized into Concept Understanding (CU), Misconception (M), Partial Understanding (PU), and Not Understanding the Concept (NUC) to capture both understanding and misconception patterns. In addition, effectiveness was also assessed based on the results of an ethnochemistry literacy questionnaire regarding Sasirangan fabric dyeing. This instrument consists of 15 statements distributed across three indicators: (1) understanding of chemical aspects related to Sasirangan, (2) integration of local wisdom and chemistry, and (3) attitudes and motivation regarding cultural preservation.

Qualitative data for this study were derived from student responses and observational notes recorded during lessons utilizing digital comics. These data were analyzed thematically using coding to identify meaningful

aspects, which were then grouped into categories: specifically representational linkages, cultural relevance, and usability challenges before being synthesized into broader themes. These synthesized qualitative themes were used to interpret and contextualize the quantitative data, shedding light on how students perceived representational relationships and why misconceptions persisted (Cresswell & Cresswell, 2018). Quantitative data regarding validity and practicality were analyzed descriptively using percentage scores, while effectiveness was assessed by comparing pretest and posttest results between the experimental and control groups. Differences between the groups were tested using the Mann-Whitney U test at a significance level of 0.05. Qualitative and quantitative findings were integrated and compared side-by-side to identify points of convergence and complementarity, resulting in an interpretation aligned with the Convergent Parallel Design. (Cresswell & Clark, 2011; Cresswell & Cresswell, 2018).

## RESULT AND DISCUSSION

This digital comic was developed by integrating the tetrahedral representation model with the ethnochemistry of Sasirangan fabric dyeing. Produced as an interactive flipbook, the comic narrates the Sasirangan production and dyeing processes while linking them to the chemistry of colloids. It utilizes tetrahedral representations designed to help students grasp chemical concepts comprehensively while connecting them to cultural contexts. (da Silva Júnior, 2023). The resulting comic serves as a learning resource that combines visual elements, narrative, and cultural context to enhance conceptual understanding and link chemistry to daily life, specifically local wisdom, while fostering motivation and an appreciation for local culture.

The tetrahedral representations integrated into the digital comic encompass microscopic, macroscopic, symbolic, and human elements. The microscopic element depicts particle movement within the colloidal dispersion system; the macroscopic element illustrates the Sasirangan dyeing process; the symbolic element presents the molecular formulas of the dyes used; and the human element addresses the ethnochemistry, covering the cultural practices, values, and significance of Sasirangan fabric and its implications within Banjar culture (Schuessler et al., 2024). This integration is intended to reduce common misconceptions in colloid learning by helping students relate what they see (macroscopic) to what happens at the particle level (microscopic) and how it is expressed scientifically (symbolic), while keeping the learning grounded in a culturally meaningful context (Bai et al., 2022; Hu-Au et al., 2021; Souza & Porto, 2024; Wicaksono, 2022).

Several recent studies have demonstrated the effectiveness of integrating digital learning media and multi-representational approaches in chemistry education. Dewi et al. (2023) reported that ethnochemistry-based e-modules significantly improved students' chemical literacy by embedding socio-cultural contexts into learning, particularly in addressing environmental problem-solving skills. Similarly, Ningrum et al. (2021) developed augmented reality-based learning media on hydrocarbon concepts and found substantial improvements in students' multi-representational abilities at macroscopic, submicroscopic, and symbolic levels. Furthermore, Anggraini et al. (2024) developed Instagram- and TikTok-based learning content using a multi-representation approach and demonstrated that social media-based learning media were both highly feasible and effective in increasing students' engagement and conceptual understanding. Although these studies successfully implemented digital and multi-representational learning media, they primarily focused on technological platforms and cognitive outcomes, with limited emphasis on the systematic integration of local cultural contexts into representational frameworks.

The novelty of this product lies in the systematic integration of ethnochemistry into a tetrahedral representation-based digital comic, a topic that has rarely been explored in prior studies. This integration enables students to connect chemical concepts with everyday phenomena and local culture, for instance, the Banjar cultural practice of making sasirangan fabric, specifically regarding the dyeing process and the treatment of dye waste. This research offers value to the field of education by presenting a culturally integrated digital comic learning model that incorporates tetrahedral representations of chemical concepts. The resulting digital comics can strengthen students' conceptual understanding and ethnochemical literacy. A validity test of the digital comic was conducted to ensure that the resulting comic met the standards required for use as a high-quality learning resource (Devi & Rusdinal, 2023; Laksana, 2024). Validation was conducted by three experts who evaluated aspects of both content and media. The assessment of the content aspect covered content accuracy, presentation structure, and language, while the media aspect covered text display, image quality, and the comic's functionality as a learning medium. The assessment results and the validators' suggestions were used to revise and refine the digital comic (Suprihatin et al., 2025). The validation results are presented in Table 1.

**Table 1.** Validity Results of Digital Comic Media

| Aspect   | Indicator               | Validation Result | Information |
|----------|-------------------------|-------------------|-------------|
| Material | Contents                | 87.62             | Very Good   |
|          | Construction            | 81.90             | Very Good   |
|          | Language                | 89.33             | Very Good   |
|          | Text Display            | 86.67             | Very Good   |
| Media    | Image Display           | 85.33             | Very Good   |
|          | Function of Comic Media | 86.67             | Very Good   |

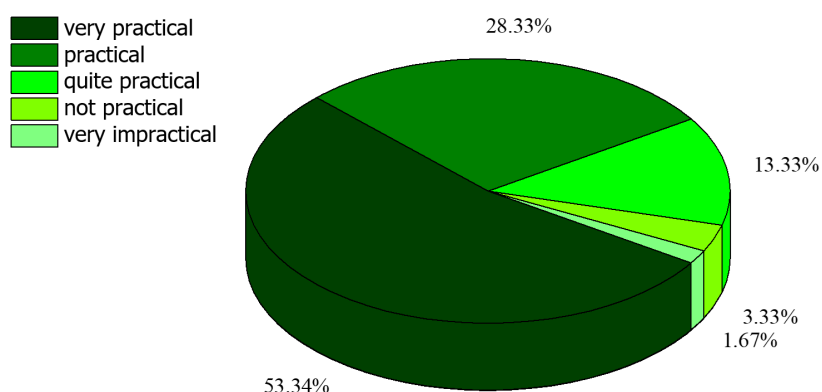
Based on Table 1, the material aspect achieved excellent results across all indicators. The contents indicator score of 87.62 indicates that the resulting digital comic aligns with the chemistry curriculum, presents material accurately and systematically, and effectively links ethnochemical concepts. The construction score of 81.90 further demonstrates that the comic features a well-structured storyline and systematic explanations, effectively bridging cultural phenomena with chemical concepts. This is crucial, as it helps students connect the chemistry concepts learned in school with everyday phenomena, including cultural elements. The language score of 89.33 reflects excellent language use within the storyline; the text is communicative and easily understood by students, avoiding ambiguities that could lead to misconceptions.

The media aspect also yielded excellent results across all indicators. The text display score of 86.67 falls into the very good category, indicating high readability, effective component layout, and consistent text placement. These factors are vital for facilitating student reading and comprehension of the storyline and its connection to the ethnochemical context. The image display indicator scored 85.33, also placing it in the excellent category; this suggests that the visuals support the learning representations within the comic rather than serving merely as decorative layout elements. The media function indicator scored 86.67, signifying that the digital comic effectively fosters student engagement and successfully links concepts to culture and real-life contexts. Overall, the digital comic, integrating tetrahedral representations and ethnochemistry, demonstrates both visual and pedagogical suitability for chemistry instruction (Devi & Rusdinal, 2023; Laksana, 2024). Evaluations from content and media experts served as the basis for revising and refining the digital comic. Table 2 outlines the validators' findings and suggestions, along with the revisions made to improve the comic. Revisions were made to strengthen the connections within the chemical tetrahedral representation and clarify chemical concepts, specifically regarding colloidal systems, as well as to enhance readability and learning-support features, in accordance with principles for developing culture-based digital learning media (Suprihatin et al., 2025).

**Table 2.** Examples of Validator Suggestions and Revisions Implemented in the Digital Comic

| Validator finding (before revision)                                                                                                                               | Revision implemented (after revision)                                                                                                                                                                         | Aspect/Indicator        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| Several panels introduced Sasirangan dyeing as a cultural activity, but the link to the targeted chemistry concept (colloidal systems) was not stated explicitly. | Added short "concept bridge" boxes in relevant panels (e.g., "This mixture forms a dispersed system/colloid") and inserted key terms that connect cultural phenomena to colloidal systems.                    | Material – Content      |
| The storyline moved too quickly from dye preparation to dyeing, potentially reducing students' ability to follow causal reasoning across representations.         | Revised panel sequencing by adding 1–2 transition panels that clarify process steps (preparation → dispersion → interaction with fabric fibers → observed outcome).                                           | Material – Construction |
| Some scientific terms were potentially ambiguous for students and could lead to multiple interpretations (e.g., "dissolve" vs "disperse").                        | Simplified wording and revised dialogues to distinguish "dissolution" and "dispersion"; added concise definitions for key terms within the storyline.                                                         | Material – Language     |
| Text size and placement in several panels reduced readability on common student devices.                                                                          | Increased font size, improved spacing, and repositioned text bubbles to avoid overlapping with visuals; standardized font style across scenes.                                                                | Media – Text Display    |
| Microscopic illustrations needed clearer cues so students would not interpret colloids as true solutions; particle depiction was not sufficiently explicit.       | Refined microscopic panels by adding visible dispersed particles, labels (e.g., "dispersed phase/dispersion medium"), and simple visual cues to support micro-symbolic linking without overloading the panel. | Media – Image Display   |

The practicality of the digital comic was evaluated using a student response questionnaire to determine its level of acceptance, ease of use, and utility within the learning process (Eliza et al., 2023). This practicality test ensured that the developed digital comic was not only valid in terms of content and media design but also well received by students following its use in instruction. The results of the digital comic's practicality test are presented in Figure 1.

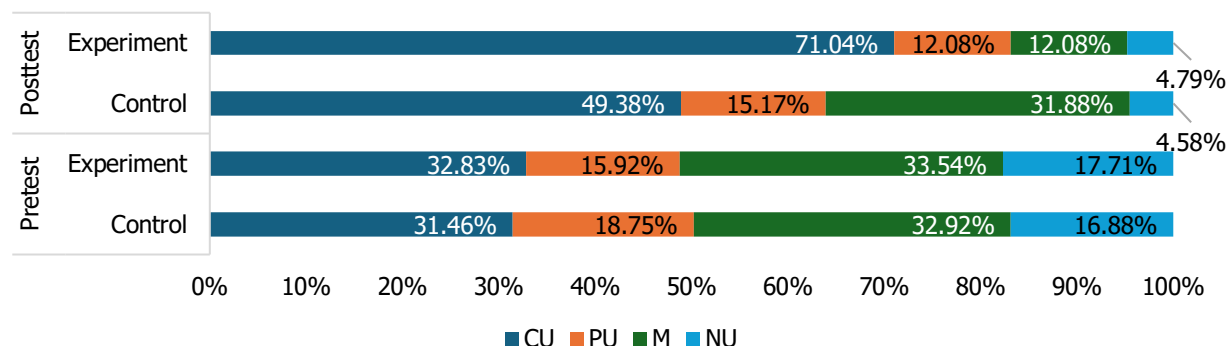


**Figure 1.** Student Responses to the Practicality of Digital Comics

Based on Figure 1, student responses to the developed digital comic indicate that 53.33% found it very practical, while 28.33% found it practical. Overall, the digital comic, which integrates tetrahedral representations and ethnochemistry, can be considered a practical learning medium. These results demonstrate that the majority of students found the digital comic easy to use and beneficial for learning, particularly in understanding the topic of colloidal systems. However, 13.33% of students provided a "quite practical" response. This suggests that a small number of students still required an adjustment period, a natural occurrence, given that not all students are initially familiar with using digital media in a comic-style flipbook learning format.

The results of the practicality test were further supported by qualitative data derived from students' open-ended responses regarding the digital comic and observations made during the learning process. This data was categorized into themes using the coding system described in the research methodology section. The thematic analysis revealed that the comic was considered practical due to its engaging visual design, systematic, easy-to-follow storyline, and connection to real-life phenomena, specifically Banjar culture and the production of sasirangan fabric. The cultural elements incorporated into the digital comic bridged the gap between chemistry content and students' daily cultural experiences, thereby enhancing their motivation to learn chemistry. However, some challenges were encountered while using the digital comic. These included technical issues such as inconsistent internet connectivity, variations in screen sizes affecting readability, and slow loading speeds when opening the digital chemistry flipbook, particularly on devices with low specifications.

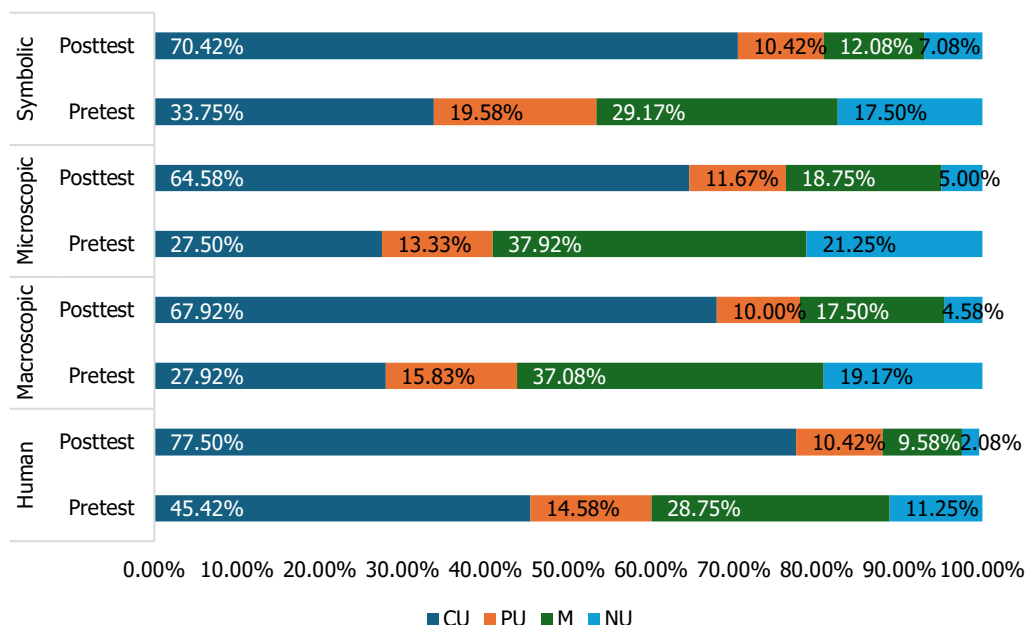
In terms of usage conditions, the digital comic was accessed predominantly on students' personal devices (primarily smartphones and, in some cases, laptops) during classroom learning, with internet access provided through school connectivity and/or students' data packages. Therefore, ease of access depended partly on network quality and device specifications. Despite these limitations, the relatively small proportions of "not practical" and "very impractical" responses (3.33% and 1.67%, respectively) indicate that the digital comic posed minimal barriers for most students and remained feasible for classroom use. Overall, these findings confirm that the developed digital comic is highly practical and can be used as a practical learning medium in chemistry (Umamah et al., 2023). The effectiveness of tetrahedral representation-based digital comics in improving students' representational understanding was assessed through descriptive and inferential analyses. Descriptive analysis was used to examine changes in conceptual categories before and after learning in both control and experimental classes, while inferential analysis was used to test whether observed differences were statistically meaningful. The results of students' comprehension of representation are presented in Figure 2.



**Figure 2.** Results of the student representation comprehension test.

Figure 2 shows that the proportion of students in the Concept Understanding (CU) category increased in both groups, with a substantially larger increase in the experimental class (from 32.83% to 71.04%) than in the control class (from 31.46% to 49.38%). This pattern suggests that the digital comic supported a stronger shift from fragmented understanding toward integrated comprehension. One plausible explanation is that the comic provides coordinated representational scaffolding: macroscopic observations are immediately paired with microscopic depictions and symbolic cues, while the human (cultural) context sustains meaning-making, so students can construct links across representations rather than learning each representation in isolation (Ridwan et al., 2025; Wahyudiati, 2022). The decreases in Partial Understanding (PU) and Not Understanding the Concept (NUC) in the experimental class further indicate that the learning transition was not merely superficial but involved movement toward full conceptual coherence after using the digital comic.

A key indicator of conceptual restructuring is the change in the Misconception (M) category. The control class showed only a slight decrease (32.92% to 31.88%), whereas the experimental class showed a marked decrease (33.54% to 12.08%). This reduction is analytically important because misconceptions in colloidal materials often stem from students' difficulty distinguishing between dispersed systems and true solutions or suspensions, and from failures to connect observable phenomena (e.g., apparent homogeneity, stability, light scattering) with particle-level explanations and correct symbolic descriptions. The comic likely reduced these misconceptions through two mechanisms. First, visual representational cues (e.g., particle depictions, consistent labeling, and panel-by-panel mapping from macro to micro to symbolic) can make invisible features of colloids more cognitively accessible and reduce incorrect generalizations based only on appearance. Second, the cultural narrative (Sasirangan dyeing) anchors abstract ideas in a familiar, meaningful process, increasing students' willingness to reason about "why" phenomena occur rather than memorize terms, which is essential for correcting misconceptions (Farheen & Lewis, 2021). In other words, misconceptions decreased not simply because students received more information, but because the comic strengthened cross-representational coherence and offered a contextual storyline that promotes conceptual sense-making. To identify which representational dimensions were most affected, student outcomes were further examined across the tetrahedral representation categories shown in Figure 3.



**Figure 3.** Understanding Results Based on Tetrahedral Representation Categories.

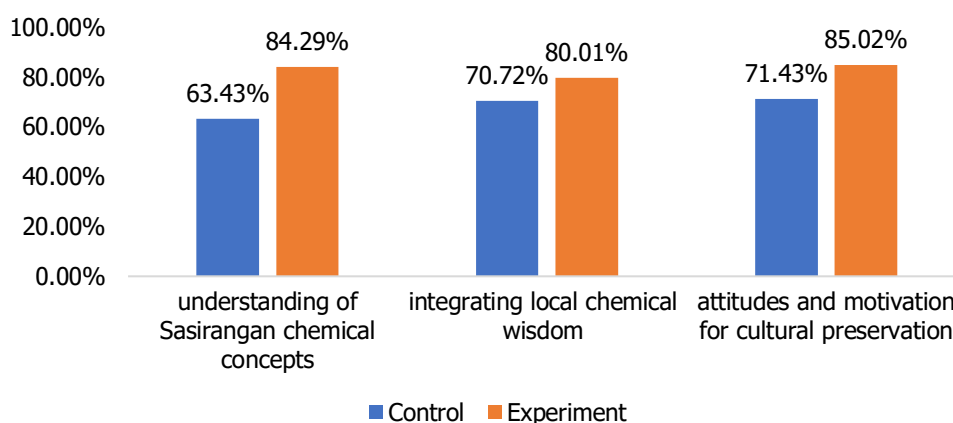
Improvements were observed across all four representations, indicating that the comic supported holistic representational development rather than improving only one layer. The human representation showed a strong increase in CU (from 45.42% to 77.50%) alongside a decrease in misconceptions (from 28.75% to 9.58%). This suggests that embedding everyday and socio-cultural contexts helped students interpret colloidal concepts through meaningful experiences, enabling them to connect the content to real-life practices rather than treating it as disconnected abstract knowledge. The macroscopic representation also improved substantially (CU from 27.92% to 67.92%; M from 37.08% to 17.50%), supporting the interpretation that presenting observable colloidal phenomena through the Sasirangan dyeing storyline strengthened students' concrete understanding and reduced initial confusion. Substantial gains were also found in microscopic and symbolic representations, indicating strengthening at more abstract levels. For microscopic representation, CU increased from 27.50% to 64.58% while misconceptions decreased from 37.92% to 18.75%. This improvement is consistent with the role of micro-visualization in supporting accurate particle-level reasoning, especially for concepts that students cannot directly observe. For symbolic representation, CU increased from 33.75% to 70.42%, and misconceptions decreased from 29.17% to 12.08%, indicating improved ability to translate phenomena into chemical terminology and models. Taken together, the pattern across Figure 7 implies that the most influential features of the comic are likely the combined effects of (a) structured visual mapping between representations and (b) culturally grounded human context that sustains engagement and meaning; both features work together to support representational integration rather than competing as separate influences (Ridwan et al., 2025; Wahyudiati, 2022; Farheen & Lewis, 2021).

In addition to descriptive results, inferential analysis was conducted to ensure that the improvement was not due to chance. A normality test (Kolmogorov–Smirnov) yielded a  $p$ -value  $< 0.05$ , indicating a non-normal distribution; therefore, the analysis proceeded with the nonparametric Mann–Whitney U test. The Mann–Whitney U test yielded a  $p$ -value  $< 0.05$ , indicating a statistically significant difference between the experimental and control groups, supporting the conclusion that the digital comic positively affected students' representational understanding. To complement the significance testing, the magnitude of the intervention effect was also described using effect sizes. Because pretest–posttest data were available, learning gains were quantified with Cohen's  $d$ , which can be calculated either from the within-group pre–post change in each class or from the between-group difference in gain scores (posttest–pretest). This reporting is important because it indicates the strength of the improvement in practical terms, not merely whether it is statistically detectable. In this study, the experimental class showed a large effect (Cohen's  $d = 1.91$ ), indicating a substantial learning gain after using the tetrahedral representation-based digital comic. In contrast, the control class showed a small-to-moderate effect (Cohen's  $d = 0.46$ ), suggesting more limited improvement under conventional learning.

Despite these positive results, the interpretation of effectiveness should consider limitations of the Four-Tier Diagnostic Test in the context of colloidal materials. First, the breadth of colloid concepts is wide, and a limited number of items may not capture all key sub-concepts (e.g., stability factors, particle size distribution, and conditions affecting dispersion). Second, the multiple-choice reasoning tiers may constrain students' explanations compared with open-ended reasoning, meaning some nuanced understanding or alternative

misconceptions may not be fully detected. Third, confidence ratings can be influenced by students' familiarity with the Four-Tier format; students may under- or overestimate confidence independent of actual understanding. Therefore, the findings should be interpreted as strong evidence of improvement within the measured indicators, while broader representational competence in colloidal materials may require additional assessment formats. Overall, these findings provide empirical support for the claim that culturally integrated tetrahedral-representation digital comics can strengthen students' representational competence and reduce persistent misconceptions. The results suggest that integrating humanistic ethnochemical narratives with explicit visual scaffolding enhances conceptual accuracy and representational linkage, offering an instructional model adaptable to other abstract chemistry topics (Ridwan et al., 2025; Wahyudiati, 2022).

The ethnochemical literacy results indicate consistent differences between the control and experimental classes across the three assessed indicators. Strengthening ethnochemical literacy is central to the use of ethnochemistry-based digital comics, as students are expected not only to understand chemical concepts but also to connect them with local wisdom and develop attitudes that support cultural preservation. As shown in Figure 4, the experimental class achieved higher overall scores than the control class, suggesting that the comic effectively facilitated both conceptual and cultural meaning-making.



**Figure 4.** Results of the students' ethnochemical literacy test

The largest difference was observed in understanding Sasirangan-related chemical concepts, where the experimental class reached 84.29%, higher than the control class (63.43%). This finding suggests that embedding chemical explanations in the Sasirangan dyeing storyline supports students in constructing more authentic understanding, because concepts are presented through familiar phenomena and practices rather than as abstract definitions. The Sasirangan dyeing process naturally illustrates dispersion in a liquid medium, observable changes during mixing and dye uptake, and the linkage between macroscopic outcomes (color intensity and uniformity) and microscopic reasoning (dispersed particles and interactions with fabric fibers). Through narrative sequences, visuals, and contextual examples, the comic therefore helps students interpret chemical ideas in a more meaningful and memorable way (Cahyani & Wahyudiati, 2023). Examples of item statements used to reflect this indicator include: "I can explain the Sasirangan dyeing process using appropriate chemical concepts," and "I can distinguish whether the dye mixture in Sasirangan dyeing is closer to a true solution, colloid, or suspension based on its characteristics."

A similar pattern emerged in the integration of local chemical wisdom, where the experimental class achieved 85.01% compared with 70.72% in the control class. This result indicates that the comic supported students' ability to connect chemistry with cultural practices and values in the Banjar community, for instance by interpreting traditional procedures as knowledge-rich processes that involve chemical principles. The integration of cultural elements into learning materials creates a contextual experience that encourages students to recognize chemistry as embedded in community life, rather than as knowledge that exists only in textbooks (Junaidi et al., 2025). Illustrative item statements for this indicator include: "I can relate local practices in Sasirangan dyeing to chemical concepts learned in class," and "I can identify forms of local wisdom in Sasirangan dyeing that reflect scientific reasoning or careful observation." Compared to ethnochemical learning contexts reported in other studies (e.g., ethnochemistry in traditional food processing, herbal preparations, or other local crafts), Sasirangan is particularly relevant for solution/colloid instruction because the dyeing stages provide repeated, observable examples of mixing, dispersion, and interaction in liquid media, enabling clearer mapping between cultural practice and core chemistry concepts.

The attitudes and motivation for cultural preservation indicator also showed higher achievement in the experimental class (85.02%) than in the control class (71.43%). This pattern suggests that the ethnochemical comic influenced not only cognitive outcomes but also affective engagement with local heritage. The storyline,

cultural messages, and concrete examples of preservation practices embedded in the comic likely helped students view Sasirangan as a living cultural asset worth sustaining. Example statements reflecting this indicator include: "I feel motivated to participate in preserving Sasirangan culture," and "Learning chemistry through Sasirangan makes me more appreciative of local cultural heritage." Overall, the experimental class achieved an average ethnochemical literacy of 84.77%, indicating that the digital comic effectively strengthened ethnochemical literacy across the conceptual, integrative, and affective dimensions. This study advances culturally responsive chemistry education by providing empirical evidence that ethnochemistry-integrated digital media can simultaneously strengthen students' understanding of context-based chemical concepts and their capacity to connect chemistry with local wisdom, while also fostering positive preservation-oriented attitudes. The broader impact lies in offering a scalable approach for integrating indigenous and local knowledge systems into formal chemistry instruction through digital learning media, supporting more inclusive, contextual, and culturally sustainable science education models.

## CONCLUSION

The ethnochemistry-based digital comic developed in this study is feasible, practical, and effective for chemistry learning. Integrating human, macroscopic, microscopic, and symbolic representations, the comic received high ratings from expert validators across material and media aspects, and student responses indicated that it was practical due to its ease of use, attractive visuals, and support for understanding the content. Its effectiveness was reflected in significantly greater improvements in students' representational understanding and ethnochemical literacy in the experimental class than in the control class, as supported by inferential testing. These findings imply that integrating Sasirangan ethnochemistry within a tetrahedral representation framework can strengthen the connection between abstract chemical explanations and culturally grounded phenomena, making chemistry learning more meaningful and engaging. This study is limited to using intact classes from two schools, a relatively short implementation period, a flipbook-based format that is not yet fully interactive, and limited test coverage of colloidal concepts. Future studies should involve broader samples and longer interventions and further develop the media into more interactive formats (e.g., embedded feedback/adaptive quizzes) or immersive applications (e.g., AR/VR), while extending the approach to other chemistry topics and ethnochemical contexts.

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