

INTEGRATING ETHNOCHEMISTRY AND AUGMENTED REALITY TO SUPPORT CHEMICAL REPRESENTATION AND PROBLEM-SOLVING SKILLS IN ACID-BASE CHEMISTRY

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Abstract: Problem-solving and representational competence are critical yet challenging skills for students to master in chemistry education, particularly in abstract topics like acid-base chemistry. This study investigates the effectiveness of an innovative learning module that integrates local cultural knowledge (ethnochemistry) with immersive digital visualization technology (Augmented Reality/AR) to address these challenges. Utilizing a quantitative pre-experimental design with a one-group pretest-posttest model, the study was conducted with 26 second-semester undergraduate chemistry education students at Universitas Mataram, Indonesia. Data were collected using validated chemical representation competence and problem-solving skills tests, alongside observation sheets. The results of a paired-sample t-test revealed statistically significant improvements in both domains ($p < 0.001$). The students' mean score for chemical representation competence increased from 40.77 to 66.92 (N-gain = 0.45, medium improvement), with a large effect size (Cohen's $d = 1.58$). Concurrently, problem-solving skills demonstrated a high advancement, shifting from a mean score of 39.23 to 84.23 (N-gain = 0.74, high improvement; Cohen's $d = 1.53$). Qualitative observation data supported these findings, showing high student engagement and active conceptual reasoning during the intervention. The findings suggest that the module's strength lies in its complementary synergy: ethnochemistry provides a familiar macroscopic anchor that contextualizes learning, while AR functions as a representational scaffold that reduces cognitive load by visualizing invisible submicroscopic molecular interactions. This study provides practical implications for designing culturally responsive and technology-enhanced instructional materials in higher education.

Keywords: Augmented Reality, Ethnochemistry, Acid-Base Chemistry, Problem-Solving Skills.

1. INTRODUCTION

Problem-solving has long been recognized as one of the most important competencies in chemistry education (Mulyani and Heliawati, 2025; Cooper & Stowe, 2018). Laliyo et al., 2023; Cooper & Stowe, 2018). Consequently, developing students' problem-solving skills has become a central goal of science education worldwide. However, numerous studies have reported that students often experience considerable difficulty when solving chemistry problems, particularly those involving abstract concepts and multiple levels of representation (Phajan et al., 2025; Indriyanti et al., 2020; Mu'minah and Mulyani, 2026).

Among the various topics in chemistry, acid–base chemistry remains one of the most challenging for students (Habiddin and Page, 2020; Yuliyanti, Suyono and Sukarmin, 2022; Djarwo and Kafiar, 2023). Shaafi et al. (2025) reported that although acid–base concepts are introduced early in chemistry curricula, students frequently demonstrate persistent misconceptions and fragmented understanding. Kapıcı (2023) reported that students often experience difficulties in acid–base chemistry because the phenomena must be interpreted simultaneously at the macroscopic, submicroscopic, and symbolic levels. Ardhana et al. (2025) reported that meaningful understanding of acid–base concepts requires students to relate observable properties of solutions to invisible molecular interactions and represent these processes using chemical equations and mathematical expressions. Furthermore, Munawwarah et al. (2025) reported that students who are unable to coordinate these representational levels frequently develop misconceptions and fragmented understanding, which ultimately results in superficial conceptual knowledge and poor problem-solving performance.

The importance of representational competence in chemistry learning has been widely acknowledged. According to the triplet model of chemistry learning, meaningful understanding requires learners to establish connections among macroscopic phenomena, submicroscopic explanations, and symbolic representations. Students who successfully navigate these representations are more likely to construct coherent conceptual frameworks and apply their knowledge to solve complex problems. Conversely, limited representational competence restricts students' ability to interpret chemical phenomena, formulate explanations, and develop appropriate solution strategies. Therefore, improving students' representational competence is considered a crucial step toward enhancing their problem-solving skills (Graulich and Hedtrich, 2021; He et al., 2023; Tang and Wang, 2024).

Minata et al. (2022) asserted that in addition to representational challenges, chemistry education often faces the problem of contextual relevance. Traditional instruction frequently presents chemical concepts in abstract and decontextualized forms, making it difficult for students to perceive the relationship between chemistry and their everyday experiences. This issue may reduce engagement and limit opportunities for meaningful learning. In response, researchers have increasingly advocated for culturally responsive approaches that connect scientific concepts with learners' social and cultural environments. One such approach is ethnochemistry, which integrates indigenous knowledge, local wisdom, and cultural practices into chemistry learning.

Ethnochemistry offers opportunities to contextualize scientific concepts through authentic cultural experiences. In the Indonesian context, various traditional practices embody chemical principles that can serve as meaningful learning resources. Examples include the use of natural acid-base indicators derived from local plants, traditional food fermentation processes, coconut oil production, betel chewing practices, and the application of limewater in daily activities. By linking scientific concepts with familiar cultural phenomena, ethnochemistry can promote relevance, engagement, and conceptual understanding. Previous studies have demonstrated that ethnochemistry-based learning contributes positively to students' scientific literacy, environmental awareness, and appreciation of local knowledge. Nevertheless, while ethnochemistry provides meaningful contexts for learning, it does not necessarily address students' difficulties in visualizing molecular-level phenomena that are central to understanding chemistry (Arfianawati et al., 2016; Rahmawati et al., 2019).

Recent advances in educational technology have created new possibilities for overcoming this limitation (Mazzuco et al., 2022). Augmented Reality (AR) has emerged as a promising tool for supporting chemistry learning by integrating virtual objects into real-world environments (Ripsam et al., 2024). Unlike conventional visual media, AR enables students to interact with three-dimensional representations of chemical structures and processes in real time (Levy et al., 2024). Through AR, learners can visualize abstract phenomena that are otherwise invisible, such as ionization processes, proton transfer mechanisms, molecular interactions, and dynamic changes occurring during acid-base reactions (Ripsam et al., 2024; Ariani et al., 2025). Consequently, AR has been associated with improvements in conceptual understanding, spatial ability, motivation, and engagement in chemistry learning (Silva et al., 2023; Mazzuco et al., 2022).

From a theoretical perspective, the integration of ethnochemistry and AR offers complementary educational benefits. Ethnochemistry provides meaningful cultural contexts that help students recognize the relevance of chemistry in everyday life, while AR supports the visualization of abstract chemical processes that cannot be directly observed. Together, these approaches have the potential to bridge contextual understanding and molecular-level reasoning, thereby facilitating students' construction of chemical representations. Improved representational competence may subsequently enhance students' ability to analyze problems, identify relevant concepts, generate solution strategies, and evaluate outcomes. Therefore, integrating ethnochemistry and AR may provide a powerful learning environment for developing higher-order cognitive skills in chemistry (Gilbert and Treagust, 2009; Mazzuco et al., 2022).

Despite growing interest in both ethnochemistry and AR, research integrating these approaches remains limited. Existing studies have largely investigated ethnochemistry as a contextual learning strategy or AR as a visualization tool independently. Furthermore, most AR-related studies in chemistry education have focused on conceptual understanding, learning achievement, motivation, or attitudes toward learning. Comparatively little attention has been given to examining how the integration of culturally contextualized learning and immersive visualization technologies influences students' representational competence and problem-solving skills simultaneously. This gap is particularly evident in acid-base chemistry, where successful learning requires both contextual understanding and mastery of multiple representations (Sutrisno, 2020; Mazzuco, Alves and Nunes, 2022; Phajan et al., 2025).

To address this gap, the present study investigates the implementation of an ethnochemistry module supported by Augmented Reality in acid-base chemistry learning. The module integrates local cultural knowledge with interactive molecular visualizations to create a learning environment that is both contextually meaningful and cognitively supportive. Specifically, this study examines the extent to which the integration of ethnochemistry and AR can enhance students' chemical representation competence and problem-solving skills. By exploring the relationship between contextualized learning, technological visualization, and higher-order cognitive outcomes, this study contributes to the growing body of research on culturally responsive and technology-enhanced chemistry education.

2. RESEARCH METHODS

This study employed a quantitative pre-experimental design using a one-group pretest-posttest model. This design was selected because the study aimed to examine changes in students' chemical representation competence and problem-solving skills before and after the implementation of an Augmented Reality-supported ethnochemistry module in acid-base chemistry learning. Although the design did not involve a comparison group, it allowed the researchers to evaluate the extent to which students' performance improved after participating in the intervention.

The study was conducted at the Faculty of Teacher Training and Education, Universitas Mataram, Indonesia. The participants were 26 second-semester undergraduate students enrolled in a General Chemistry course. The participants were selected using purposive sampling because they were studying acid-base chemistry and were considered appropriate for the implementation of the learning module. The participants were chemistry education students who had previously

been introduced to basic chemistry concepts but had not experienced acid–base learning through an integrated ethnochemistry and Augmented Reality module. This context was considered suitable because acid-base chemistry requires students to coordinate macroscopic, submicroscopic, and symbolic representations while solving contextual chemical problems.

The intervention involved the implementation of an Augmented Reality-supported ethnochemistry module on acid-base chemistry. The module was designed to integrate local cultural practices with scientific explanations of acid-base concepts. The ethnochemistry contexts were used to connect chemistry concepts with students' everyday and cultural experiences, while the AR features were used to visualize abstract chemical processes that are difficult to observe directly. The AR components provided interactive three-dimensional visualizations of molecular and ionic processes related to acid-base chemistry, such as ionization, proton transfer, and particle interactions in solution. By combining cultural contexts and molecular visualization, the module was intended to support students in linking macroscopic phenomena, submicroscopic processes, and symbolic representations.

The learning intervention was conducted over three meetings, with a total duration of nine instructional hours. During the learning process, students engaged with the printed and digital module, accessed AR visualizations through mobile devices, discussed ethnochemistry-based phenomena, and solved contextual acid-base problems.

Several instruments were used to collect data in this study. First, a chemical representation competence test was used to measure students' ability to understand and connect the three levels of chemical representation: macroscopic, submicroscopic, and symbolic. The test items were developed based on acid-base concepts and required students to interpret phenomena, describe particle-level processes, and use appropriate chemical symbols or equations. Second, a problem-solving skills test was used to assess students' ability to solve contextual acid-base problems. The test consisted of open-ended questions based on ethnochemistry-related phenomena. The assessment focused on students' ability to identify relevant information, analyze the problem, apply appropriate chemical concepts. Third, an observation sheet was used to document students' learning activities during the implementation of the module. The observation focused on students' engagement with the module, interaction with AR features, participation in learning activities, and responses to contextual problem-solving tasks. Fourth, validation sheets were used to evaluate the feasibility of the module and research instruments. The module was reviewed by experts in chemistry education, content, and learning media to ensure that the instructional materials, ethnochemistry contexts, AR features, and assessment tasks were appropriate for acid–base learning.

Before implementation, the learning module and research instruments were validated by experts. The validation process examined content relevance, conceptual accuracy, clarity of language, appropriateness of ethnochemistry contexts, suitability of AR visualizations, and alignment between learning objectives, activities, and assessment indicators. The validity of the chemical representation and problem-solving tests was examined to ensure that the items measured the intended constructs. Reliability analysis was also conducted to determine the internal consistency of the instruments. Only instruments that met acceptable validity and reliability criteria were used in the main study.

Data collection was conducted in three stages. First, the Augmented Reality-supported ethnochemistry module and research instruments were validated by experts and revised accordingly. Second, participants completed a pretest to assess their initial levels of chemical representation competence and problem-solving skills. Third, students participated in three instructional sessions using the module, during which observational data were collected to document students' engagement and learning activities. Upon completion of the intervention, a posttest was administered using the same indicators as the pretest. The resulting data were used to examine changes in students' chemical representation competence and problem-solving skills following the implementation of the module.

Descriptive statistics were used to summarize students' pretest and posttest scores in chemical representation competence and problem-solving skills. Data normality was assessed prior to inferential testing. A paired-sample t-test was conducted to examine differences between pretest and posttest scores at the 0.05 significance level. In addition, normalized gain (N-gain) and Cohen's d effect size were calculated to determine the magnitude of improvement resulting from the intervention. Observation data were analyzed descriptively to complement the quantitative findings. All statistical analyses were performed using IBM SPSS Statistics 25.

3. RESULTS AND DISCUSSION

The present study investigated the effectiveness of an Augmented Reality (AR)-supported ethnochemistry module in improving undergraduate students' chemical representation competence and problem-solving skills in acid-base chemistry.

Improvement in Students' Chemical Representation Competence

The effectiveness of the Augmented Reality (AR)-supported ethnochemistry module in enhancing students' chemical representation competence was examined through descriptive and

inferential analyses. Table 1 presents the descriptive statistics of students' pretest and posttest scores.

Table 1. Descriptive statistics of chemical representation competence

Test	Mean	SD
Pretest	40.77	12.94
Posttest	66.92	17.15

The results indicate a substantial increase in students' chemical representation competence following the intervention. The mean score increased from 40.77 in the pretest to 66.92 in the posttest, suggesting that students demonstrated a better ability to interpret and connect macroscopic, submicroscopic, and symbolic representations after participating in the learning activities.

Prior to inferential testing, data normality was assessed. Although minor deviations from normality were observed in the score differences, additional non-parametric analysis produced consistent results. A paired-sample t-test revealed a statistically significant difference between pretest and posttest scores, $t(25) = 8.08$, $p < .001$. Furthermore, the intervention yielded a large effect size (Cohen's $d = 1.58$), indicating a substantial educational impact. The average N-gain score was 0.45, which falls within the medium improvement category.

This improvement can be interpreted through the framework of multiple representations in chemistry learning. Kapıcı (2023) highlighted that successful chemistry learning requires students to integrate macroscopic, submicroscopic, and symbolic representations when interpreting chemical phenomena. Similarly, Phajan et al. (2025) found that students' representational competence in chemistry is strongly influenced by their ability to connect macroscopic, submicroscopic, and symbolic representations. In this study, the AR-supported module provided visual support that helped students connect observable acid–base phenomena with molecular-level explanations and symbolic expressions.

The findings are also consistent with Laohapornchaiphan and Chenprakhon (2024), who reported that students often struggle to understand chemistry at the submicroscopic level because molecular processes cannot be directly observed. AR visualization in this study helped reduce this difficulty by displaying particle interactions, ionization processes, and acid–base reactions in a more concrete and interactive form. This supports previous research indicating that visual and interactive technologies can strengthen students' representational understanding in chemistry.

Furthermore, Phajan et al. (2025) highlighted that representational competence is closely related to students' ability to reason chemically. Students who can interpret, translate, and coordinate multiple representations are more likely to develop deeper conceptual understanding. Therefore, the improvement found in this study suggests that the integration of AR into an ethnochemistry module did not merely increase students' exposure to visual media but also supported their representational reasoning in acid-base chemistry.

The ethnochemistry component also contributed to this improvement. By presenting acid-base concepts through local cultural practices, the module situated abstract chemical ideas within familiar contexts. This is consistent with Rahmawati et al. (2020), who argued that ethnochemistry can make chemistry learning more meaningful by connecting scientific concepts with students' cultural experiences. In the present study, cultural contexts provided the macroscopic anchor, while AR provided submicroscopic visualization. The combination of these two elements helped students build stronger links among the three levels of chemical representation., thereby supporting students' construction of more coherent representational frameworks.

Improvement in Students' Problem-Solving Skills

The second analysis focused on students' problem-solving skills. Table 2 presents the descriptive statistics for students' problem-solving skills before and after the intervention.

Table 2. Descriptive statistics of problem-solving skills

Test	Mean	SD
Pretest	39.23	31.49
Posttest	84.23	16.77

The results showed that students' mean score increased substantially from 39.23 in the pretest to 84.23 in the posttest. This increase indicates that students became more capable of analyzing contextual acid-base problems, identifying relevant chemical concepts, developing solution strategies, and evaluating their answers after learning with the AR-supported ethnochemistry module.

The paired-sample t-test revealed a statistically significant difference between pretest and posttest scores, $t(25) = 7.80$, $p < .001$. The effect size was large, with Cohen's $d = 1.53$. The normalized gain score was 0.74, which is categorized as high. These results indicate that the intervention had a strong positive effect on students' problem-solving skills.

This finding is important because problem solving in chemistry requires more than procedural calculation. Cooper and Stowe (2018) showed that students may succeed in

algorithmic problem solving without necessarily understanding underlying chemical concepts. Therefore, effective chemistry instruction should help students move beyond formula-based procedures toward conceptual and representational reasoning. The present study suggests that the AR-supported ethnochemistry module supported this shift by requiring students to solve problems based on cultural phenomena and molecular-level explanations.

The high improvement in problem-solving skills may be explained by the contextual nature of the learning tasks. Context-based chemistry learning has been shown to help students recognize the relevance of chemistry and apply scientific concepts to meaningful situations. Minata, Rahayu, and Dasna (2022) reported that context-based approaches can improve students' engagement and understanding because chemical concepts are introduced through real-world situations rather than isolated abstractions. In this study, ethnochemistry-based problems encouraged students to apply acid-base concepts to culturally familiar phenomena, which may have strengthened their ability to analyze and solve problems.

The role of AR was also central. Ibáñez and Delgado-Kloos (2018) reported that AR can support STEM learning by enhancing visualization, interaction, and conceptual understanding. Similarly, Mazzuco et al. (2022) found that AR has become an important pedagogical resource in chemistry education because it helps students visualize abstract concepts. In the present study, AR likely supported problem solving by helping students construct more accurate mental models of acid-base processes. When students could visualize how particles interact in solution, they were better able to explain and solve related chemical problems.

From the perspective of Cognitive Load Theory, the use of AR may have reduced unnecessary cognitive effort by externalizing abstract molecular processes. Sweller, van Merriënboer and Paas (2019) argued that learning becomes more effective when instructional design reduces extraneous cognitive load and supports schema construction. In this study, AR visualizations may have reduced the burden of mentally imagining invisible processes, allowing students to allocate more cognitive resources to analyzing problems and developing solutions.

Relationship between Chemical Representation and Problem-Solving Skills

A noteworthy pattern in the findings is that both chemical representation competence and problem-solving skills improved significantly, but the improvement in problem-solving skills was higher. The N-gain score for problem-solving skills was 0.74, while the N-gain score for chemical representation competence was 0.45. This suggests that the module was particularly effective in helping students apply chemical concepts to solve contextual problems.

This result supports the argument that representational competence is an important foundation for chemical problem solving. Nickel et al. (2025) explained that multiple

representations provide cognitive and social affordances that help learners construct scientific understanding. In chemistry, students need to interpret phenomena, represent invisible processes, and use symbolic tools to solve problems. Therefore, improved representational competence can support more effective problem-solving strategies.

However, the greater improvement in problem-solving skills suggests that ethnochemistry may have provided an additional advantage beyond visualization alone. The cultural contexts embedded in the module may have helped students understand the relevance of acid-base chemistry and recognize how chemical concepts can be used to interpret real-life phenomena. This aligns with situated learning theory, which emphasizes that knowledge is more meaningful when learned in authentic contexts. In this study, ethnochemistry functioned as an authentic context, while AR functioned as a representational scaffold.

Thus, the findings suggest that the strength of the intervention lies in the integration of two complementary supports. Ethnochemistry contextualized the problem, whereas AR visualized the chemical mechanism. This integration helped students move from cultural phenomena to molecular explanations and then to problem-solving strategies. Such a pathway is particularly relevant in acid-base chemistry, where students must understand observable properties, particle-level processes, and symbolic equations simultaneously.

Observation data supported the quantitative results. During the intervention, students appeared actively engaged with the module and AR features. They used mobile devices to access AR visualizations, discussed the relationship between local cultural practices and acid-base concepts, and attempted to explain chemical processes using multiple representations. Students also showed interest when cultural phenomena familiar to their daily lives were connected with scientific explanations.

These observations suggest that the AR-supported ethnochemistry module created an active and meaningful learning environment. The use of familiar cultural contexts appeared to increase students' curiosity, while AR visualizations helped them explore abstract chemical processes more concretely. This finding is consistent with studies showing that AR can increase motivation and engagement in science learning and that ethnochemistry can enhance the relevance of chemistry instruction.

The observation results also indicate that students did not merely use AR as a visual attraction. Instead, AR functioned as a learning scaffold that helped students discuss and explain chemical phenomena. This distinction is important because technology-enhanced learning is only pedagogically meaningful when technology supports conceptual reasoning rather than

simply increasing novelty. In the present study, AR was embedded within structured module activities and ethnochemistry-based problem tasks, making it part of the learning process rather than an isolated digital feature.

Overall, this study demonstrates that integrating ethnochemistry and Augmented Reality into acid-base chemistry instruction has considerable potential for enhancing students' chemical representation competence and problem-solving skills. These findings contribute to the growing body of research on culturally responsive and technology-enhanced chemistry education and provide practical implications for the design of innovative instructional materials in higher education.

4. CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS

Based on the results and discussion, it can be concluded that the implementation of an Augmented Reality-supported ethnochemistry module effectively enhanced students' chemical representation competence and problem-solving skills in acid–base chemistry. Students showed significant improvement in chemical representation competence, with the mean score increasing from 40.77 to 66.92, supported by a medium N-gain of 0.45 and a large effect size. Their problem-solving skills also improved substantially, from 39.23 to 84.23, with a high N-gain of 0.74 and a large effect size. These findings indicate that ethnochemistry provided meaningful cultural contexts, while AR supported students in visualizing abstract molecular processes. The integration of both approaches created a more engaging and cognitively supportive learning environment that helped students connect macroscopic phenomena, submicroscopic explanations, and symbolic representations when solving contextual acid-base problems.

SUGGESTIONS

Based on the findings, chemistry educators are encouraged to integrate ethnochemistry and Augmented Reality into other abstract chemistry topics, such as electrochemistry, chemical equilibrium, and molecular geometry, to support meaningful and representational learning. However, because this study used a one-group pretest-posttest design with a relatively small sample, future studies should involve control groups, larger samples, and more rigorous experimental designs to provide stronger and more generalizable evidence of the module's effectiveness.

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