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Developing an Augmented Reality Chemistry Textbook on Acids and Bases with Ethnochemistry to Enhance Students Understanding of Chemical Representations

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Abstract: This development research presents an Augmented Reality(AR)-based textbook that integrates chemical concepts with the SASAMBO culture, highlighting an innovative approach to ethnochemistry. The study aims to produce a practical, valid, and effective AR textbook to enhance students' understanding of chemical representations. The research follows the 4D development model: Define, Design, Develop, and Disseminate. The textbook was validated by two experts and tested for effectiveness with a limited implementation involving 26 students. Data were collected using validation and practicality questionnaires, as well as pretest-posttest evaluations. Validation data were analyzed using Aiken's V, while improvements in students' understanding were assessed with a paired t-test via IBM SPSS Statistics 25. Results show high validity (Aiken's $V = 0.9$), strong practicality (86% average score), and a significant increase in understanding ($t = 16.871$, $p < 0.005$). These findings suggest that the AR-based textbook is a valid, practical, and effective tool for enhancing students' comprehension of chemical representation.

Keywords: Acids and Bases; Augmented Reality; Chemical Representation; Ethnochemistry.

Introduction

Chemistry education at the secondary school level provides a foundation for students' understanding of matter and its transformations. However, previous studies have shown that students often face difficulties in mastering the abstract and complex concepts of chemistry [1,2]. One of the main challenges in learning chemistry is the need to understand and connect the three levels of chemical representation: the macroscopic, submicroscopic, and symbolic levels [3]. The macroscopic level refers to observable phenomena, such as color changes or gas formation during chemical reactions. The submicroscopic level involves descriptions at the particle, atomic, and molecular scales, which are not visible to the naked eye. Meanwhile, the symbolic level includes the use of chemical symbols, reaction equations, and mathematical models to represent chemical processes [4, 5].

According to Busada and Aini, most chemistry textbooks owned by students only depict the submicroscopic representation and do not provide dual or hybrid representations [6]. Consequently, students struggle to connect these three levels of representation, which limits their ability to develop a deep and coherent understanding of chemical concepts. The ability to link all three representation levels is essential for applying chemistry in everyday life, yet students' difficulty in integrating these levels often leads to fragmented understanding and reduces their capacity to apply chemical knowledge to real-life situations [7].

A common example of this challenge can be seen in the topic of acids and bases, a fundamental principle in chemistry. Students may be able to observe indicator color changes (macroscopic level) or write reaction equations (symbolic level), but often struggle to visualize and comprehend the interactions of hydrogen and hydroxide ions at the submicroscopic level. This gap in understanding can lead to misconceptions and difficulties when students encounter more complex acid-base problems.

To overcome these challenges, integrating Augmented Reality (AR) technology into chemistry education presents a promising solution. AR combines digital elements with the real world, creating an interactive and meaningful learning experience [8,9]. In the context of acid and base chemistry, AR can be used to visualize three-dimensional molecular models, demonstrate ion movement in solutions, or simulate chemical reactions that are difficult to perform in school laboratories due to resource limitations. Incorporating AR into chemistry textbooks, students can "see" and interact with submicroscopic representations through their mobile devices [10, 11]. For example, by pointing a smartphone camera at a page discussing the Arrhenius theory, students can observe a 3D animation illustrating the dissociation of an acid or base in water [12]. Such visualization helps bridge the gap between macroscopic and submicroscopic levels, while reinforcing the students' understanding of symbolic representation in chemical equations.

Understanding chemical representations is a fundamental skill that needs to be continuously developed through various media [13]. The ability to visualize molecular structures, chemical reactions, and abstract concepts can be enhanced by using diverse learning tools [14]. One such educational innovation is the use of textbooks enhanced with Augmented Reality technology, allowing

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students to interact with 3D molecular models [15]. This technology connects textbook theory with visual, real-world experiences, making chemistry learning more engaging and accessible. Through multimedia approaches, complex and abstract chemistry concepts can be transformed into engaging learning experiences that foster a deeper understanding. Previous research also indicated that students'

The development of the textbook also considers pedagogical aspects, such as scaffolding strategies to support students' understanding of complex concepts, as well as the provision of various formative assessment tools using AR technology [15]. In addition, the textbook is designed to encourage active and collaborative learning, incorporating project-based assignments that integrate chemical knowledge, technology, and local wisdom. Its development involved collaboration between two chemistry education lecturers, two chemistry students, and one informatics engineering student. Validation and trials ensured the effectiveness and feasibility of the textbook for conceptual learning, with feedback from teachers and students used to refine it prior to broader implementation. Previous research also indicated that student worksheets linking the three levels of representation significantly improved students' representational abilities in electrolyte solution topics [16].

In addition to the use of modern technology, the ethnochemistry approach adds a new dimension to chemistry education by integrating scientific knowledge with local wisdom [17]. Indonesia, a country rich in cultural diversity, offers great opportunities for exploring traditional practices that embody chemical principles [18]. One such example is the traditional thread-dyeing process of the Sasak people on Lombok Island. This traditional dyeing process involves a series of steps that incorporate chemistry concepts, particularly related to acids and bases [19]. For instance, the use of various plants as sources of natural dyes involves the extraction of organic compounds with acidic or basic properties. The mordanting process, which improves dye bonding on fibers, often uses acidic or basic solutions. Even the color variations produced on songket threads can be explained through pH and acid-base reactions.

By integrating ethnochemistry related to Sasak thread dyeing into acid-base instruction, students not only learn abstract chemical concepts but also observe their real-life applications in a culturally significant practice [20]. This approach has the potential to enhance the relevance of chemistry learning for students while also promoting the preservation of traditional knowledge [21]. Developing an acid-base chemistry textbook that integrates AR technology with ethnochemistry is an innovative approach to address persistent challenges in chemistry education. AR supports students' submicroscopic understanding, while ethnochemistry contextualizes learning in culturally meaningful ways, aligning with the broader goal of Strengthening Education, Science, and Technology.

Despite the growing use of AR in chemistry education, few studies have integrated AR with ethnochemistry to simultaneously address cognitive, representational, and cultural aspects of learning. Most existing AR-based interventions focus on molecular visualization without connecting students' learning to local, culturally relevant practices. Moreover, while worksheets have shown promise in linking macroscopic, submicroscopic, and symbolic representations, no comprehensive textbook currently combines AR interactivity, scaffolding strategies, formative assessment, and ethnochemical contexts in a single resource. This research fills these gaps by developing and evaluating a novel acid-base chemistry textbook that integrates AR technology with the ethnochemistry of Sasak thread dyeing. The uniqueness lies in its dual focus: enhancing conceptual understanding through interactive 3D visualizations while simultaneously embedding chemistry learning within a meaningful local cultural practice. This approach not only strengthens representational competence but also fosters students' appreciation for the cultural context of scientific knowledge, making chemistry learning more engaging, relevant, and effective.

Research Methods

This research is a development study focused on designing and creating an interactive learning based on Augmented Reality (AR), which integrates the chemical concepts of acids and bases with the rich cultural heritage of Sasak, Samawa, and Mbojo (SASAMBO). By utilizing AR technology, the outcome of this study is an acid-base chemistry textbook enhanced with an Android-based AR application that aims to improve students' understanding of chemical representations. The research methodology follows the 4D development model proposed by Thiagarajan, which includes Define, Design, Develop, and Disseminate [22]. The following is a brief explanation of each stage in the process:

Define stage

This is the needs analysis stage. In this phase, the researcher analyzes and gathers information on the extent to which development is required. The main activity is analyzing the need to develop AR-based learning media.

Design stage

This stage involves designing the product determined in the research. The product to be designed includes an acid-base chemistry textbook and an AR application based on the Sasambo culture. The AR application will be designed to align with the chemical content from the acid-base topic and will be equipped with scannable images from the textbook. This allows the macroscopic-level acid-base concepts to be connected with the submicroscopic and symbolic levels.

Development stage

This stage focuses on producing the designed product, which will undergo repeated validation to ensure it meets the specified criteria. The outcome of this stage is an AR-based textbook that has been thoroughly tested and revised by experts in instructional development, informed by their feedback. Two experts validated the developed media. The validation aspects assessed by both experts included content, construct, and media validation. In addition, 26 students were used as samples to test its practicality. According to Borg and Gall [23] and Sugiyono [24], this number is sufficient for conducting a practicality test.

Dissemination stage

This is the distribution phase of the verified textbook, allowing it to be used by the public. In this phase, the improved AR application and acid-base textbook can be implemented.

The development of the AR-based learning media was carried out at the Faculty of Teacher Training and Education, University of Mataram. The subjects of this study were the second-semester students enrolled in the general chemistry course. Data collection methods involved the use of research instruments, including validation sheets, questionnaires to measure practicality, and pretest-posttest instruments to analyze students' understanding of chemical representations.

The data analysis technique employed descriptive quantitative methods. The researcher used Aiken's V formula to analyze validation results and determine the level of validity. To refine measurement outcomes, a rating scale from 1 (very irrelevant) to 5 (very relevant) was applied [25]. Validity criteria were determined using a decision category table based on the kappa moment [26]. The effectiveness of the ethnochemistry-integrated AR-based acid-base chemistry textbook in improving students' understanding of chemical representations was assessed by analyzing the pretest-posttest scores using a paired t-test with IBM SPSS Statistics 25 [27]. The rubric for assessing students' understanding of chemical representations is shown in Table 1.

Table 1. Rubric for Assessing Students' Understanding of Chemical Representations

Score	Understanding Description	Category
85-100	- Correctly analyzes all types of representations - Able to connect the three levels of representation - Uses accurate concept	High
70-84	- Recognizes most representations - Able to connect two representations with reasonable accuracy - Contains misconceptions or lacks of logical explanation	Moderate
40-69	- Has difficulty recognizing submicroscopic representation - Makes inaccurate connections between representations - Contains misconceptions in explaining the concept	Insufficient
<40	- Does not recognize types of representations - Unable to connect the three levels of representation - Very low understanding and tends to rel yon memorization	Low

Results and Discussion

This study focuses on the development of chemistry learning materials incorporating Augmented Reality (AR) and local cultural content, specifically SASAMBO ethnochemistry. The materials are presented in the form of a mobile AR application and a textbook that integrates SASAMBO cultural elements into acid-base chemistry concepts. The development process employs the 4D model, comprising four key stages: Define, Design, Develop, and Disseminate [28].

The initial stage, Define, involved a comprehensive needs analysis to determine the urgency and relevance of developing AR-integrated learning materials. This analysis drew upon various literature sources and curricular demands, revealing that the current educational curriculum encourages the integration of information and communication technologies (ICT) into the learning process. Such integration is believed to enhance conceptual understanding and foster active student engagement in the classroom.

However, implementing this vision poses significant challenges for educators, who are expected to demonstrate creativity and innovation in designing effective, technology-integrated instructional media. This is particularly relevant in the context of high school chemistry education, where abstract concepts—such as acids and bases—are often perceived as complex and difficult to grasp [7, 29]. Students tend to show greater interest and achieve deeper understanding when chemistry content is contextualized in real-life scenarios, thereby making learning more meaningful and enjoyable.

To address these challenges, this research seeks to develop an AR-enhanced chemistry textbook on acid-base topics that integrates elements of Sasambo ethnochemistry. The second stage of the 4D model, Design, involved creating a comprehensive textbook that is pedagogically sound and technologically enriched. The textbook includes AR markers that, when scanned, display submicroscopic representations of molecular structures for chemical compounds. The content is structured into three main learning activities: (1) acid-base interactions, (2) ion equilibrium and pH calculations, and (3) theoretical foundations of acid-base chemistry. The textbook cover is illustrated in Figure 1, and a sample AR marker is presented in Figure 2.

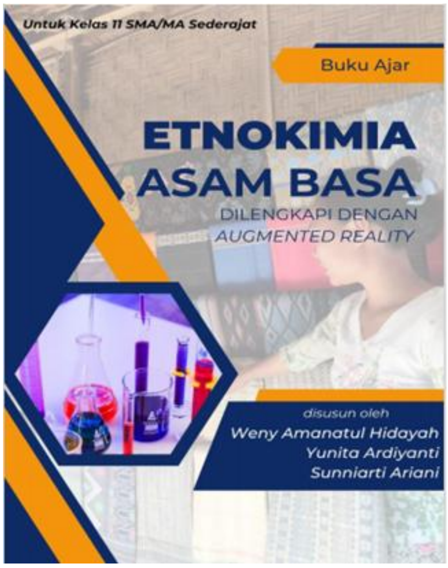

Figure 1. Cover of the Acid-Base Textbook

In addition, the researchers designed the AR application using several software tools, including Unity, Vuforia, Blender, and Android Studio. The markers used in the application were prepared by the researchers, such as photographs of hydrochloric acid (HCl), sodium hydroxide (NaOH), vinegar, and caustic soda.

*"Dalam pelarut air **asam** merupakan zat yang menghasilkan ion hidrogen, $H^+_{(aq)}$ dan **basa** merupakan zat yang menghasilkan ion hidroksida $OH^-_{(aq)}$, yang saling menetralkan"*

Dalam teorinya, Arrhenius membedakan asam-basa berdasarkan kemampuannya terionisasi dan terdisosiasi dalam suatu larutan yaitu **asam-basa kuat** dan **asam-basa lemah**. Asam kuat akan terionisasi secara sempurna menjadi ion-ion $H^+_{(aq)}$ dan basa kuat terdisosiasi secara sempurna menjadi ion-ion $OH^-_{(aq)}$. Contoh asam kuat yang terionisasi dalam air ditunjukkan seperti pada gambar struktur molekul berikut ini:

$HCl + H_2O \longrightarrow H_3O^+ + Cl^-$

Scan AR untuk melihat bentuk molekul dari larutan asam klorida (HCl). Arahkan HP anda ke gambar.

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HCl merupakan larutan asam yang tidak berwarna dan bersifat korosif. HCl juga merupakan asam kuat yang bersifat polar sehingga sangat mudah larut dalam air.

Sedangkan asam lemah akan sulit terionisasi menjadi ion-ion $H^+_{(aq)}$ dan basa lemah sulit terdisosiasi menjadi ion-ion $OH^-_{(aq)}$. Contoh basa lemah yang terionisasi dalam air ditunjukkan seperti pada gambar struktur molekul berikut ini:

Figure 2. Marker in the book

Molecular-level animations were created using Blender software and then integrated into the AR application development process through Unity and the Vuforia platform. The resulting AR application features 3D animations accompanied by explanatory text.

The design of the developed AR application comprises various components. Screenshots of application features are presented in Figure 3, macroscopic markers for acids and bases are shown in Figure 4, and the AR interface display is illustrated in Figure 5.

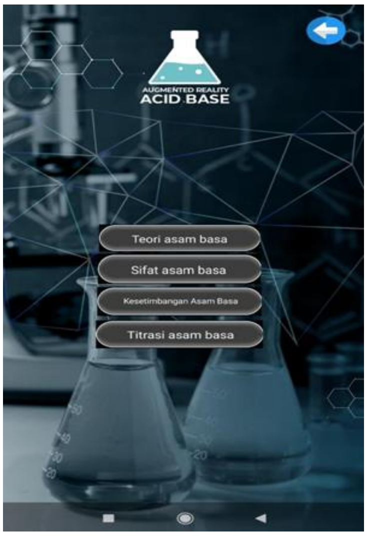

Figure 3. Application Features Screenshot

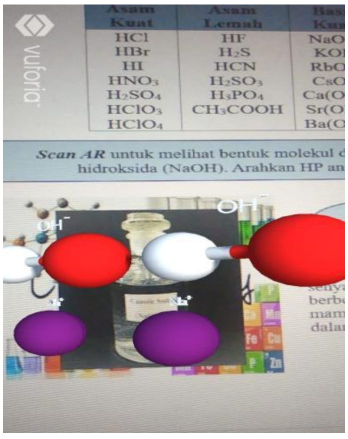

Figure 4. Marker Makroskopik Asam atau Basa

Figure 5. User Interface Display of the Augmented Reality Application

For the ethnochemistry content, the AR application was developed to include features such as screenshots of the application interface, which are presented in Figure 6, and markers in the form of macroscopic images of natural dye materials, as shown in Figure 7.

Figure 6. Application Features Screenshot

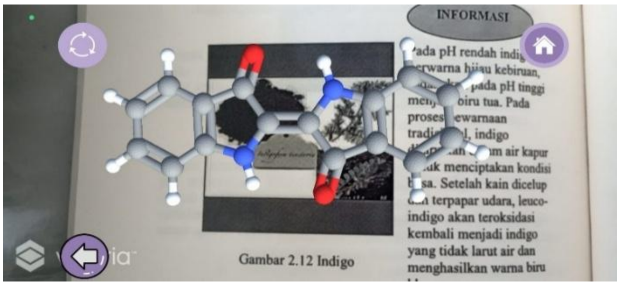

Figure 7. Marker in the form of a macroscopic image of the dye material

The third phase is the Development stage, during which the researchers conducted an evaluation of the previously developed AR media. The evaluation process involved individual testing, small group testing, and field testing, as described by Hasibuan et al. [30]. Following this, revisions were made to both the AR application and the acid-base textbook based on validation results provided by two experts. The validation results were analyzed using Aiken's V formula, yielding a score of 0.9, which falls under the "highly valid" category in terms of visual design, content presentation, content feasibility, and language clarity. These results indicated that no further revisions were necessary and the instructional media were ready for implementation. A practicality test was also conducted with students, yielding an average practicality score of 86%, indicating that the textbook is highly practical.

The fourth stage, Dissemination, is the final phase, which involves the broader distribution of the developed product [2]. In this phase, the textbook is planned to be published through the National Library (Perpusnas) and the Regional Library (Perpusda).

A limited trial was conducted with 26 students by administering a pretest before using the textbook and a posttest after its application in acid-base learning. The results of the pretest-posttest, measuring students' understanding of chemical representations in acid-base material, are presented in Figure 8.

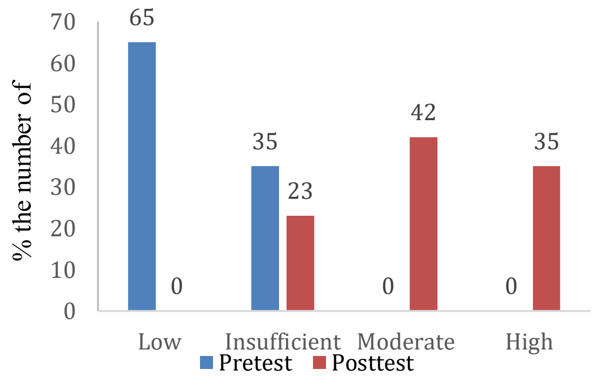

Figure 8. Pretest-posttest results of understanding chemical representation in acid-base topic

Figure 8 illustrates a notable improvement in students' understanding of chemical representations after using the AR-based ethnochemistry-integrated acid-base chemistry textbook. Prior to the intervention, students' understanding was predominantly categorized as low or insufficient. However, after using the AR-integrated textbook, their understanding significantly improved, with 35% of students achieving a high level of representational understanding.

A paired t-test analysis revealed a t-value of 16.871 with a p-value of 0.000 ($p < 0.005$), indicating a statistically significant increase in students' conceptual understanding. This suggests that the use of the developed textbook is effective in enhancing students' comprehension of chemical representations. These findings align with those reported by Levy et al. [30], who demonstrated that AR-based instructional media can enhance students' grasp of chemical representations, particularly in visualizing molecular 3D geometries. Similarly, research by Kartini and Lukman [31] confirms that the implementation of augmented reality in educational media enhances student engagement and understanding.

This research has strong potential to increase the number of engaging ethnochemistry learning resources that visualize abstract chemical concepts. In the future, the developed product will be further tested to examine its effects on students' cognitive load and analytical skills, as it shows promising potential. Additionally, an augmented reality (AR) application will be developed for other concepts in chemistry learning.

Conclusion

The development of an Augmented Reality (AR)-based chemistry textbook on acid-base concepts, integrated with the ethnochemistry of traditional Sasak songket dyeing, offers a promising solution to address challenges in teaching submicroscopic-level chemistry concepts. The research employed the 4D development model. The use of AR technology to visualize abstract concepts has the potential to enhance students' understanding of submicroscopic processes, while the integration of ethnochemistry makes the subject more culturally relevant and meaningful for learners. This approach also promotes active and collaborative learning through AR-based assessments and project-based assignments. Based on expert validation and a limited trial involving 26 students, the textbook achieved an Aiken's V score of 0.9 and a practicality score of 86%, indicating that it meets the criteria of being highly valid and highly practical. These findings support the conclusion that the developed AR-enhanced chemistry textbook, which incorporates Sasambo ethnochemistry, meets the standards of validity, practicality, and effectiveness for classroom implementation. It successfully enhances students' understanding of chemical representations by bridging abstract chemical concepts with real-world contexts through the innovative use of AR technology.

Author's Contribution

The First Researcher conducted the literature review and prepared the article draft; the Second Researcher developed the research instruments and performed data analysis; the Third Researcher reviewed the content of the augmented reality (AR) application; the Last Researcher provided research guidance, designed the study, and finalized the manuscript.

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