Educación Química

Investigación Educativa

# Enhancing High School Students' Conceptual Understanding of Acid-Base Chemistry through Augmented Reality Modules

*Mejorando la comprensión conceptual de los estudiantes de preparatoria sobre química ácido-base mediante módulos de realidad aumentada*

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**Abstract**

Understanding the acid-base concept requires grasping multiple representations. Augmented Reality (AR) technology has shown promise in enhancing students' comprehension of chemical concepts. Accordingly, digital modules integrating AR features have been developed. This study aimed to create a valid and feasible AR-based acid-base concept module and assess its effectiveness in improving students' conceptual understanding. The research followed a Research and Development framework, employing the ADDIE model as its methodological approach. A one-group pretest-posttest design evaluated the module's effectiveness. Thirty second-grade high school science students, who had previously studied acid-base concepts, were selected through convenience sampling. Instruments included multiple-choice tests and questionnaires developed by the researchers. The module achieved a validation score of 87.65% and a gain index of 0.56, indicating high feasibility. Final product testing demonstrated a significant improvement in students' conceptual understanding (Sig. 0.000 < 0.05). Students reported that the module greatly facilitated their learning and increased their interest in chemistry by integrating innovative technology. Feedback highlighted positive reactions to the engaging design, clear color schemes, and the overall ease of use, reflecting the module's effectiveness in supporting meaningful and interactive learning of acid-base concepts.

**Keywords :** acid-base, chemistry, augmented reality, digital module, conceptual understanding.

**Resumen**

Comprender el concepto de ácido-base requiere manejar múltiples representaciones. La tecnología de Realidad Aumentada (RA) ha mostrado potencial para mejorar la comprensión de los estudiantes sobre conceptos químicos. En consecuencia, se han desarrollado módulos digitales que integran funciones de RA. Este estudio tuvo como objetivo crear un módulo de concepto ácido-base basado en RA válido y factible, y evaluar su efectividad para mejorar la comprensión conceptual de los estudiantes. La investigación siguió un marco de Investigación y Desarrollo, empleando el modelo ADDIE como enfoque metodológico. Se utilizó un diseño de grupo único con pretest y postest para evaluar la efectividad del módulo. Treinta estudiantes de segundo grado de preparatoria en ciencias, que previamente habían estudiado conceptos de ácido-base, fueron seleccionados mediante muestreo por conveniencia. Los instrumentos incluyeron pruebas de opción múltiple y cuestionarios desarrollados por los investigadores. El módulo alcanzó un puntaje de validación de 87.65% y un índice de ganancia de 0.56, indicando alta factibilidad. La prueba del producto final mostró una mejora significativa en la comprensión conceptual de los estudiantes (Sig. 0.000 < 0.05). Los estudiantes reportaron que el módulo facilitó notablemente su aprendizaje y aumentó su interés en química mediante la integración de tecnología innovadora. La retroalimentación destacó reacciones positivas hacia el diseño atractivo, los esquemas de color claros y la facilidad de uso, reflejando la efectividad del módulo para apoyar un aprendizaje significativo e interactivo de los conceptos ácido-base.

**Palabras clave:** ácido-base, química, realidad aumentada, módulo digital, comprensión conceptual.

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## Introduction

Acid-base chemistry is a fundamental topic in chemistry; however, it remains challenging for students. While many students possess declarative knowledge about acids and bases, they often struggle to apply this knowledge in problem-solving tasks, indicating gaps in their conceptual understanding (Cartrette & Mayo, 2011; Nyachwaya, 2016). Research has shown that students frequently fail to apply the concept of acid-base (M. N. Petterson et al., 2020). Students often find it difficult to describe concepts such as pH, neutralization, acid and base strength, and theoretical frameworks, and frequently fail to connect these ideas to real-world solutions. They often over-rely on formulas rather than building a conceptual understanding, leading to difficulties in solving novel problems and a heavy dependence on book instructions (Sheppard, 2006). For instance, a study revealed that 66.65% of students at a particular school in Indonesia reported significant difficulty with acid-base topics (Annisa & Azra, 2023). Poor conceptual understanding of acid-base hinders students' ability to learn more advanced material, as acid-base concepts are fundamental and widely applicable across various chemical topics (Bretz & McClary, 2015; M. Petterson et al., 2020).

Conceptual understanding helps students grasp complex theories, principles, and ideas, going beyond simple memorization. It forms a basis for comprehending procedural knowledge (Hurrell, 2021) and enables students to connect and transfer knowledge effectively (Mills, 2016). Chemistry is particularly challenging due to its abstract nature, especially in acid-base concepts (Ryu & Paik, 2021). Misconceptions, such as misunderstanding acid-base theories, hinder learning. This lack of conceptual understanding can result in misconceptions, making it crucial to enhance students' understanding (Habiddin et al., 2022; Hoe & Subramaniam, 2016; Treagust et al., 2018). Common misconceptions are usually related to the submicroscopic view and the inability to distinguish between the various existing acid-base theories (Hoe & Subramaniam, 2016; Schmidt-McCormack et al., 2019). Implementing a more structured learning approach is crucial for improving students' understanding of acid-base concepts (Rahayu et al., 2011), which can be achieved by designing a module tailored to meet students' specific learning needs.

Modules are familiar and easy-to-understand learning media that align with learning objectives and accommodate relevant, concise, and specific content. Learning modules are tools with specific instructions and materials designed to help students achieve certain competencies (Ovando, 1993). They provide a structured, step-by-step, and active learning experience, encouraging participation and aiding in the understanding of chemistry concepts. Learning approaches that actively engage students and boost their motivation can enhance conceptual understanding (Carrizo et al., 2024; Cetin-Dindar & Geban, 2017). Research indicates that context-enhanced and text-rich learning resources improve students' understanding of science (Dori et al., 2018). Presenting more organized learning content promotes better understanding and helps prevent misconceptions (Aydin-Gunbatar & Akin, 2022). Incorporating visualizations is crucial to enhance comprehension and prevent misconceptions. The development of acid-base modules has shown positive impacts on students (Azmi & Latisma, 2022; Listia & Andromeda, 2022; Yerimadesi et al., 2019); however, many of these modules have not been implemented experimentally and often lack effectively incorporated multiple representations.

In acid-base learning, multiple representations illustrate the nexus between observed phenomena, chemical reactions, and calculations, promoting a comprehensive understanding. Mastering acid-base concepts requires the integration of symbolic, macroscopic, and microscopic representations (Salame et al., 2022; Widarti et al., 2022). Emphasizing the distinction between observed phenomena and molecular states can aid students in comprehending acid-base chemistry (Drechsler & Van Driel, 2008). One promising feature for modules is Augmented Reality (AR), which offers interactive, real-time 3D visualizations that help students understand submicroscopic concepts (Fombona-Pascual et al., 2022).

AR technology integrates virtual objects into real environments, enhancing multi-representational learning, especially of submicroscopic concepts. AR merges digital and real-world objects, enhancing the visualization of abstract chemistry concepts (Arango et al., 2024; Makhataeva & Varol, 2020). AR, often delivered via smartphones, has shown positive outcomes in chemistry education (Cai et al., 2014), particularly in topics such as molecular structures (Khairani & Prodjosantoso, 2023). Research indicates AR improves students' understanding of chemistry, including acid-base concepts (Alfaro et al., 2022), but further evaluation is needed on its broader impact (Ariani et al., 2024). Given these challenges, this study aims to develop an AR-assisted digital module focused on acid-base concepts to enhance students' conceptual understanding. The research question guiding this study is: "Is the AR-assisted acid-base module effective in improving students' conceptual understanding of acid-base concepts?" The objectives are to develop a valid and feasible AR-assisted acid-base module and to evaluate its effectiveness in improving conceptual understanding.

## Methodology

This Research and Development (R&D) project aims to develop an AR-assisted acid-base module for second-grade high school students using the ADDIE model, which includes five stages: (1) analysis, (2) design, (3) development, (4) implementation, and (5) evaluation (Lee & Owens, 2004). The ADDIE model was chosen for its effectiveness in creating targeted and dynamic learning media. The module's effectiveness was tested through a one-group pretest-posttest design. This study was conducted at a school in Malang, Indonesia, with thirty second-grade natural science students selected through convenience sampling. Three 60-minute learning sessions were held, with pretest and posttest data analyzed using JASP and a paired-sample t-test. Pretest and posttest sheets, each with 15 questions, measured students' conceptual understanding of acid-base concepts.

The multiple-choice questions used in both tests were validated by experts, achieving a validation score of 80%, indicating they were highly suitable for use as assessment instruments. The pretest and posttest questions were not identical but similar. Reliability scores were 0.608 and 0.659, respectively, indicating the tests are reliable (Peterson, 1994; Schmitt, 1996). Qualitative data from questionnaires provided additional insights, including feedback from students and validators. Content analysis was conducted on an open questionnaire about student suggestions for media development, which were visualized in a Word Cloud using Orange Data Mining software. The Likert scale regarding learning media, according to students, was displayed in a stacked bar chart using Excel. All instruments were developed by the authors and validated for effectiveness.

To determine the module's effectiveness, the gain index formula (Hake, 1998) calculated the increase in students' cognitive test scores from pretest to posttest. Validity was assessed by media and topic experts, who evaluated questionnaires, media, and study questions through a Likert scale (1–5) and an open-ended suggestion question. Scores were converted to percentages to represent overall validity using the formula: (Total score obtained / Maximum possible score) × 100%. A readability analysis measured the module's accessibility. Effectiveness was determined by analyzing the increase in cognitive test results. This study was approved by the Institutional Review Board of Universitas Negeri Malang Research Ethics Committee (2.8.12/UN32.14/PB/2024, August 2, 2024).

## Results and discussion

### *Results of AR Integrated Module Development*

**Analysis Stage.** The needs analysis was conducted using a Likert scale questionnaire (1–5) with statements related to students' difficulties, their needs for learning media, and their perceptions of AR. The questionnaire revealed that students struggle with acid-base concepts, particularly in understanding multiple representations. Learning is hampered by limited use of digital devices, as most materials are printed. Students strongly support more engaging digital modules, finding textbooks insufficient for chemistry comprehension. They prefer colorful, interactive materials to enhance understanding and motivation. This aligns with research indicating that students require attractive learning media for acid-base topics (Syafruddin et al., 2024). After calculating the average percentage from the questionnaire, the needs assessment showed that 81.9% of students desire updated, accessible learning media, supporting the development and implementation of digital learning media.

**Design Stage.** This stage began with creating a storyboard outlining the application's components and instructions. The module design was developed using Canva, 3D molecular markers were created with Molview, the application display was designed in Adobe Illustrator, and the app was built in Unity. The finalized PDF module was synced with Google Drive for easy access. This stage, along with development, is crucial for AR media creation, which often requires significant time and cost (Sırakaya & Alsancak Sırakaya, 2022).

FIGURE 1. (a) startup screen; (b) the main menu.


**Development Stage.** The digital module was enhanced with AR technology for deeper understanding and named MODUSA, derived from *Modul Digital Konsep Asam Basa* ("digital module of acid-base concepts"). Upon opening the app, users see a camera scanner interface for AR functionality. The initial screen includes a "HOME" button directing users to the main interface with an e-book display, usage instructions, AR marker scans, and practice questions.

The homepage provides essential information about the application, including button functions, instructions, module content, and practice questions. The e-book offers a comprehensive exploration of acid-base concepts, divided into sub-chapters on the nature of acids and bases, their properties, relationships between concepts and properties, and applications in daily life. Figure 3 illustrates learning material showing how acids with multiple hydrogen atoms, such as $H_2SO_4$ or $H_2CO_3$, release $H^+$ ions in water, with chemical equations and microscopic visualizations supported by AR features. Students are tasked with writing the ionization reaction of $H_2CO_3$ and illustrating the process.

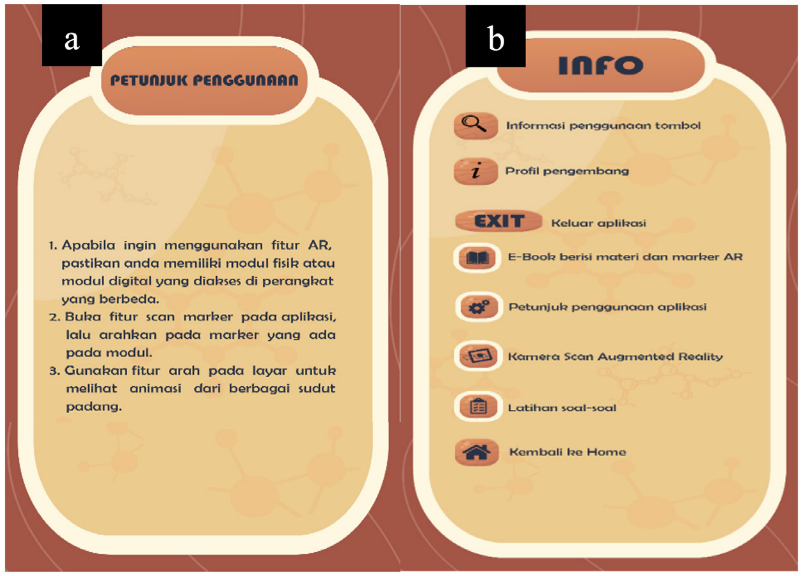
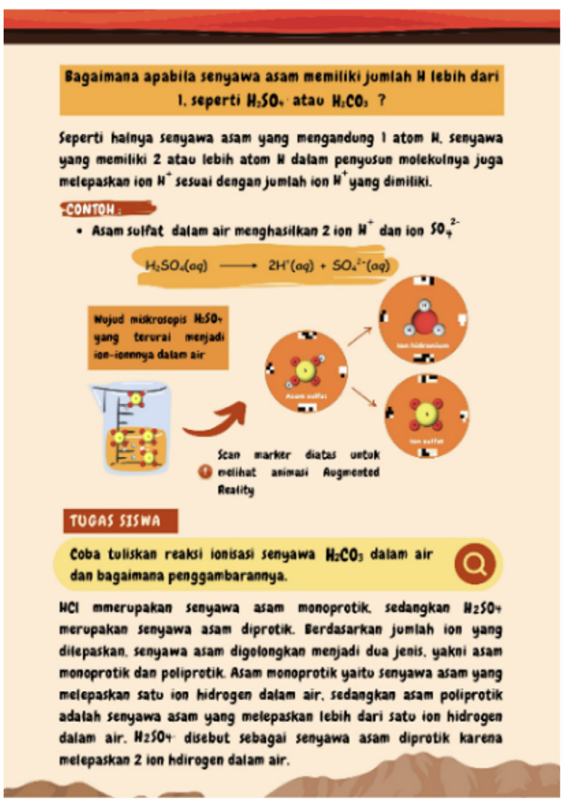



FIGURE 2. (a) the user guide; (b) an overview of the button function.

FIGURE 3. Display of the acid-base module within the application.




**Validity Testing.** Chemistry lecturers and teachers evaluated the module's feasibility and appropriateness. Media validation yielded 86.33% validity, material validation 86%, and student readability tests 86.67%, indicating the module is valid and highly feasible for use. Expert feedback provided constructive suggestions for improvement, which were incorporated before classroom implementation. The application is not publicly available; a drive link was provided for research participants.

**Implementation Stage.** Learning acid-base concepts occurred in three 60-minute sessions using discovery-based scientific approaches. The first session introduced MODUSA and AR features, enabling interactive visualization of ionization processes. The second session explored Arrhenius, Brønsted-Lowry, and Lewis theories, with students analyzing chemical equations and determining acid-base strengths through case studies. The final session included a post-test and brief material review to assess conceptual understanding.

**Evaluation Stage.** Statistical analysis using JASP evaluated the AR-assisted module's impact. A normality test confirmed normally distributed data ($W = 0.931$, $p = .054$). A paired-sample t-test revealed a significant improvement in posttest scores ($t(29) = -12.117$, $p < .001$). The N-gain index of 0.56 (moderate category) indicated significant learning gains (Hake, 1998). These results suggest that the AR-assisted digital module enhances students' understanding and is a valid, practical tool for teaching acid-base concepts.

### *Effects on Students' Conceptual Understanding*

The development process produced the MODUSA app, a digital learning module for the acid-base concept. Learning modules are designed for introductory acid-base learning, which is typically taught in 11th grade at the high school level. Designed to address challenges in learning media, MODUSA uses AR to enhance the experience. The app includes learning modules and practice questions linked to Google Drive and Google Forms, ensuring it is lightweight and accessible for students with minimal device resources. MODUSA offers three ways to use its AR features: (1) paired use in class, (2) independent study with two devices, and (3) printed modules with AR scanning via a mobile phone.

AR is a learning tool focusing on visualization for students (Ardyansyah & Rahayu, 2024; Fombona-Pascual et al., 2022; Lin & Wu, 2021) and offers simulation activities (Ibáñez & Delgado-Kloos, 2018). The AR feature in this module offers a unique educational experience by displaying 3D images of the molecules involved in acid-base reactions. These visualizations are designed to help the student understand how molecular shapes change during acid-base reactions, thereby enhancing their understanding of the structural transformation of each compound. This can help students understand how reactions occur, which is very necessary in understanding acid-base (Cooper et al., 2016). The use of both 2D and 3D images in AR interactive animations further helps students comprehend these concepts at macroscopic, submicroscopic, and symbolic levels. Ultimately, the visualization of abstract concepts provided by AR makes invisible scientific concepts observable, and the interactivity enables students to have greater engagement in internalizing and exploring them (Cheng & Tsai, 2013). This abstract visualization can reduce the possibility of misconceptions related to the submicroscopic view and make the learning of each theory more memorable, allowing students to distinguish between them more easily. Although AR is a visualization medium, a study shows that the primary effect of AR is motivation (Garzón & Acevedo, 2019). This is consistent with the findings during the study, where students appeared highly motivated in learning.

During the learning phase, students responded positively to the structured educational approach, especially to the augmented reality components. They showed great enthusiasm and inquisitiveness when exploring these AR tools, which enhanced their overall participation in the learning process. This high level of engagement transformed them into active participants in their education, leading to improved comprehension compared to students who learned through reflection or passive methods (Shiue, 2019). Other studies also indicate that AR implementation significantly enhances student motivation, with students reporting enjoyment while using AR-based media and demonstrating improved comprehension (Ardyansyah & Rahayu, 2023; Wong et al., 2021). AR promotes learning motivation, making students more active and consequently improving their academic performance, while also enhancing their conceptual understanding and academic retention (Amores-Valencia et al., 2022; Amores-Valencia & Burgos, 2023; Chen & Liu, 2020). This finding aligns with existing research demonstrating that students' conceptual understanding of chemistry is significantly influenced by their interest in learning and visuospatial thinking ability (Nieswandt & West, 2007; Wu & Shah, 2004). This aligns with the effects offered by AR. Furthermore, a study highlighted that understanding acid-base concepts is strongly correlated with motivational factors (Tseng et al., 2010). Therefore, this learning media succeeded in improving students' conceptual understanding.

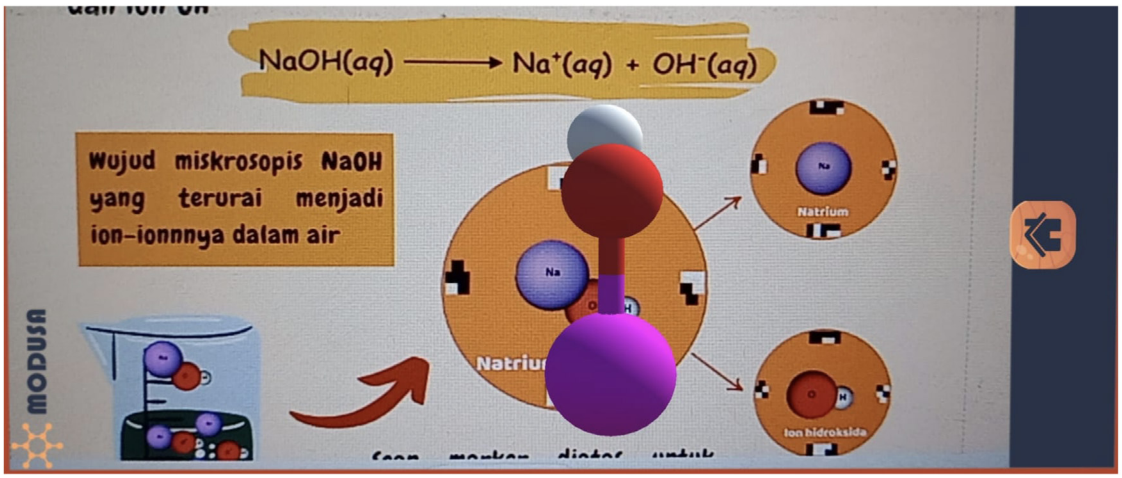



FIGURE 4. AR feature that appears in the acid-base module.

Based on the pretest-posttest conducted, students' conceptual understanding increased significantly, suggesting there may be an influence of this AR-integrated module on conceptual understanding. Similar improvements in understanding through AR-assisted modules have been observed in studies focusing on molecular shapes (Hurrahman et al., 2022) and chemical bonding (Apriani et al., 2021), further supporting the module's role in enhancing multiple-representation understanding in chemistry education. These results are also in line with previous studies using AR in chemistry (Alfaro et al., 2022; Cai et al., 2014; Khairani & Prodjosantoso, 2023). Other studies highlight how AR-enhanced books can increase learning motivation by offering practical and direct ways to explore learning material compared to conventional books (Hung et al., 2017). This aligns with this research, which uses AR-integrated modules to improve student understanding. The module not only serves as a learning resource but also plays a role in ensuring students' readiness to use AR.

The AR-integrated module can ensure students gain knowledge that is not only reliable but also structured and directly connected with AR visualization media, thus ensuring their understanding. Students frequently become more captivated by the AR technology itself rather than the educational content it delivers, creating a significant challenge when implementing augmented reality in learning environments (Mazzuco et al., 2022). The use of games has entertaining and engaging aspects that often distract students from learning objectives. Moreover, the use of smartphones can distract students from learning (Anshari et al., 2017). To avoid this, the use of e-modules (which are structured texts) can provide direct instruction, thus keeping students focused on learning goals (Dankbaar et al., 2016, 2017). Structured chemistry learning is crucial in ensuring students do not develop misconceptions, including acid-base topics (Islamiyah et al., 2022; Rahayu et al., 2011). Therefore, having AR integrated into these modules can ensure students receive structured and directed learning, which is essential for the conceptual understanding of acid-base topics.

Feedback from students confirms that the AR-digital module positively impacts their understanding of the acid-base concepts. In addition to the quantitative data gathered from the questionnaire, students have also provided impressions and suggestions for further improvement. Figure 5 displays a diagram of student feedback regarding their views on the developed learning media, in terms of design, usability (1–4), accessibility (5–8), and functionality aspects (9–12). Overall, the majority showed positive views toward design (94.33%), accessibility (91%), and functionality (92.83%). Other research also shows that most students have positive views toward AR in chemistry learning (Abdinejad et al., 2021; Cai et al., 2014). Consumers view mobile applications that incorporate augmented reality more favorably in terms of enjoyment, utility, information value, and usability, which increases their likelihood of using the application (Oyman et al., 2022). Meanwhile, students' opinions about suggestions for learning media development are illustrated in Figure 6. From the word cloud, it can be seen that several words such as "suggestions," "hopefully," "maybe," "add," and "improved" indicate a hope for improvements in the learning media in the future. However, some words also reflect students' appreciation, such as "good," "hope," "interesting," "excellent," and "helpful." The tone of the opinion is generally positive, with specific suggestions for improvement like adding more practice questions, improving accessibility, and making the app more engaging.

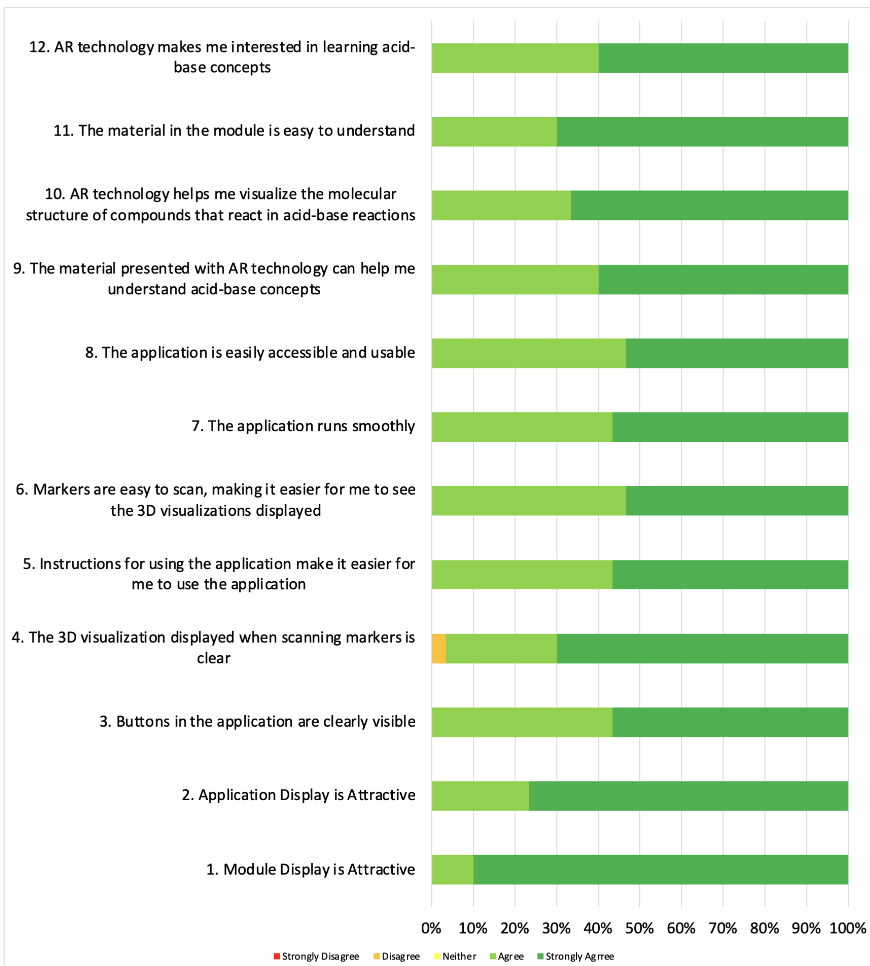



FIGURE 5. Students' feedback (N = 30) about their views on the AR-integrated module developed, regarding its design, usability, accessibility, and functionality.


FIGURE 6. Word cloud of Students' Opinions about Suggestions for Learning Media Development.

## Conclusion

This research and development (R&D) project focuses on developing an acid-base concept module application enhanced with AR features for second-grade high school students. The product, validated with a score of 87.65% and a gain index of 0.56, demonstrates high feasibility. Final product testing revealed a significant increase in students' understanding of acid-base concepts (Sig. 0.000 < 0.05). The AR-integrated MODUSA module effectively enhances conceptual understanding by combining visual interactivity with structured instructional design. AR's integration within a structured e-module addresses a known challenge in AR learning, which is student distraction. Additionally, AR helps students bridge the gap between abstract and concrete representations of chemical phenomena. These visualizations enable learners to observe molecular transformations during acid-base reactions. It not only makes abstract chemical concepts more accessible but also increases student engagement and motivation, factors that are critical for meaningful learning in science education. This suggests that AR-based modules like MODUSA hold great promise for future applications in chemistry learning and beyond.

The AR module presents a valuable tool for enhancing students' understanding of acid-base topics within a school-based learning environment. However, educators must be mindful of the smartphones' specifications accessible to students, as this may affect AR implementation. Future development efforts should prioritize the creation of lighter applications to ensure compatibility with devices that have lower specifications. It needs to be understood that this problem is often encountered in the implementation of AI as a learning medium (Sırakaya & Alsancak Sırakaya, 2022; Zhang & Yao, 2025). It is also important to recognize that this study utilized a one-group pretest-posttest design, which inherently limits the generalizability of the results. A study also reported that limited respondents are a problem frequently encountered in research on AR as a learning medium (Ramli et al., 2024). To obtain more robust and comprehensive insights into the effectiveness of the AR module, future research should consider adopting a quasi-experimental design with two groups and random sampling.

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