Development of a Chemistry Module on Buffer Solutions Using Dual Representations Assisted by Animation

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Abstract. Buffer solutions are a crucial concept in chemistry that students often find difficult to grasp. An effective method to enhance students' understanding is through the use of dual representations assisted by animation. Dual representations involve using various forms of visualization, such as diagrams, graphs, and animations, to help students comprehend abstract concepts more effectively. The research type employed is research and development (R&D) using a 4-D model consisting of four stages: define, design, develop, and disseminate. The research subjects were 26 students from class XII MIPA 1 SMA Negeri 5 Banda Aceh. Data collection techniques were conducted by distributing questionnaires for student needs analysis, module and animation feasibility assessment, educator response to modules and animations, and student understanding tests. The developed module obtained very good assessment results from 2 validators with an average percentage of 89.16%, while the animation media received very good assessment results with an average percentage of 80.43%. Educators' responses to modules and animations were categorized as very good, with percentages of 94.17 and 95.84% respectively. Students' responses were also categorized as very good with an average percentage of 87.2%. The results of students' understanding were categorized as good with an overall score of 82.60%. Based on the results of this research, it is concluded that the animation-assisted multiple representation module on buffer solution material is highly suitable for use as teaching material in the learning process.

Keywords: Multiple chemical representations; Chemistry modules; animations; buffer

Introduction

Buffer solutions are crucial in chemistry education, often posing challenges for students to grasp. To enhance student comprehension, employing dual representations with animation proves highly effective. By utilizing multiple forms of visualization such as diagrams, graphs, and animations, abstract concepts like buffer solutions become more accessible and easier to understand for students (Muhammad, et al., 2023). Misconceptions regarding buffer solutions have been identified among students, emphasizing the need for innovative teaching methods like dual representations to address these challenges. 

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Additionally, the development of interactive e-books has shown promise in improving students' representational abilities in understanding buffer solutions, highlighting the significance of multimedia tools in enhancing learning outcomes in chemistry education (Idha et al., 2022). The utilization of three levels of representation in chemistry macroscopic, submicroscopic, and symbolic simultaneously aids in the comprehension of chemical concepts. By integrating all three, we can provide a comprehensive explanation of various chemical phenomena, from simple to complex (Mathias et al., 2023; Johnson et al., 2023; Kapici, 2023; Tonyali et al., 2023; Rahayu et al., 2023). Students' ability to transition between these levels of representation enables a deep understanding of chemistry. However, it should be noted that students often possess alternative concepts and misconceptions at the submicroscopic level (Talanquer, 2022). The role of teachers is crucial in guiding students to understand chemical phenomena at each level of representation and addressing these alternative concepts. Additionally, the characteristics of chemical representations, such as iconicity, quantitativeness, granularity, and dimensionality, have a significant impact on students' ability to use and understand these representations. Therefore, further analysis of these characteristics can enhance students' ability to comprehend chemistry through representation.

The use of multiple representations supported by animation in chemistry education indeed involves employing various types of visuals like moving images, animations, and simulations. These representations play a crucial role in enhancing chemistry learning outcomes by improving concept understanding, performance, self-efficacy, cognitive structures, mental models, and reducing misconceptions (Margaretha, et al., 2023). Additionally, visualization in chemistry lessons through animations and simulations enhances student motivation, learning activities, and the ability to understand complex or hazardous experiments that cannot be conducted in real-time. Furthermore, instructional activities utilizing chemistry-based computer simulations and animations have been found to support students in learning science process skills effectively, such as formulating hypotheses, planning experiments, and drawing conclusions, thereby facilitating knowledge construction and concept comprehension in Tanzanian secondary schools (Shertayeva, at al., 2023). Effective chemistry education involves utilizing multiple external representations to aid students in understanding complex chemical concepts across different levels of abstraction. By integrating various forms of representation such as texts, pictures, diagrams, and graphs (Mathias, at al., 2023), students can grasp chemical phenomena more effectively. Visualization plays a crucial role in enhancing learning experiences by promoting logical and imaginative thinking (Shertayeva at al., 2023). However, challenges arise when students struggle to differentiate between submicroscopic, microscopic, and macroscopic levels of chemical processes.

Analogies are commonly used to bridge this gap, but careful design is necessary to prevent misconceptions (Liliana & Mammino, 2023). Textbooks also play a significant role in providing visual representations of chemical phenomena, aiding in students' comprehension of abstract concepts (Johnson, at al., 2023). Integrating these strategies can make chemistry education more interactive, engaging, and comprehensible for students. An interview was conducted with chemistry educators at SMA Negeri 5 Banda Aceh, where it was found that in the process of teaching chemistry, concepts are delivered directly through PowerPoint-assisted presentations. However, this approach has not been able to adequately depict concepts at the submicroscopic level. This does not align with the goals of the curriculum implemented at the school, namely the 2013 curriculum, where the qualification requirements for basic and secondary education emphasize the importance of students' abilities to act and think critically, creatively, collaboratively, productively, communicatively, and independently (Ministry of Education and Culture, 2013).
In the learning process, it is important for educators to select teaching materials that support the success of learners. One effective form of teaching material is modules, designed to facilitate independent learning without the direct presence of educators. These modules have been equipped with various supporting components, allowing learners to study independently. The use of technology such as computers can be an effective alternative to facilitate understanding of chemistry at the submicroscopic level. With the use of computers, visualizations of molecular representations can be displayed simultaneously and adjusted to observations at the submicroscopic level (Ariana, et al., 2020). The implementation of animation in the chemistry learning process provides significant benefits in helping learners visualize concepts in chemistry (Zulfahmi, et al., 2021). The use of animation media assists learners in understanding chemistry materials better. Animation, consisting of a series of images processed to create motion, is one of the effective media for this purpose (Chairiyah, 2021).

Research conducted by (Ezeudu & Ezinwanne, 2013) indicates an improvement in learner performance when using simulations in chemistry learning compared to learning without using simulation media with conventional methods. Animations can be developed using the Macromedia Flash computer program, which is capable of representing information in various forms, including text data, video, audio, animation, and images. Buffer solution materials are susceptible to misconceptions due to their theoretical concepts and calculations, especially in terms of buffer solution calculations similar to the concept of salt hydrolysis calculations (Qadri, et al., 2019). Determining the pH of a solution after adding a small amount of strong base, strong acid, or dilute solution is a complex concept to explain verbally. This is supported by previous research (Marathusholiha et al., 2017), which states that buffer solutions and salt hydrolysis are abstract and complex materials, requiring deep understanding to study them. Based on the issues outlined, this research will focus on the development of a multiple representations module supported by animation in learning buffer solution materials.

**Methods**

The approach used in this research is qualitative. The research method applied is the research and development (R&D) method using the 4-D model, which consists of four stages of development: define, design, develop, and disseminate. The R&D method is a research method used to produce a specific product that is then studied for its effectiveness (Sugiyono, 2015). The development research of the module and animation media was conducted at SMA Negeri 5 Banda Aceh located on Jalan Hamzah Fansuri, Kopelma, Banda Aceh City. The research period started from the design stage, development stage, to the implementation stage, which began from January 2023 to February 2024. The research subjects consist of twelfth-grade students of SMA Negeri 5 Banda Aceh in the academic year 2023/2024. The research instruments include several questionnaires, such as student needs questionnaires, module feasibility questionnaires, animation feasibility questionnaires, student response questionnaires, and educator response questionnaires. Additionally, this research also employs comprehension test questions for students. Sample selection was conducted from 26 students of XII MIPA 1. The sampling method employed was simple random sampling, where research subjects were randomly selected without considering strata within the population (Sugiyono, 2017). Data analysis in this research utilized qualitative descriptive analysis techniques. The assessment of media feasibility was performed using a percentage formula as described in Table 1.
Table 1. Criteria for Assessing the Feasibility of Module and Animated Media

<table>
<thead>
<tr>
<th>No</th>
<th>Score (%)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>81.25&lt; skor≤100</td>
<td>Very Feasible</td>
</tr>
<tr>
<td>2</td>
<td>62.50 &lt;skor ≤81.25</td>
<td>Worth</td>
</tr>
<tr>
<td>3</td>
<td>43.75 &lt;skor ≤ 62.50</td>
<td>Decent Enough</td>
</tr>
<tr>
<td>4</td>
<td>25 &lt;skor ≤ 43.75</td>
<td>Not Feasible</td>
</tr>
</tbody>
</table>

(Source: Muhafid & Widiyatmoko, 2013)

The research data was obtained using questionnaires for educators and students, employing a Likert scale with four options. The questionnaires were distributed to the respondents, and after the data was collected, it was analyzed using simple statistics with a percentage formula. The response results were evaluated based on the feedback provided by the students and educators, using assessment standards with score criteria and categories ranging from poor to excellent. The data obtained is presented in Table 2.

Table 2. Criteria for Assessment of Educator and Learner Responses

<table>
<thead>
<tr>
<th>No</th>
<th>Score (%)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75&lt;skor ≤ 100</td>
<td>Very Good</td>
</tr>
<tr>
<td>2</td>
<td>50 &lt;skor ≤ 75</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>25 &lt;skor ≤ 50</td>
<td>Simply</td>
</tr>
<tr>
<td>4</td>
<td>≤ 25</td>
<td>Less</td>
</tr>
</tbody>
</table>

(Source: Muhafid & Widiyatmoko, 2013)

Assessment of students' comprehension test data was conducted to evaluate the level of understanding after using the module and animation media on buffer solution materials. The level of student comprehension was assessed by comparing the minimum completion criteria (KKM) score with the test scores of the students, with the KKM value in SMA Negeri 5 Banda Aceh being ≥72. The comprehension test consists of 21 multiple-choice questions that have been validated by academic validators. Subsequently, the categories of student scores were determined based on the criteria listed in Table 3.

Table 3. Criteria for Percentage Assessment of Knowledge Competency

<table>
<thead>
<tr>
<th>No</th>
<th>Value</th>
<th>Predicate</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86-100</td>
<td>A</td>
<td>Very Good</td>
</tr>
<tr>
<td>2</td>
<td>71-85</td>
<td>B</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>56-70</td>
<td>C</td>
<td>Simply</td>
</tr>
<tr>
<td>4</td>
<td>0-55</td>
<td>D</td>
<td>Less</td>
</tr>
</tbody>
</table>

(Source: Muhafid & Widiyatmoko, 2013)

Results and Discussion

Define Stage

The define stage in the research process is crucial for setting the objectives and boundaries of the study. This stage involves collecting extensive information about core challenges in the learning process, such as through direct interviews with chemistry educators. It also includes exploring concepts and identifying misconceptions and learning
barriers, especially in complex subjects like chemistry. Thoroughly defining the research focus and understanding fundamental issues ensures a strong foundation for the subsequent stages, leading to a comprehensive and effective study at SMA Negeri 5 Banda Aceh.

The interviews revealed some important findings:

Student difficulties: Some students encounter difficulties in understanding buffer solution materials. This indicates the need for a more effective learning approach for this subject matter. Textbook Usage: The textbooks used by students are standard-issue, but the material presented in these books is not considered adequate in helping students understand the concepts of buffer solutions. This condition highlights the need for the development of alternative teaching materials that are more comprehensive and clear. Insufficient use of multiple representations: The multiple representations approach, known as one of the effective methods in chemistry education, is not optimally utilized by educators in developing teaching materials. This indicates the potential to enhance the quality of teaching materials by integrating various visual, symbolic, and submicroscopic representations in learning. By understanding these fundamental issues, the define stage provides a solid foundation for formulating research objectives and establishing the scope of the material to be further investigated. The next step in the define stage involves collecting information from students by distributing a needs analysis questionnaire. This questionnaire contains questions aimed at obtaining a deeper understanding of the teaching materials previously used by students. Based on the results of the needs questionnaire filled out by the students, the following findings were obtained:

A total of 77% of students expressed that they have never learned buffer solution materials using learning resources such as modules. This indicates that the use of module-based learning approaches is not common among students in the context of buffer solution materials. Furthermore, 84% of students stated that they feel the need to be provided with modules for learning buffer solution materials. From these findings, it can be concluded that there is a fairly high demand from students to use modules as one of the learning resources in understanding buffer solution materials. Additionally, 77% of students showed an interest in learning using chemistry-based multiple representation modules.

Misconceptions about buffer solutions were detected among students, highlighting the need for more effective learning approaches. Additionally, the use of cognitive conflict-based chemistry learning was found to be effective in reducing students' misconceptions about acid-base materials, emphasizing the importance of innovative teaching methods to enhance understanding (Idha et al., 2022). Moreover, the study on students' understanding of acid-base concepts using a two tier multiple-choice diagnostic test revealed that a significant percentage of students had misconceptions, indicating a gap in comprehension that traditional textbooks may not adequately bridge (Mary et al., 2022). These findings collectively underscore the necessity for more engaging and comprehensive educational strategies to improve students' grasp of buffer solution concepts. 

Design Stage

a. Developing an animation for teaching buffer solutions in chemistry involves several key stages. First, you need to plan the content, outlining the concepts and learning objectives. Then, create a storyboard detailing the sequence of events and visuals. Write a script that aligns with the visuals and effectively communicates the concepts. Next, design and
animate the visuals, utilizing both 2D and 3D techniques. Incorporate dual representations, showing both symbolic and graphical depictions of the concepts. Consider adding interactive elements to engage students further. Test the animation with a sample audience and gather feedback for revisions. Integrate the animation into the broader module and evaluate its effectiveness in achieving learning objectives. Through these stages, you can develop an engaging and educational animation for teaching buffer solutions in chemistry.

These components include:
- **Front Cover**: The cover page includes module identity, such as the title, author, and other relevant information about the module.
- **Introduction Section**: This section provides instructions for using the module, learning objectives, basic competencies to be acquired by students, explanations of the components of the module, and a concept map to provide a visual overview of the relationships between concepts in buffer solution materials.
- **Learning Section**: This section is the core of the module, containing comprehensive and systematic explanations of buffer solution materials, presented using multiple representations including images, diagrams, and text.
- **Closing Section**: This section includes self-assessment to test students' understanding, a summary of the material to clarify the concepts learned, answer keys to check students' responses, a glossary to explain difficult terms, and a bibliography to provide students with relevant reading references.

By systematically organizing this module, it is expected to provide optimal assistance in the learning process of buffer solution materials. This module is designed to be a clear and comprehensive guide for students in understanding complex concepts in chemistry. The design results can be seen in Figure 1. This stage involves the process of designing instructional media, resulting in a product in the form of interactive animation media. This instructional media is developed using macromedia flash 8 software. The design of the instructional media begins with the design of the main navigation buttons (home) and the creation of hyperlinks on each page, accompanied by relevant animations of buffer solution materials. Next, basic competencies (KD) and core competencies (KI), learning indicators, and learning objectives are added to ensure that this media covers all relevant aspects of the curriculum. Then, this instructional media directs students to the main material, which includes basic concepts, components, principles, pH calculations, and the role of buffer solutions in the context of chemistry.

![Figure 1. Initial module design](image-url)
b. Animation Design Stage

The development of an animation for a chemistry module on buffer solutions follows key stages: planning content, storyboarding, scriptwriting, designing and animating visuals, integrating dual representations, adding interactive elements, testing, integration, and evaluation. This comprehensive process aims to create an engaging educational tool. The instructional media includes a bibliography for additional student reference and a researcher profile for insight into the developer. Storyboarding focuses on concept analysis, emphasizing macroscopic views through simple experiments and symbolic representations for buffer solution components. Submicroscopic aspects clarify buffer operation principles, while concepts like pH and buffer roles incorporate multiple representations for enhanced understanding.

![Initial design (a) Menu (b) Animation of adding a small amount of strong acid to the buffer solution.](image)

**Figure 2.** Initial design (a) Menu (b) Animation of adding a small amount of strong acid to the buffer solution.

**Develop Stage**

In the development stage of a chemistry module on buffer solutions utilizing dual representations assisted by animation, key steps include content planning, storyboarding, scriptwriting, design and animation, integration of dual representations, testing, and evaluation. This phase ensures the creation of an effective and engaging educational resource. In the development stage of a chemistry module focusing on buffer solutions with dual representations assisted by animation, key steps involve content planning, storyboarding, scriptwriting, design and animation, integration of dual representations, testing, and evaluation (Rahmawan, 2023). This phase is crucial for ensuring the effectiveness and engagement of the educational resource. Research and development methodologies, such as the 4D model and the ADDIE model, are commonly utilized to guide the creation and evaluation of these modules, ensuring validity, practicality, and effectiveness for high school students (Nur at al., 2022). By incorporating various experts' feedback, conducting student trials, and assessing practicality and learning outcomes, these modules aim to enhance students' understanding of complex chemistry concepts through interactive and visually stimulating educational materials. The development stage consists of assessing the feasibility of the module and animations. Feasibility assessment is conducted to measure the feasibility of the module and animation media. The assessment is carried out by two expert validators. Module Feasibility Assessment. Feasibility
assessment is evaluated based on aspects of graphics, presentation, language, content, and multiple representation aspects.

![Figure 3. Percentage of module feasibility assessment](image)

From the assessment conducted by two expert validators on the module, overall aspects obtained an average of 89.16%, which falls into the "very feasible" category. This is in line with the study by (Assma, et al., 2018), stating that modules achieving an average of 91.25% meet the criteria of being highly feasible, indicating that the quality of the module is suitable for use by educators and students.

**Feasibility Assessment of Animated Media**

The feasibility assessment of animation media is evaluated based on aspects of systematicity, aesthetics, language, content, multiple representation, and technical aspects.

![Figure 4. Percentage of Animation Feasibility Assessment](image)
Based on the assessment results of two expert validators on the animation media across all aspects, an average score of 80.43% was obtained, falling into the "very feasible" category. This is consistent with the findings of Iswara, (Kuswandi & Husna, 2020), which stated that animation media with an average score of 88% falls into the "very feasible" category, indicating that animation media is suitable for use in the teaching and learning process by educators and students.

**Disseminate Stage**

This stage represents the final step in the 4-D model after validation and revision. The purpose of this stage is to determine and test the effectiveness of a product in learning. Educator Feedback on Modules and Animation Media. Questionnaires regarding feedback were distributed to educators to obtain their responses regarding the modules and animation media. The results of educators' feedback on the modules and animations can be seen in Figure 5. Based on the results from Figure 5, it can be observed that Educator I’s feedback on the multiple representation learning module yielded an average score of 93%, falling into the "very good" category. Similarly, Educator II’s average percentage score for the multiple representation learning module feedback was 95%, also categorized as "very good." These findings are in line with previous research indicating that educators’ feedback on modules received a score of 86.31% in the highly positive category (Irfandi, et al., 2018). Educator I’s feedback on the multiple representation learning animation yielded an average score of 85%, falling into the "very good" category. Meanwhile, Educator II’s feedback on the multiple representation learning media yielded an average score of 90%, also categorized as "very good." These findings align with previous research indicating that educators' feedback on animation media received a very positive response, with a percentage of 86% (Latifah & Lazulva, 2021).

![Figure 5. Educator’s Responses to the Module and Animation Media](image)

**The students' responses to the module and multimedia animations**

The students' responses to the module and multimedia animations supported by multiple representations showed an average percentage score of 87.2%, categorized as "very good." This result is consistent with previous research indicating that students' responses to multimedia learning based on multiple representations in chemistry obtained a score of 88.7%, falling into the "interested" category (Mujakir, 2017). The use of multiple...
representations supported by animations in chemistry learning helps students visualize abstract and complex concepts. This can enhance their understanding of chemistry and make learning more enjoyable.

Questionnaire surveys were distributed to students to obtain feedback on the module and multimedia animation. The results of students' responses to the module and multimedia animation with multiple representations showed an average percentage score of 87.2%, categorized as "very good". This finding is consistent with previous research, where students’ responses to chemistry learning media based on multiple representations obtained a score of 88.7%, falling into the "interested" category (Mujakir, 2017). The use of multiple representations supported by animation in chemistry learning helps students visualize abstract and complex concepts. Thus, this can enhance their understanding of chemistry and make learning more enjoyable.

Learner Understanding

The level of students' understanding of buffer solution material can be determined from the scores obtained by students who have answered the given test questions. The data on students' understanding of chemistry multiple representation modules aided by Animations on buffer solutions can be seen in Figure 6.

![Figure 6. Bar Diagram of Student’s Understanding of Macroscopic, Submicroskopic, Symbolic Aspects](image)

The data shown in Figure 6 indicates that the level of macroscopic understanding is 83.8% with a good criterion, the level of submicroscopic understanding is 83.3% with a good criterion, and the level of symbolic understanding is 83.7% falling under the good criterion. Based on these scores, learning using modules and animation media on buffer solutions can help improve students' understanding of buffer solution materials. This is consistent with the findings of (Smith & Metz, 1996), which revealed that teaching chemistry using submicroscopic visual aids can enhance students' understanding abilities. Similarly, in line with the research by (Susanto, et al., 2015), the learning outcomes of students improved after using chemistry multiple representations, with knowledge increasing to 82.86, representing an average increase of 79%/0.79, and all students achieved learning completeness with a high increase in scores.
Conclusion

Suitability for Education: The research underscores that the module, enriched with multiple representations in chemistry and animation on buffer solutions, is highly suitable for both educators and students. Expert validators rated the module and animation as "very feasible" (89.16 and 80.43%, respectively), while educator and student feedback consistently rated them as "very good" (94.17 and 95.84% for educators; 87.2% for students). Effectiveness in Enhancing Learning: The feedback from educators and students, alongside comprehension test results, indicates that the module significantly enhances understanding and learning in chemistry. With student comprehension test scores at 82.60% classified as "good," the module's effectiveness in conveying complex concepts is evident. Potential for Implementation: Given the positive assessments and high suitability for educational use, the research concludes that the module based on multiple representations in chemistry, supported by animation on buffer solutions, is ready for implementation in high schools as a valuable teaching resource.

Reference


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