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ENHANCING CONCEPTUAL UNDERSTANDING OF BUFFER SOLUTIONS WITH AN INTERTEXTUAL E-BOOK PROTOTYPE

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ABSTRACT

The intertextual-based e-book prototype helps students understand buffer solutions by connecting the three levels of chemical representation: macroscopic, submicroscopic, and symbolic. This connection allows students to visualise chemical phenomena from simple to complex. The study aims to enhance students' conceptual understanding using this e-book prototype. The research and development (R&D) method followed five stages: research and information gathering, product development planning, initial product development, limited trials, and initial product revision. This process yielded a highly validated e-book prototype that promotes innovation. The validation results showed high feasibility in substance (85.71%), instructional methods (90.90%), and language (100%). Experts deemed the e-book prototype highly effective in improving conceptual understanding through its intertextual approach. Pretest and posttest assessments of 30 students indicated improved conceptual understanding after using the e-book. Initially, students demonstrated macroscopic and symbolic level abilities without associating the three levels of representation. After using the e-book, they could connect these levels, enhancing their understanding and conceptual understanding. The N_Gain scores for pretest and posttest assessments were 0.48 for the high category, 0.45 for the medium category, and 0.44 for the low category, showing moderate improvement. The t-test results (Sig. (2-tailed) = 0.000 < 0.05) confirmed the effectiveness of the e-Book. Teacher and student responses averaged 90% and 85.5%, respectively, indicating that the intertextual-based e-book on buffer solutions is highly suitable as a self-learning resource to improve conceptual understanding.

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INTRODUCTION

Chemistry phenomena can be explained using three levels of representation: macroscopic, submicroscopic, and symbolic [1]. Students' ability to connect these three levels enhances their understanding of chemistry [2]. Understanding at the macroscopic level, supported by explanations at the submicroscopic and symbolic levels, is essential for comprehending observations and experimental results [3]. However, students often need help with submicroscopic and symbolic representations, which are abstract and not directly observable, leading to frequent misconceptions during chemistry lessons [4].

Students face challenges connecting the three levels of representation in chemistry learning [5, 6]. They tend to memorise chemical equations (symbolic) without grasping the macroscopic and submicroscopic aspects [7]. A higher understanding of the macroscopic level than the submicroscopic and symbolic levels has been observed [6]. Knowledge of chemistry without clear understanding can be confused due to the lack of connections between the macroscopic, submicroscopic, and symbolic levels [8]. This results in difficulties in understanding concepts and solving problems, leading to low learning outcomes in chemistry [9].

Research has identified various challenges students face in understanding buffer solutions [10], [11]. Difficulties include explaining the definition of buffer solutions (67%), identifying buffer and non-buffer solutions (71%), calculating the pH of acidic and basic buffer solutions (82%), calculating the pH of buffer solutions with the addition of small amounts of acid, base, and dilution (100%), and explaining the function of buffer solutions in living organisms (69.7%) [11].

Students struggle with chemistry problems due to an inability to connect the three levels of representation [12]. Observations indicate that chemistry teaching has yet to develop these levels fully, impairing students' problem-solving abilities [13]. Chemical equations at the symbolic level represent changes in substances at the macro level or particle interactions at the submicron level to solve problems [14]. Macroscopic, submicroscopic, and symbolic representations are used without considering classroom interconnections. Visualising these connections is essential in chemistry education, helping students think critically and solve problems effectively, leading to a deeper understanding of chemical concepts and success in the learning process.

Effective use of chemical representations in education enables students to develop critical thinking skills and solve complex problems, enhancing their understanding of concepts [15], [16]. Intertextual learning strategies provide conceptual understanding by offering real-life experiences transformed into chemistry's three levels of representation. This approach helps students construct meaningful knowledge of chemical concepts [17]. Intertextuality can be a strategy for building understanding through various levels of chemical representation related to everyday experiences [18]. Intertextual relationships among chemical representations are constructed from students' thinking and social interactions among classmates, textbooks, and other lessons [18]. Understanding these intertextual connections is crucial in chemistry education, providing students with comprehensive understanding and enhancing conceptual understanding.

Computer technology can visualise material at the submicroscopic level from simple to complex, employing two-dimensional images, three-dimensional graphics, words, animations, or simulations and linking them with other levels [17]. Visualisation of chemical phenomena and related concepts through animation can be explained using computer-based technology, thereby aiding students in enhancing their understanding of chemical concepts, particularly buffer solution concepts [19].

Integrating technology into learning materials is crucial for developing resources that provide advantages over conventional methods. One such resource is the electronic book (e-book), which helps students visualise the three levels of representation concepts in chemistry [20]-[23]. Previous studies have shown that e-books used for chemical representations do not fully connect all three levels of representation. Therefore, it is necessary to create intertextual-based e-books that illustrate the interconnectedness of these levels, positively impacting chemistry learning [24].

A survey of chemistry teachers and students from eight high schools in Jakarta revealed that these schools still rely on printed books issued by the Ministry of Education or private publishers, with none using e-books. Additional learning resources include student worksheets, which could be more extensive in presenting the three levels of chemical representation. Consistent with earlier findings [23], only 25% of chemistry teachers use e-books to teach buffer solutions, while 75% continue using traditional textbooks. The e-books used are typically downloaded from the internet and lack interactivity. Thus, developing interactive e-books that visualise the interconnectedness of the three levels of chemical representation is essential.

Research indicates that intertextual-based learning improves concept understanding by highlighting the interrelation of macroscopic, submicroscopic, and symbolic representations, thereby enhancing student success in learning [24], [25]. Specifically, intertextual learning has been shown to improve students' understanding of buffer solutions [17].

Given these considerations, developing an intertextual-based e-book prototype focused on buffer solutions aims to enhance students' conceptual understanding, aligning with the relevant chemistry competence standards. This innovation integrates digital technology into education, fostering opportunities to advance the quality of education in line with Society 5.0. Using interactive media to visualise chemical representations shifts traditional education towards a more interactive and intelligent approach

METHODS

1. Research Design

The method used in this study is the Research and Development (R&D) approach as outlined by Borg and Gall, which aims to develop and test products. The research and development process is cyclical, involving ten main steps [26]. Due to time constraints, only five stages were implemented in developing the intertextual-based e-book prototype on buffer solutions. The research steps are illustrated in **Figure 1**.

2. Research Participants and Instruments

This study was conducted at a public senior high school in Jakarta City, involving 30 twelfth-grade students who had previously studied buffer solution concepts in the eleventh grade. Participants were selected randomly to represent a range of cognitive abilities (high, medium, and low). After the trial, the same students and five teachers completed a user feedback questionnaire, assessing the format, quality, and appeal of the developed prototype e-book.

Feasibility testing included two experts in Chemistry Education and two in Indonesian language and literature. Their feedback was used to refine the prototype e-book on buffer solution concepts.

The research instruments used for data collection were essential to address the research questions. These instruments included the Substantive Feasibility Sheet, the Instructional Method Feasibility Sheet, the Language Feasibility Sheet, the Media Feasibility Sheet, and pretest and posttest sheets to measure students' conceptual understanding.

The validation criteria for the feasibility of the intertextual e-book prototype guided the creation of these instruments. The feasibility test for the prototype included the following criteria: concept descriptions aligned with chemistry concepts, starting with phenomena (macroscopic level), followed by explanations (submicroscopic level) and visualisations (symbolic level); links between macroscopic, submicroscopic, and symbolic levels in concept descriptions; macroscopic illustrations aligned with laboratory or everyday phenomena; clear and understandable illustrations; and illustrations describing concepts involving links between macroscopic, submicroscopic, and symbolic levels.

The process flow of the R&D method phases is depicted in **Figure 1**.

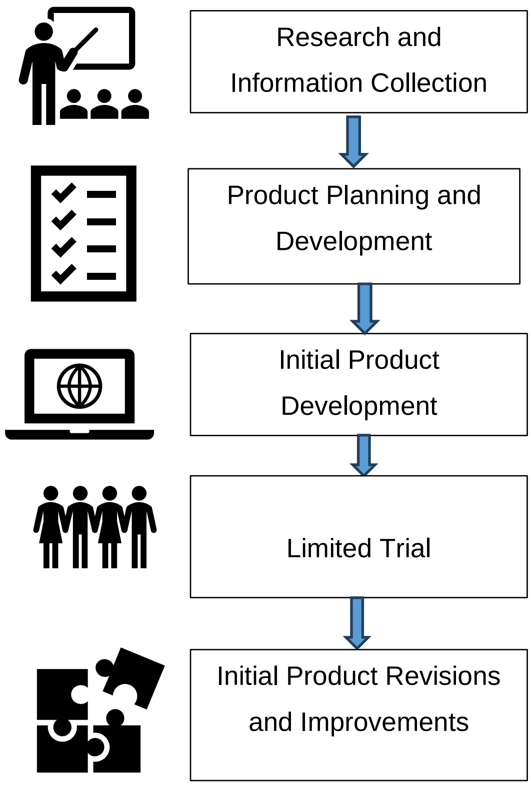


Figure 1. Stages of R&D model development

3. Data Analysis

The quantitative data from this research comes from limited trial tests to assess students' conceptual understanding after using the developed e-book prototype. Pretests and posttests were administered to 30 twelfth-grade students at a senior high school in Jakarta to measure students' conceptual understanding.

The improvement in conceptual understanding for each indicator was determined using the N_Gain (normalised gain) calculation. The pretest and posttest scores were processed to obtain a gain score, as adapted from [27]. This method measures the difference between post-test and pretest scores within the same group. The N_Gain value provides insight into how much improvement in conceptual understanding occurs after an intervention or treatment. Mathematically, N_Gain is calculated using the formula:

$$\text{N\_Gain} = \frac{skor\ posttest - skor\ pretest}{\text{skor maksimum} - skor\ pretest}$$

Information:
N_Gain = normalised gain
Pretest = initial learning grade
Postest = final grade of learning

The gain index criteria are classified [28] based on **Table 1**

Table 1. N_Gain Index Criteria

N-Gain	Criteria
g ≥ 0,7	Tall
0,3 > g ≥ 0,7	Keep
g < 0,7	Low

The posttest refers to the test score after the intervention, and the pretest refers to the test score before the intervention. The N_Gain value ranges from -1 to 1. A positive value indicates improved conceptual understanding, while a negative value indicates a decrease. The higher the N_Gain value, the greater the improvement in conceptual understanding.

A T-test was carried out using a Paired Samples T-Test to evaluate the increase in students' understanding of concepts using intertextual-based e-books. The T-test compares the positive and significant influence on student achievement and attitude (pretest and posttest results) before and after the intervention. The effectiveness of intertextual-based e-books in improving students' understanding of buffer solutions was analysed using the pretest and posttest results, following the formula [28]:

$$t = \frac{\bar{x} - \mu_0}{SE} = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}$$

SE: Standard error
$\bar{x}$: Average value of the sample
μ_0 : Average of the population (known)
s : Sample standard deviation

RESULTS AND DISCUSSION

1. Characteristics of *Intertextual-Based* eBook Prototypes

The buffer solution e-book prototype systematically covers concepts such as properties, components, principles, pH calculation, the role of living organisms, and preparation of buffer solutions, all organised based on intertextuality [28]. Chemistry involves three levels of representation (**Figure 2**): macroscopic, submicroscopic, and symbolic. Teaching the relationship between these levels is essential [30-32].

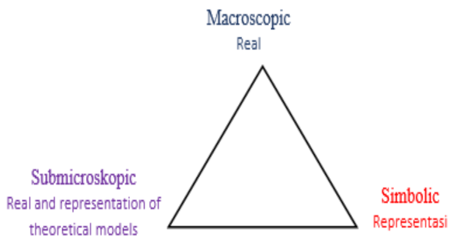


Figure 2. Three-Level Relationship of Chemistry Learning Representation

The concept descriptions are presented using an intertextual approach: displaying macroscopic phenomena, linking macroscopic-symbolic aspects, and connecting macroscopic-submicroscopic-symbolic aspects.

The intertextual-based e-book prototype allows students to visualise chemistry concepts and enhance their conceptual understanding [17], [18]. The prototype presents real macroscopic phenomena of buffer solutions, aligning with Edgar Dale's learning theory (1969), which recommends using media directly related to real objects for optimal learning outcomes [29]. The example is illustrated in **Figure 3**

Figure 3. Macroscopic Level Visualization

The macroscopic-symbolic aspect of buffer solution components is depicted in **Figure 4**.

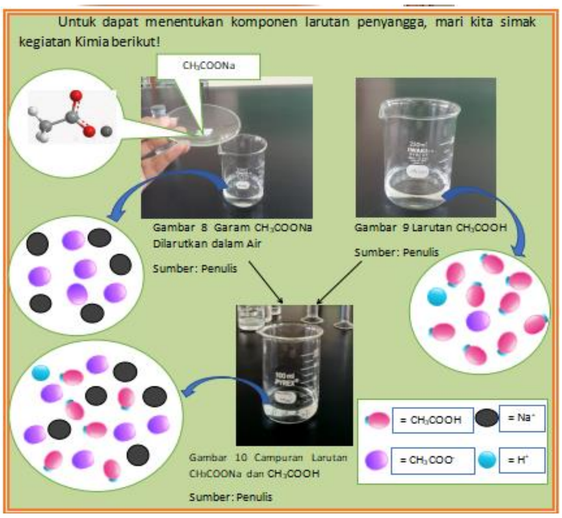


Figure 4. Visualisation of macroscopic-symbolic aspects of the eBook Prototype.

The prototype e-book illustrates the principles of buffer solutions through animated videos, linking macroscopic-submicroscopic-symbolic aspects, as shown in **Figure 5.**

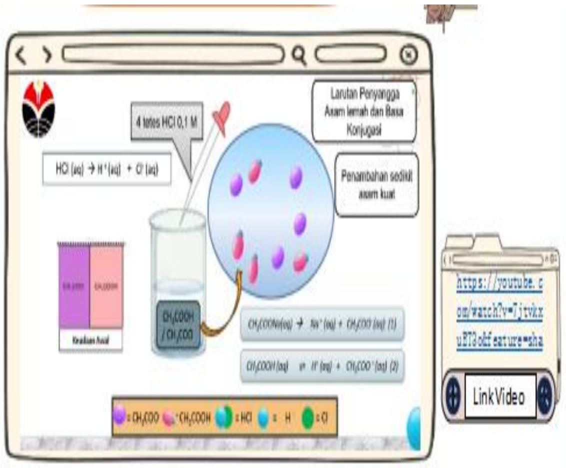
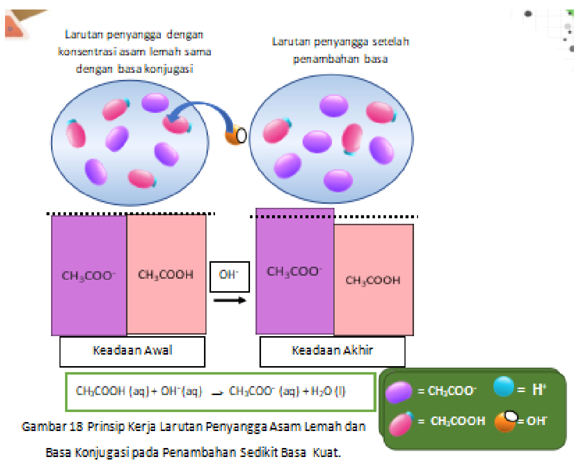


Figure 5. Macroscopic-submicroscopic-symbolic animated video visualisation

The depiction of the submicroscopic-symbolic aspect in the working principle of buffer solutions within the intertextual-based prototype e-book is shown in Figure 6.

Figure 6. Visualisation of submicroscopic-symbolic aspects of the e-Book Prototype



2. Pretest and Posttest Results of Student Conceptual Understanding

Intertextuality in chemistry, adapted from literature, involves understanding a concept by relating it to other texts or representations. In chemistry, this strategy links the macroscopic, submicroscopic, and symbolic levels [33]. Research indicates that intertextuality connects students' experiences and knowledge, transforming real experiences into three levels of representation, allowing students to build meaningful knowledge of chemical concepts [17], [34].

Conceptual understanding involves re-explaining concepts in one's own words, indicating memorisation and deep understanding [35]. A strong grasp of concepts allows students to relate new information to existing knowledge without altering the core meaning. Understanding buffer solutions is important as it helps students understand and apply the concept in various contexts. Chemistry education requires associating the three levels of representation to enhance students' conceptual understanding.

A pilot test was conducted with twelfth-grade high school students. The test involved administering pretest questions to 30 students, divided into three groups: 10 high-level, 10 medium-level, and ten low-level students. After the pretest, students were given the e-book prototype to study overnight and took the posttest the following day. The pretest and posttest results for each category of students on the buffer solution concept are shown in **Figure 7**.

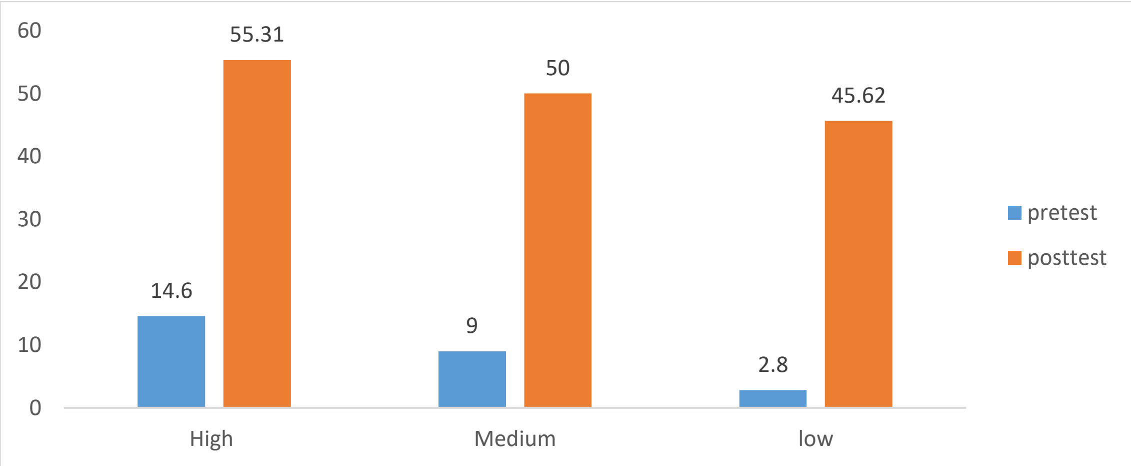


Figure 7. Graph of Student Prettiest and Postest Averages

Figure 7 illustrates the significant differences in the average pretest and posttest scores for each category of students. High-level students had a pretest average of 14.06 and a posttest average of 55.31. Medium-level students had a pretest average of 9 and a posttest average of 50. Low-level students had a pretest average of 2.8 and a posttest average of 45.62. Each category significantly increased average scores after using the e-book prototype.

The post-test results indicated improvements in each test question for high, medium, and low-level students. Using the intertextual-based e-book prototype enhanced students' understanding of buffer solution concepts. This improvement can be attributed to learning resources that employ various representations in chemistry, which help students associate different levels of representation and improve their conceptual understanding.

3. Pretest and Posttest Results of Conceptual Understanding (N_Gain score)

Data analysis revealed increased conceptual understanding across all student groups, with an average N_Gain score of 0.46, indicating moderate improvement [27]. The N_Gain (normalised gain) was calculated, and the average pretest-posttest results for each student category are presented in **Table 2**.

Table 2. Average Percentage Scores of Pretest and Posttest for Each Student Category

Student Categories	Average Score					
	Pretest	Posttest	100 - Pretest	Gain	N_Gain	N_Gain (%)
High	14.06	55.31	85.94	41.25	0.48	47.99
Medium	9	50	91	41	0.45	45.05
Low	2.8	45.62	97.2	42.82	0.44	44.05
Average	8.62	50.31	91.38	41.69	0.46	45.70

Table 2 shows that overall, there is an improvement in student's conceptual understanding after using the Intertextual-based e-book prototype, with a moderate interpretation of the buffer solution concept. The improvement in conceptual understanding for high-category students is the highest (0.48) with a moderate interpretation. The improvement for moderate-category students (0.45) and low-category students (0.44) is relatively lower with a moderate interpretation. A positive N_Gain value indicates improved conceptual understanding using the Intertextual-based e-book prototype.

4. Effectiveness of Prototype e-Book Based Intersection (Test T)

Decision-making regarding the effectiveness of the intertextual-based e-book prototype is based on the independent t-test results (2-tailed). The hypothesis test criteria are as follows: H0 is accepted if the probability value (Sig.) > significance level (α) 0.05, and H0 is rejected if the probability value (Sig.) < significance level (α) 0.05. The calculation of Sig. (2-tailed) is shown in **Table 3**.

Table 3. Sample T-test Test Results

Measurement	Value
Mean Difference	8.90
Std. Deviation	0.54
Std. Error Mean	0.10
t	18.31
df	29
Sig. (2-tailed)	0.000

Bused on the t-test analysis (paired sample t-test), the Sig. The value (2-tailed) is 0.000, which is less than 0.05. Therefore, H0 is rejected, and Ha is accepted. This indicates that using intertextual-based e-books significantly improves students' conceptual understanding.

5. Teacher and Student Responses

Analyzing the responses from teachers and students to the intertextual-based e-book prototype involves examining the percentage values obtained. According to

[38], the criteria derived from the teacher response questionnaire indicate a very positive reception, with a score of 90%. This suggests that teachers find the prototype highly suitable for student use as a self-learning resource to enhance their understanding of chemical concepts, particularly in buffer solutions

.

Figure 8. Visualization of the Buffer Solution.

The teachers' feedback highlights the effectiveness of the intertextual-based e-book in helping students visualize and comprehend buffer solution concepts. **Figure 8** illustrates the visualization of the buffer solution phenomenon as presented in the e-book prototype.

The description of concepts in the e-book must provide contextual insights to encourage readers to discover and apply positive aspects in their daily lives [36]. A video of the buffer solution phenomenon in the blood illustrates the buffer solution properties. This video is a macroscopic representation that can be directly observed [37]. It shows a buffer solution in the blood, with submicroscopic-symbolic explanations to interpret the properties of chemical particles and understand chemical phenomena [38], such as the components and working principles of carbonate buffer solutions in the blood.

Figure 9. Macroscopic Visualization of Chemical Activities

After watching the video, students deduce how the buffer system in the blood enables the human body to neutralize the effects of damage caused by acidic or alkaline conditions. This activity aims to give students a deductive understanding by ensuring a strong grasp of concepts and their applications in specific situations. The chemical activities presented in the e-book prototype are shown in **Figure 9**.

A video that combines submicroscopic and symbolic representations illustrates the buffer solution properties. The video explains the working principle of the buffer solution and includes animations of its components. The animations make the e-book prototype appealing (coherent, straightforward, easy to understand, and interactive), ensuring the integrity of the conveyed meaning is well-maintained [36]. Visualization of the macroscopic, submicroscopic, and symbolic linkage aspects in the e-book prototype can be observed in **Figure 10**.

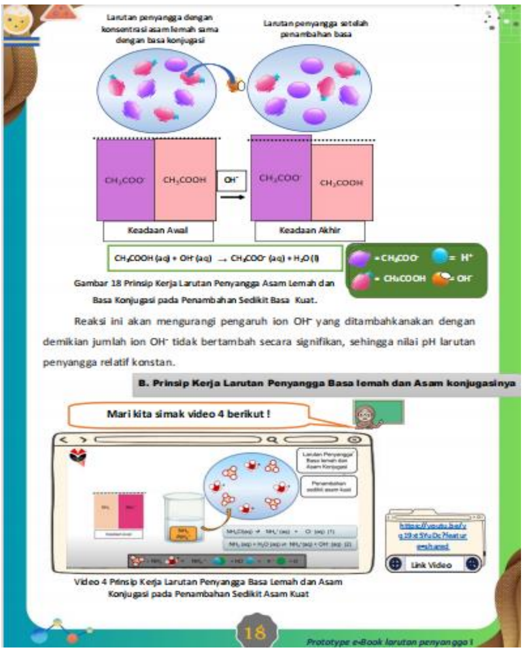


Figure 10. Submicroscopic-Symbolic Visualization and Macroscopic-Submicroscopic-Symbolic Animation Video

The students' responses to the e-book prototype were highly positive, with a percentage score of 85.5%. This indicates the intertextual-based e-book prototype on buffer solution concepts is very well-received. Therefore, the intertextual-based e-book prototype can assist students in solving chemistry problems by linking the three levels of chemical representation. This enhancement in conceptual understanding helps teachers improve learning outcomes in school

CONCLUSION

The feasibility test for the intertextual-based e-book prototype on buffer solution concepts yielded highly positive results. Substance aspects scored 85.71%, instructional methods 90.90%, language 100%, and media 96.43%, all rated very feasible. Key suggestions included refining concepts and definitions, using higher-order thinking skills (HOTS) questions, and ensuring accuracy and consistency in formulas and calculations. Instructional methods should follow the ABCD formulation, use simple language, and maintain consistency in terminology and chemical equations. Font size, text proportions, and image and video presentations also needed adjustments. The pretest and posttest results demonstrated significant improvements in students' conceptual understanding. High-category students had a N_Gain score of 0.48, medium-category students 0.45, and low-category students 0.44, indicating an overall enhancement in understanding buffer solutions. The e-book helped students better explain and associate macroscopic, submicroscopic, and symbolic representations. The rapid advancement of technology in education necessitates creative and innovative teaching methods. The intertextual-based e-book prototype has proven to enhance chemistry learning for high school students. It can serve as a reference for teachers in integrating technology into teaching materials, ultimately improving educational outcomes.

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