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Effectiveness of Implementing E-Books on Phase Equilibrium Based on Multiple Representations to Improve Students' Critical Thinking Skills

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Abstract: This study aims to test the effectiveness of using e-books on phase equilibrium based on multiple representations in improving students' critical thinking skills. The study design is non-randomized because subjects were not randomly assigned to the experimental and control groups. Both groups were given different treatments to observe the intervention's effect on critical thinking skills. The experimental group received instruction using an e-book based on multiple representations, while the control group used conventional learning media, namely printed textbooks. The sample used in this study consisted of students enrolled in the Physical Chemistry II course in the Chemistry Education program at the Universitas Jambi, with Class B serving as the experimental group and Class A as the control group. The instrument used in this study was a critical thinking skills test designed to measure students' critical thinking abilities, both before and after the implementation of the multiple-representation-based e-book. The results of the hypothesis test using ANCOVA yielded a significance value of 0.00, which is less than 0.05. Based on the research results, it can be concluded that the implementation of a multiple-representation-based e-book on phase equilibrium significantly improves students' critical thinking skills.

Keywords: Critical thinking skills; e-book; Multiple representation.

Introduction

Education plays a crucial role in enhancing the quality of human resources who possess broad knowledge and strong character (Rinadevi et al., 2025). Higher education in the 21st century is expected to produce graduates who not only master conceptual knowledge but also possess higher-order thinking skills such as critical thinking, problem-solving, and data-driven decision-making. 21st-century skills such as problem-solving, collaboration, teamwork, and critical thinking can equip college graduates to navigate the Society 5.0 era (Taufiqurrahman, 2023). Improving the quality of education can be achieved through curriculum reform, educational policy changes, and the integration of technology into learning (Yunitasari et al., 2025). Current learning is supported by technology to foster creativity, collaboration, innovation, and students' social responsibility (Anjarwati et al., 2025). Critical thinking skills are one of the competencies of higher-order thinking-oriented learning that need to be developed (Novianti, 2020). Critical thinking skills can support the achievement of the Sustainable Development Goals; therefore, quality education must be implemented (Boluk et al., 2019; Straková & Cimermanová, 2018). Students with critical thinking skills can research, evaluate, synthesize, interpret, and generate information (Manurung et al., 2023). Therefore, the learning process in higher education needs to be designed innovatively to actively encourage students' cognitive engagement and optimally develop critical thinking skills.

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In reality, however, students' critical thinking skills remain relatively low, particularly when it comes to understanding abstract and complex chemistry concepts. One of the most challenging topics is phase equilibrium. This topic requires students to simultaneously understand phenomena across three levels of chemical representation: macroscopic (observable phenomena such as changes in the state of matter), submicroscopic (particle interactions that cannot be directly observed), and symbolic (phase diagrams, graphs, and mathematical equations). Students' inability to connect these three representations leads to difficulties in performing analysis, evaluation, and drawing logical conclusions, which ultimately results in low critical thinking skills. Learning that fails to accommodate the development of critical thinking skills will result in low learning outcomes (Yang et al., 2025).

The multiple representations approach is a relevant strategy for addressing these issues. Multiple representations is an approach that presents information across three interconnected levels of chemical representation: the macroscopic, submicroscopic, and symbolic levels (Johnstone, 2000). This approach enables students to understand chemical concepts more comprehensively by integrating various interrelated forms of representation. Not only does it aid conceptual understanding, but multiple representations also have the potential to enhance critical thinking skills, as students are required to compare, interpret, and evaluate information from various representational perspectives. Multiple representations can serve to understand an idea encompassing tables, graphs, images, and symbols (Rotua et al., 2025). Furthermore, multiple representations encourage students to view a phenomenon from various perspectives, thereby enhancing critical thinking skills (Chrestella et al., 2021). Thus, there is a clear connection between the use of multiple representations and the development of higher-order thinking skills.

The use of technology is one of the key factors in the success of learning activities today (Suherman et al., 2025). Learning activities are enhanced by the use of information technology (Granić, 2022). Technology-integrated learning makes it easier for students to access and understand the material (Yudiyanto et al., 2020). Learning becomes more flexible, interactive, effective, meaningful, and engaging due to the use of technology (Gamage et al., 2023; Yaseen et al., 2025; Zou et al., 2025). Information technology has a positive impact on the learning process (De' & Kaugi, 2023). The integration of technology into learning can enhance students' digital competencies and their engagement in the learning process (Ma et al., 2024). The use of multimedia in learning can significantly improve learning outcomes (Hidayati et al., 2020). This places a demand on teachers and schools to be able to implement technology-based learning activities (Nasrulloh et al., 2025). The use of technology helps instructors enhance innovation and the quality of learning (Indrati et al., 2025). Learning using media can increase student engagement in deep thinking and connecting knowledge to daily life (Fatimah et al., 2026).

Significant changes have occurred in the world of education alongside the development of digital technology (Awila et al., 2025), such as the integration of multiple representations into digital learning media like interactive e-books. Unlike conventional e-books, which are static, interactive e-books based on multiple representations allow for the dynamic integration of text, images, submicroscopic animations, and diagram visualizations. Improving digital literacy is a critical need today to enhance a broader range of skills compared to conventional learning activities, even though conventional learning is still widely practiced (McLean et al., 2017; Saadah et al., 2025). The use of interactive learning media can enhance students' understanding (Marita et al., 2025). This aligns with the characteristics of learning in the Society 5.0 era, where technology functions not only as a tool but also as a means to create meaningful, student-centered learning experiences. Interactive learning media can serve as a solution to the gap between curriculum demands and student characteristics in implementing 21st-century learning (Huljanah & Zai, 2025).

E-books enable the integration of various types of media and interactivity that can stimulate a more active and independent learning process (Wulandari et al., 2025). Digital learning media can present learning materials interactively and enhance students' independent learning (Amini et al., 2025). Compared to traditional printed books, e-books offer flexibility in presenting material and allow readers to interact directly with the content through multimedia features (Pratiwie, 2024).

However, research specifically examining the effectiveness of e-books based on multiple representations in improving students' critical thinking skills regarding phase equilibrium material remains limited. Most previous studies have focused only on the general use of digital media or on a single type of representation, without systematically integrating the three levels of chemical representation into a single learning medium. Furthermore, the relationship between multiple representations and critical thinking indicators such as analysis, evaluation, and synthesis has not been extensively explored empirically.

The novelty of this study lies in the development and testing of an interactive e-book based on multiple representations that explicitly integrates the three levels

of chemical representation (macroscopic, submicroscopic, and symbolic) with indicators of critical thinking skills (analysis, evaluation, and synthesis) within the context of phase equilibrium material. This study not only develops digital learning media but also examines how the integration of these representations can directly facilitate students' critical thinking processes.

This research is important because, first, phase equilibrium is a fundamental topic in chemistry that involves a high level of abstraction, thus requiring an appropriate teaching approach. Second, students' low critical thinking skills indicate a gap between the demands of 21st-century learning and teaching practices that remain conventional. Third, the suboptimal use of digital technology in chemistry education presents an opportunity to introduce more effective and interactive media innovations. Thus, the results of this study are expected to contribute to the development of chemistry instructional designs that are more adaptive, innovative, and focused on enhancing students' higher-order thinking skills.

Method

This study employed a quasi-experimental research approach using a non-equivalent control group design. This design was chosen because the research subjects could not be randomly assigned; therefore, existing classes were used as the experimental and control groups. To minimize differences in initial ability between the groups, this study used a pretest as a covariate in the analysis. The population in this study consists of all students in the Chemistry Education Program at the Universitas Jambi who are taking Physical Chemistry II during the even semester of the 2024/2025 academic year. In this study, Class B served as the experimental group and Class A as the control group, each consisting of 19 students. The experimental group received instruction using an e-book based on multiple representations, while the control group used conventional learning media in the form of printed textbooks. The research instrument used was a critical thinking skills test in the form of structured essay questions designed to measure critical thinking indicators such as analysis, evaluation, and inference. This test was administered as a pretest and posttest. The instrument underwent content validity testing by experts and reliability testing to ensure its suitability as a measure of critical thinking skills. The data obtained were analyzed in several stages. First, prerequisite tests—specifically normality and homogeneity tests—were conducted to ensure the data met the assumptions of parametric statistics. Next, the data were analyzed using ANCOVA (Analysis of Covariance). The use of ANCOVA in this study aimed to test the differences in critical thinking skills between the experimental and control groups by controlling the pretest scores as covariates, thereby minimizing the influence of differences in initial ability between groups and making the analysis results more accurate.

Result and Discussion

This study aims to examine the effectiveness of using e-books on phase equilibrium based on multiple representations in improving students' critical thinking skills. Before the intervention was administered, a pretest was conducted in both the experimental and control groups. The pretest results for critical thinking skills in the experimental and control groups are presented in Table 1.

Table 1. Initial Critical Thinking Skills

Critical Thinking Skill Aspects	Experimental	Control
Interpretation	71.63	71.37
Analysis	72.32	70.89
Evaluation	71.05	71.42
Inference	74.74	71.79
Explanation	72.84	72.16
Self-regulation	72.68	71.79
Average	72.54	71.57

Based on Table 1, the initial critical thinking skills of students in both classes were relatively comparable and still needed improvement. This indicates that both groups had sufficiently comparable baseline conditions for the intervention. The low scores in the interpretation aspect were attributed to the abstract and complex nature of the phase equilibrium material, as well as the students' limited ability to understand various scientific representations. According to Maslakhatunni'mah et al. (2019), interpretation is the ability to understand and express the meaning of various experiences and data. Mastering the problems demonstrated by the answers to the questions asked is one indicator of the interpretation aspect (Ananta et al., 2023). Based on the identified issues, a phase equilibrium e-book based on multiple representations offers several advantages, including a large number of practice problems, the use of concrete analogies, and the integration of interpretation-prompting questions.

The low level of the analysis aspect indicates that students have difficulty connecting concepts. This aligns with the view (Benyamin et al., 2021) that analysis encompasses the ability to identify key information and select appropriate problem-solving strategies. Indicators of the analysis aspect include recognizing and using basic reasoning terminology, as well as identifying arguments and explanations (Ghifari et al., 2025).

Therefore, the strategy employed to enhance analytical skills in this study involves using case-based questions or experimental data and encouraging students to write scientific arguments.

Evaluation is the ability to apply logic when making judgments, identify underlying assumptions and motivations in arguments, and test the validity of an argument (Novandi et al., 2025). The low level of evaluation in early critical thinking skills may be due to a lack of experience in assessing arguments or scientific evidence and learning activities that do not lead to evaluation. One of the efforts made to improve critical thinking skills in this study was to apply an e-book on phase equilibrium based on multiple representations because it uses questions based on arguments and evidence and involves students in evaluative discussion activities.

The inference ability, which scored 74.74 in the experimental class and 71.79 in the control class, shows that students had difficulty drawing logical conclusions from the available information, whether from texts, graphs, simulations, or experimental data. This is reinforced by the limited number of evaluative and reasoning questions in the learning process. Meanwhile, the low score in the explanation aspect may be due to the students' lack of practice in constructing arguments and explanations, as well as their low conceptual understanding. The low score in the self-regulation aspect of students' critical thinking skills is caused by the lack of a culture of reflection in learning, as well as the absence of explicit stimuli to assess and improve their logic or thinking strategies. The low aspects of inference, explanation, and self-regulation in the sample class were given a phase equilibrium e-book based on multiple representations that used reflective questions at the end of each topic, provided self-assessment exercises, and provided detailed formative feedback.

Before lectures began, students were given access to e-books on phase equilibrium material based on multiple representations through the Jambi University e-learning platform and were asked to read and study certain topics before face-to-face meetings took place. In lectures, students in the experimental class were given e-books on phase equilibrium based on multiple representations and studied the material interactively, noting down important concepts. Lecturers facilitated discussions based on the content of the e-books and gave students HOTS questions, such as analyzing phase diagrams or concluding the effect of pressure on boiling points. Students completed exercises based on real-life cases. At the end of the learning process, students in the experimental and control classes worked on final critical thinking questions to test the effectiveness of the e-book on phase equilibrium based on multiple representations that was used. The results of the final critical thinking skills in the experimental and control classes are presented in Table 2.

Table 2. Final Critical Thinking Skills

Critical Thinking Skill Aspects	Experimental	Control
Interpretation	87.42	81.26
Analysis	88.11	81.58
Evaluation	86.32	79.16
Inference	88.05	79.58
Explanation	88.32	81.42
Self-regulation	87.21	79.42
Average	87.57	80.40

Table 2 shows that the use of e-books based on multiple representations in the experimental class resulted in a greater improvement in critical thinking skills compared to the control class. The improvement in interpretation was demonstrated by the students' ability to read and understand information presented through various representations, such as graphs, animations, and narrative text. In addition, students are also more skilled at analyzing relationships between concepts, such as the relationship between pressure, temperature, and phase changes. Students' inferences develop because they are accustomed to drawing logical conclusions from data presented in the form of graphs or simulations. In terms of evaluation, students are beginning to be able to assess the quality of scientific arguments based on the evidence provided. Students' explanations become more logical, structured, and use appropriate scientific language. E-books encourage reflective processes by providing thought-provoking questions in each section of the learning material. Students become more active in correcting their errors in thinking and finding out why their answers are wrong. The learning process focuses not only on the results, but also on the reasons behind the answers. Thus, e-books not only convey information, but also train students to think critically in a comprehensive manner.

The improvement in critical thinking skills is also evident in changes in student learning behavior. Before using e-books, many students only read the material passively and relied on memorization. However, after using e-books, students began to actively explore each representation presented. The use of e-books equipped with navigation features can make interaction with the material more active, and the presence of images, videos, and animations can enhance understanding and provide a more in-depth learning experience (Mahfiroh & Muslim, 2023). Students discuss more often, ask questions, and connect chemistry concepts with real phenomena. Students not only answer questions, but also explain their thought processes in depth. This shows that the aspect of self-regulation in critical thinking is beginning to develop. Students become more

aware of their thought processes and try to correct them when logical errors occur. Graph-based and simulation-based exercises can help students develop evaluative and argumentative skills. Attractive and interactive visual displays motivate students to understand the material more thoroughly. Therefore, e-books become learning tools that not only convey knowledge but also shape more mature critical thinking.

The results of critical thinking skills are then tested for normality. A normality test was conducted on the difference between the initial and final critical thinking scores. The results of the normality test for the sample classes are shown in Table 3 below.

Table 3. Normality Test

Class	Significance	Description
Experimental	0.42	Normal
Control	0.30	Normal

Based on the normality test results in Table 3, the significance value is greater than 0.05 in both classes. These results indicate that the critical thinking ability data in the sample class is normally distributed. The critical thinking ability data was then subjected to a homogeneity test. The homogeneity test results are presented in Table 4.

Table 4. Homogeneity Test

Test	Significance	Description
Homogeneity	0.30	Homogeneous

Based on the results of the homogeneity test in Table 4, it shows that the significance value obtained is 0.30. These results indicate that the critical thinking ability data obtained is homogeneous data, so that parametric statistical tests can be carried out in this study. The hypothesis results in this study use ANCOVA. The data results from ANCOVA are shown in Table 5.

Table 5. Hypothesis Test

Test	Significance	Description
ANCOVA	0.30	Significant

The results of the study indicate that the use of multiple representation-based e-books on phase equilibrium material has a significant effect on improving students' critical thinking skills. These results are in line with the research (Saputra & Ramadhan, 2024) that the use of interactive e-books can improve students' critical thinking skills. This may be due to the assumption that the multiple representation approach can help students understand complex and abstract concepts more deeply (Nikat et al., 2021).

The multiple representation approach in e-books in this study provides variety in the way students process information. The material is not only presented in narrative text form, but also supplemented with graphics, diagrams, visual simulations, and problem-based exercises. This diverse representation encourages students to connect various forms of information, identify patterns, and analyze the relationships between variables in phase equilibrium systems. This cognitive process directly trains critical thinking skills, particularly in the aspects of analysis, evaluation, and inference.

Unlike the control group, which used conventional media in the learning process, students in the experimental group tended to be more active in constructing their own understanding. Learning with interactive e-books provided opportunities for students to explore concepts independently, test their understanding through simulations, and reflect on their knowledge through thought-provoking questions. This is in line with the principle of constructivism in learning, which emphasizes the importance of active learning experiences and direct involvement in constructing meaning. These results are in accordance with research Sitaresmi & Nirmalasari (2025) that the use of interactive e-books can increase independence and direct involvement in learning, thereby improving learning outcomes.

Students in the experimental group showed higher enthusiasm and motivation to learn. Students believed that e-books helped them understand the material more thoroughly and enjoyably. Interactive visualizations helped reduce cognitive load, especially in understanding microscopic representations and phase diagrams, which are usually difficult to understand through text alone. The results of this study indicate that the use of multiple representation-based e-books is effective in improving students' critical thinking skills, because this medium not only conveys information, but also challenges students to think, analyze, and draw conclusions.

Conclusion

Based on the research results, the implementation of an e-book on phase equilibrium based on multiple representations was found to have a significant effect on improving students' critical thinking skills. This was demonstrated by the results of the ANCOVA test, which yielded a significance value of 0.00 (less than 0.05), indicating a significant difference between the experimental and control classes after controlling for initial ability. Descriptively, the mean critical thinking ability increased from 72.54 to 87.57 in the experimental class, while in the control class it increased from 71.57 to 80.40. Improvements occurred across all measured aspects of critical thinking—interpretation, analysis, evaluation, inference, explanation, and self-regulation—

with greater improvements observed in the experimental class compared to the control class. Thus, multiple-representation-based e-books are effective as a learning medium for improving students' critical thinking skills in phase equilibrium material. A further recommendation from this study is that multiple-representation-based e-books can be used as an alternative learning medium for abstract chemistry material, and future research is suggested to test this on other topics or with a larger sample size.

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All authors declare that there is no conflicts of interest.

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