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Effectiveness of a STEM-Based High School Chemistry Textbook with Scaffolding Strategy to Improve Students' Critical Thinking Skills

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Abstract: This study aims to explain the effectiveness of STEM-based high school chemistry textbooks with scaffolding strategies to improve critical thinking skills. This type of research involved research and development by adapting the Borg and Gall development models. The research instrument used was a critical thinking essay test. The research subjects were students of class XI A SMA Negeri 3 Singaraja. The research design used was a pre-experimental with one-group pretest-posttest design. The data were analyzed using a normalized gain score and a one-sample proportion test. The results showed that the n-gain score obtained was 0.56. The one-sample proportion test results showed a significance value of 0.001. Thus, a STEM-based high school chemistry textbook with a scaffolding strategy is effective in improving students' critical thinking skills.

Keywords: Chemistry; Critical thinking skills; Scaffolding; STEM; Textbooks

Introduction

The ability to think critically is necessary for project management, issue-solving, and making wise judgments with a variety of tools (Fullan & Langworthy, 2014). Critical thinking skills are the most needed by 21st-century individuals (Ganira, 2022; Hacioglu & Gulhan, 2021). In this era, life requires individuals to switch from only passively receiving information to becoming active thinkers who can solve problems that exist in society (Fazylova & Rusol, 2016).

Indonesian students' critical thinking skills were still quite low. This may be observed from the 2018 PISA (Program for International Students Assessment) results, which showed that the average ability of Indonesian students in reading, mathematics, and science was below the average ability of students from other countries that were members of PISA (OECD, 2019). In addition, the results of the latest release of PISA data in 2022 revealed that Indonesian students' abilities in reading, math, and science had decreased compared to PISA data in 2018 (OECD, 2023) . Meanwhile, Priyadi et al. (2019) found that students' critical thinking skills remained relatively low, particularly in the evaluation category. That research found students could solve calculation problems but were unable to interpret the calculation results.

The causes of students' low critical thinking skills include: (1) the practice questions presented by teachers still do not meet the criteria; (2) students are less actively involved in building their knowledge; and (3) students' learning habits tend to be passive (not questioning more deeply the explanation given by the teacher) (Setianingsih & Roshayanti, 2022). In addition, Priyadi et al. (2019) reported that students are not used to applying the concepts learned to real-life problems.

The government has made efforts to overcome this issue. Recently, the Indonesian government has changed the 2013 curriculum to the independent curriculum (Kepmendikbudristek, 2022). Improving educational quality through the implementation of an independent curriculum must be bridged with learning aids such as

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books that conform to curriculum criteria. The government has a mandatory book for use by educational institutions. However, it does not rule out the possibility that teachers can use other relevant books. Teachers can also build books based on the qualities and requirements of the students (Kemendikbudristek, 2022).

Textbooks are valuable learning aids that serve not only as instructional guides for teachers but also as tools for students to shape their thinking patterns (Sumarni & Supanti, 2021). The use of textbooks allows students to learn competency coherently, provides orientation regarding the material being taught, and facilitates exercises and activities for students so that students are accumulatively able to master all competencies in a complete and integrated manner (Shehab & BouJaoude, 2017).

An initial study at SMA Negeri 3 Singaraja class XI for the 2022–2023 academic year found that chemistry teachers and students were using translated chemistry textbooks that were not in accordance with the independent curriculum. Teachers complained about the disjointed presentation structure and disorganized distribution of material. This caused students to have difficulty understanding concepts, following the learning flow, and learning independently. The limited variety of chemistry textbooks that are in accordance with the independent curriculum also makes it difficult for teachers to choose learning materials.

Meanwhile, literature studies showed that the chemistry books used by teachers have a simple presentation and are less able to provide training to develop critical thinking skills (Permatasari et al., 2019). Furthermore, according to Salim et al. (2019), several chemistry books are prepared with simple statements that do not stimulate students' critical thinking. These books generally present questions in the cognitive understanding dimension and lack a specific structure to help students build critical thinking.

Other researchers have done a lot of development research. One of them is research by Priyatni et al. (2020), who reported that the development of a chemistry digital book on inquiry-based acid-base titration material is suitable for use in chemistry learning. However, that study could not demonstrate the benefit of books in enhancing critical thinking skills. These books were developed digitally, so students are not free to access them because they require an internet network. Students who are more comfortable reading printed books are less well facilitated. This is not consistent with the needs of the independent curriculum, which requires customized learning based on student characteristics. Innovations in textbook development that can be carried out are the application of the STEM approach and scaffolding strategies in books. STEM is an approach that integrates science, technology, engineering, and mathematics into learning (DeJarnette, 2018). Sanders in Wolfmeyer et al. (2015) explains that science helps students develop an interest in and understanding of the world, as well as collaboration and experimentation skills. Technology involves the application of computational knowledge to meet human needs. Engineering is the skill of designing solutions to real-world problems. Mathematics provides analytical skills, problem-solving, and an understanding of the world through modeling (Khairiyah, 2019).

STEM learning can help students develop critical thinking abilities (Ananda et al., 2023; Hacioglu & Gulhan, 2021; Topsakal et al., 2022). Other researchers who investigated the development of STEM-based teaching materials reported that STEM teaching materials received a good response from teachers and students (Asih et al., 2020; Irmita, 2018; Izza et al., 2023). STEM-based teaching materials can also improve student's mastery of concepts, problem-solving, and critical thinking abilities (Ananda et al., 2023; Hidayatulloh et al., 2020; Khairati et al., 2021; Pangesti et al., 2017; Paramita et al., 2021; Purnamasari et al., 2020).

Adding scaffolding strategies to STEM-based textbooks will provide the latest innovations in developing learning materials. Wood et al. in Bakker et al. (2015) stated that the scaffolding strategy is a learning strategy that helps students in the early stages and then reduces this assistance until students can independently solve problems. Scaffolding strategies have also been demonstrated to boost students' critical thinking (Miatun & Khusna, 2020).

Badri et al. (2019) showed that interactive instructional materials with metacognitive scaffolding for students' mathematical thinking and reflective skills have very good qualifications, with a percentage of 85.6%. The development of textbooks with scaffolding strategies is still limited. Teachers generally use scaffolding strategies to improve the learning process in the classroom. Recent research indicates that incorporating scaffolding strategies into educational materials is beneficial. One example is the scaffolding based LKPD developed by Pratama et al. (2019). These LKPD can be used to train students' understanding of concepts in heat material (Pratama & Saregar, 2019).

Analysis of the class XI Chemistry book showed that the book already contains STEM elements. However, the distribution of the emergence of each STEM component is still not evenly distributed. Anggraini et al. Nurita (2021) stated that although there is no limit to the percentage of STEM components in a book, it would be better if the four STEM components had the same percentage in the book. Meanwhile, the scaffolding aspect of the book is still not visible.

According to the description above, this research carried out the development of a STEM-based high school chemistry textbook with a scaffolding strategy to improve critical thinking skills. This research aims to explain the effectiveness of STEM-based high school chemistry textbooks with scaffolding strategies in improving students' critical thinking skills.

Method

The kind of research was research and development. The product of this research is a STEM-based high school chemistry textbook with a scaffolding strategy. This research adopted the Borg and Gall development model, which only took seven steps, including research and information gathering, planning, initial product development, preliminary field tests, main product revision, main field test, and operational product revision. The effectiveness test was carried out at the main field test stage. Research designed to test effectiveness used pre-experimental with a one-group pretest-posttest design. The effectiveness test was carried out in class XIA of SMA Negeri 3 Singaraja. The number of class XIA students involved was 29 students.

The research instrument used a critical thinking skills test with 12 essay questions. The critical thinking skills test used consists of five main indicators. The critical thinking skills test indicators used in critical thinking skills, according to Ennis (1985), included basic clarification, basic support, inference, advanced clarification, and strategies and tactics. The content validity, item validity, reliability, and level of difficulty of the critical thinking skills test were tested before the test was used. The test result showed that 12 questions were valid. The test has a reliability of 0.861 in the high category and has a difficulty level consisting of 3 easy questions, 5 medium questions, and 4 difficult questions.

The research analysis techniques used were descriptive and inferential. Descriptive analysis was carried out by presenting pretest and posttest scores, n-gain scores, and critical thinking skills profiles. The criteria for obtaining an n-gain score are grouped into three categories, as shown in Table 1.

Table 1. N-gain Score Criteria

N-gain Score	Criteria
N-gain > 0.70	High
0.70 ≥ N-gain ≥ 0.30	Medium
N-gain < 0.30	Low

The book was considered effective if the minimum n-gain score was in the medium range. Meanwhile, the critical thinking skills profile was classified according to Table 2.

Table 2. Critical Thinking Skills Profile Category

Percentage (%)	Category
86 – 100	Very good
76 – 85	Well
60 – 75	Enough
55 – 59	Not Enough
≤ 54	Very Less

The inferential analysis used was a one-sample proportion test. A sample proportion test was performed to evaluate the following hypothesis:

H_0: STEM-based high school chemistry textbooks with scaffolding strategies are not effective in improving critical thinking skills.

H_a: A STEM-based high school chemistry textbook with effective scaffolding strategies to improve critical thinking skills.

The proposed hypothesis was tested at a significance level of 5% with a π value of 75. A π value of 75 was used to refer to the lower limit of the Learning Objectives Completeness Criteria (KKTP) set by teachers at the school. In the one-sample proportion test, H_0 was rejected if the significance value was <0.05, while H_0 was accepted if the significance value was >0.05.

Result and Discussion

The effectiveness test consists of six meetings, namely one pretest meeting, four in-class learning meetings, and one posttest meeting. The effectiveness test began with giving a pretest to students. Then proceed with the application of the book. The textbooks used in the effectiveness test were valid and practical. The effectiveness test was carried out in one chapter of this book. That chapter is on hydrocarbons. Learning activities took place face-to-face. Finally, the effectiveness test was closed by giving a posttest to students. A summary of the effectiveness test results is presented in Table 3.

Table 3. Pretest and Posttest Results

Descriptive Data	Pretest	Posttest
Average Value	56.44	81.84
Lowest Value	38.78	69.39
The Highest Score	69.39	91.84
N-gain Score		0.57 (Medium)

Table 3 shows the average n-gain score of 0.57 in the medium category. These results indicated that STEM-based high school chemistry textbooks with scaffolding strategies were effective in improving students' critical thinking skills. Next, the posttest scores were analyzed using a one-sample proportion test to test the proposed hypothesis. The normality test was required as a prerequisite for the one-sample proportion test. The

normality test used was Shapiro-Wilk. Normality test and one-sample proportion test using the SPSS application. In the normality test, a significance value of 0.107 was obtained. This result was greater than the significance level of 0.05. This shows the posttest scores of students' critical thinking skills have a normal distribution, allowing the one-sample proportion test to proceed. The results of the one-sample proportion test can be found in Table 4.

Table 4. One Sample Proportion Test

		Category	N	Asymp. Sig. (2-tailed)
Posttest	Group 1	<=75	5	0.001[a]
	Group 2	>75	24	
	Total		29	

Table 4 shows a significance value of 0.001. The significance value is smaller than 0.05, so H_0 was rejected, or H_a was accepted. Thus, it can be stated that STEM-based high school chemistry textbooks with scaffolding strategies were effective in improving students' critical thinking skills. The results of the one-sample proportion test also showed that 24 students got a score greater than the KKTP with a classical completion percentage of 83%. However, as many as five students still got scores less than or equal to the KKTP.

The effectiveness of STEM-based high school chemistry textbooks with scaffolding strategies in improving thinking skills can be explained for several reasons. The integration of STEM activities in the book provides experimental and practical experiences for invited students to participate in physical activities that trigger critical thinking. Through this approach, textbooks not only function as a source of information but also as a tool for developing essential critical thinking skills for students. This is consistent with the opinion of Baharin et al. (2018), which stated that STEM emphasizes activities that involve problem-solving through investigative activities. STEM learning can provide opportunities for students to solve surrounding problems through the concepts and knowledge they have by trying new things to face new challenges (Linder et al., 2016). Several studies have also found that STEM learning has been proven to be able to shape students' critical thinking skills (Maskur et al., 2022; Parno et al., 2021; Prastika et al., 2022).

This result aligned with research by Paramita et al. (2021), which showed that the STEM-based digital teaching materials developed have been able to improve students' critical thinking skills in physics instrumentation material. In addition, research by Pangesti et al. (2017) reported that STEM-based teaching materials were able to increase high school students' mastery of concepts. The development of STEM-based chemistry textbooks can also be used to improve students' problem-solving abilities (Hidayatulloh et al., 2020).

Meanwhile, the scaffolding aspect can be seen in the presentation of material in the book, which was prepared considering the zone of proximal development's student. Such a presentation can increase students' self-confidence in facing learning challenges. The scaffolding integrated into the book not only provides initial support according to the learner's level of understanding but was also designed to gradually reduce that support as the complexity of the material increases. Providing a sequence of practice problems from the lowest to the highest difficulty levels in the book was able to present thinking tasks that were suited to students' abilities and encouraged students to grow and strengthen critical thinking skills throughout their learning. This was in accordance with the basic scaffolding theory. Scaffolding is based on Vygotsky's zone of proximal development theory. According to this theory, learning occurs when students work on or manage tasks that have not yet been learned, but these tasks are still within students' reach (Trianto, 2007). Scaffolding, in this context, creates support appropriate to the zone of proximal development.

The research findings by Sunaryo et al. (2019) support the effectiveness of scaffolding in chemistry learning. That research indicated that scaffolding learning enhances critical thinking skills in comparison to traditional learning. Cahyono et al. (2021), Miatun et al. (2020) reported that scaffolding is a learning strategy that can be used to improve students' critical thinking skills. Overall, combining STEM learning with scaffolding strategies in high school chemistry textbooks forms an innovative and effective approach to improving students' critical thinking skills.

The number of students who received n-gain scores in the low, medium, and high categories was also requested. The study's findings revealed that 2 students who received n-gain scores were in the low category (6.90%), 14 students in the medium category (48.28%), and 13 students in the medium category (44.83%). That variation was attributed to multiple factors, including variations in students' initial abilities, their level of engagement and discipline in learning participation, and their familiarity with addressing complex problems. The success of scaffolding is greatly influenced by determining the zone of proximal development, namely combining students' initial abilities by looking at previous learning outcomes. This will affect the amount of assistance that teachers must provide to students.

Meanwhile, the profile of students' critical thinking skills is shown in Figure 1. Figure 1 shows that there was an increase in students' critical thinking skills in all indicators after learning with the STEM-based high school chemistry textbooks with scaffolding strategies.

First, the indicator of elementary clarification increased from the previous 67% (enough) to 91% (very good). Furthermore, there was an increase in the indicator of basic support from 57% (not enough) to 86% (very good). Students also succeeded in improving their skills in indicators of inference from 54% (not enough) to 83% (well). There was a significant increase in the advanced clarification indicator sufficient from 34% (not enough) to 61% (enough). Finally, the score on the strategy and tactics indicator increased from 65% (enough) to 83% (well). Higher post-test results on each indicator provide a positive picture of the effectiveness of the book in improving students' critical thinking skills.

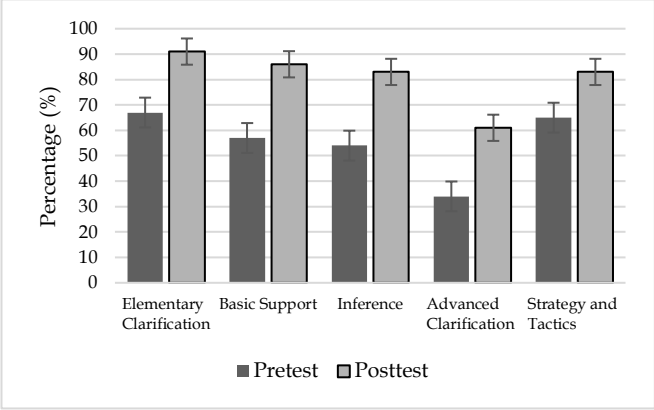

Figure 1. Student critical thinking skills profile graphic

However, the minimum increase occurred in the strategy and tactics indicators, with an increased range of 18%. That can be caused because students face challenges in generating fresh ideas for problem-solving, a difficulty influenced by their established problem-solving habits. The indicator of advanced clarification obtained the smallest posttest percentage, namely 61% in the enough category. That can be caused by several factors, such as the student's initial level of understanding and the complexity of the material. These findings were in accordance with the research results of Setianingsih et al. (2022), Priyadi et al. (2019), who stated that students' learning habits tend to be passive, are less actively involved in building their knowledge and are not used to applying concepts to real-world problems, causing the achievement of critical thinking skills to be less than optimal.

There have been several obstacles encountered in this research. The design of learning asked students to complete one project at each meeting. However, it turns out that this was too burdensome for students. To overcome this, tasks were divided into large groups. Some assignments also cannot be completed during class meetings due to lack of time, so students have taken the assignments home. This means that teacher control over completing assignments cannot be carried out fully.

Some students did not make maximum use of the features in textbooks, so the advantages of the book cannot be fully obtained. Some students also seemed less enthusiastic about reading and watching the work instruction videos that had been provided. Students tend to ask the teacher directly when they experience difficulties. This problem occurred due to the lack of discipline and self-confidence of students in the learning process. Such study habits can hinder the achievement of independent learning goals. Therefore, the teacher's role is needed in adjusting learning strategies such as holding personal guidance sessions, providing positive reinforcement for students' efforts, and presenting learning situations that support active involvement. A teacher can motivate students by showing them the direct benefits of using books, such as increasing their understanding of concepts. This aims to achieve learning objectives and improve critical thinking skills.

Conclusion

STEM-based high school chemistry textbooks with scaffolding strategies were considered effective to improve students' critical thinking. The results of the n-gain score showed an average n-gain score of 0.57 in the medium category. In addition, the results of the one-sample proportion test obtained a significance value of 0.001. This value was smaller than 0.05, so Ha was accepted, which means that the STEM-based high school chemistry textbook with scaffolding strategies was effective in improving students' critical thinking abilities. The results of the pretest and posttest scores showed an increase in all indicators of critical thinking skills after learning from the book. Suggestions for students who use textbooks as a learning resource are to actively read, be involved in every activity presented in the book, and build self-confidence in solving problems so that the book can effectively improve students understanding of chemical concepts and critical thinking skills. Teachers also need to provide high motivation when students lose self-confidence, but teachers should also refrain from providing excessive assistance so that students can be independent in their learning.

Author Contributions

Conceptualization, K. D. L, I. N. S, I. B. P. M.; methodology, K. D. L, and I. N. S.; validation, I. N. S, and I. B. P. M.; formal analysis, K. D. L, I. N. S, I. B. P. M.; investigation, K. D. L.; resources, I. N. S, I. B. P. M.; data curation, I. N. S.: writing—original draft preparation, K. D. L.; writing—review and editing, I. N. S.: visualization, K. D. L. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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