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Author for correspondence:
Ahmad Tawalbeh
tawalbeh.ahmad92@gmail.com
Yarmouk University, Irbid, Jordan

The Effectiveness of Using the Educational Scaffolding Model in Teaching Chemistry on The Development of Critical Thinking Among 9th Grade Students

Ahmad Tawalbeh, Abdullah Khataybeh

Abstract

Background/purpose. The study aimed to investigate the effectiveness of using the educational scaffolding model in teaching chemistry on the development of critical thinking among 9th-grade students. Since the traditional teaching method in chemistry may hinder students' ability to apply scientific concepts in various situations, thereby affecting the development of their critical thinking, this research aims to develop critical thinking among ninth-grade students by teaching chemistry using educational scaffolding.

Materials/methods. This study adopted the experimental approach with a quasi-experimental design. The sample was randomly selected and comprised 50 male and female students, evenly distributed across two groups from Osarah Secondary School and Baoun Secondary School, both affiliated with the Directorate of Education in Ajloun Governorate. The study included one tool, which is a critical thinking skills test.

Results. Results indicated that the experimental group using an educational scaffolding model significantly outperformed the control group in critical thinking skills tests. Statistically significant improvements were observed in overall scores and in specific sub-skills: deduction, interpretation, and evaluation, while prediction showed the least improvement. These findings confirm the effectiveness of the scaffolding model in enhancing students' critical thinking abilities.

Conclusion. The study revealed notable variations in critical thinking skills, with the experimental group benefiting significantly from a supportive, interactive learning environment. The educational scaffolding model, used in teaching Metal reactivity, focuses on higher-order thinking skills. The study recommends incorporating this model into the curriculum, redesigning teaching plans, and preparing specialized training programs.

1. Introduction

Teaching chemistry at the primary level poses significant challenges due to its abstract nature, which demands deep understanding, scientific reasoning, and critical thinking skills. It necessitates teaching models that extend beyond memorization to include experimentation and a connection between theory and practice. Recent educational trends emphasize interactive models that engage learners in building their knowledge and enhancing their independence in learning, notably the scaffolding model, which provides gradual support to learners, contributing to improving their academic achievement and developing their higher-order thinking skills.

This study aims to examine the effectiveness of the educational scaffolding model in teaching chemistry and in developing critical thinking skills among ninth-grade students.

The scaffolding model is an application of constructivist theory, emphasizing that knowledge is reconstructed through interaction with the learning environment rather than transferred directly. It involves providing gradual support to students, which is decreased over time as they develop the ability for independent learning, drawing on Piaget's and Vygotsky's theories (Piaget, 1970; Vygotsky, 1978). Vygotsky's social learning theory highlights the zone of proximal development, the gap between what learners can do alone versus with support from more experienced individuals. The scaffolding approach focuses on targeted assistance during learning, progressively fading this support as learners achieve independence in knowledge acquisition, as outlined by Wood, Bruner, and Ross (1976).

Instructional scaffolding is an effective tool for supporting student learning, providing students with the guidance they need to acquire knowledge and understand scientific phenomena in ways that suit their different abilities. As Davis (2019), Aikhuele (2020), and Walqui (2006) point out, the diversity of educational scaffolding makes it more adaptable to learners' needs, thereby enhancing their learning and developing skills in a sustainable manner.

Instructional scaffolding has a set of characteristics that make it an effective tool for enhancing learning. Providing appropriate information and guidance to learners enhances their comprehension and understanding of the course material. There are a set of characteristics that distinguish educational scaffolding, the most important of which are: providing clear instructions to learners; clarifying the goal of learning, which helps them understand the subject and its requirements; supporting the continuity of learning by guiding learners toward completing the required tasks; enhancing the ability to predict and anticipate by posing stimulating questions; and reducing knowledge gaps and meeting students' learning needs (Azih, Nwosu, 2011; Van de Pol et al., 2019).

2. Theoretical Framework

Instructional scaffolding, as classified by Al-Hulahil (2024), consists of five primary types: Strategic scaffolding involves cognitive and non-cognitive methods introduced gradually by the teacher to assist learners in tasks and problem-solving. Process scaffolding provides guidance for learners to enhance their understanding through information search. Procedural scaffolding clarifies the steps needed to acquire concepts or skills. Conceptual scaffolding utilizes visual aids or tools to help classify and label concepts. Lastly, metacognitive scaffolding helps learners reflect on their problem-solving through strategies such as planning, organizing, self-reflection, and evaluation. This teaching approach, rooted in constructivist theory, gradually helps learners bridge the gap between existing and new knowledge, effectively fostering critical thinking and facilitating the reorganization of their understanding based on prior knowledge.

The scaffolding model is an educational method designed to help learners transition from their existing knowledge to new knowledge. This approach offers temporary support that is gradually diminished, allowing learners to become independently capable of problem-solving based on their experiences. Rooted in constructivist theory, the model emphasizes active cognitive support, facilitating the construction of new understandings and the reorganization of existing knowledge. According to Wood, Bruner, and Ross, educational scaffolding is a supportive process that enables learners to execute tasks they cannot complete alone. Its objectives include enhancing learners' mental and intellectual capabilities, fostering connections between disparate ideas, and cultivating critical, analytical, and logical thinking. Ultimately, it empowers learners to develop innovative solutions and creatively address complex challenges (Wood, Bruner & Ross, 1976; Mulder et al.,2016; Ernawati, 2022).

Modern educational trends prioritize student-centered learning, emphasizing the social aspects of education and the advantages of diverse learning resources. Educational scaffolding is highlighted as an effective teaching strategy in chemistry, enhancing students' scientific knowledge and critical thinking (Van Uum et al., 2017). Studies indicate that this model improves student engagement by fostering investigative thinking and facilitating access to abstract concepts through discussion and collaboration. Ultimately, it enriches problem-solving capabilities and the ability to articulate chemical phenomena.

Regarding the teacher's role in effectively employing educational scaffolding, several researchers (Shanmugavelu et al., 2020; Guo et al., 2023) have identified a set of tasks that teachers must perform to ensure its effectiveness. These include: selecting appropriate questions that align with the curriculum objectives and students' needs; setting a clear goal for each question to make students more motivated and engaged in learning; directing questions to suit students' cognitive levels to ensure they grasp abstract concepts; providing appropriate feedback to help students build a deeper understanding of the material; and encouraging students to think critically by monitoring the development of their responses and measuring the extent to which educational objectives are achieved.

The importance of the educational scaffolding model lies in its ability to enhance basic science process skills, which include observation, classification, inference, prediction, and the use of spatial and temporal relationships. These skills help students approach scientific phenomena with greater precision and systematicity, enabling them to analyze data and draw logical conclusions (Al-Shakkah, 2019).

Critical thinking is defined in the study by Metwally et al. (2023) as a mental process that analyzes and evaluates ideas and opinions objectively, free from the influence of emotions or personal biases. It requires the use of organized thinking tools such as inference, interpretation, and analysis to reach correct conclusions. Critical thinking is characterized by several key skills: analysis, which involves breaking down complex information; evaluation, assessing the validity or accuracy of information; interpretation, understanding information in context; reasoning, using evidence to reach conclusions; and Flexibility, to ability to change one's mind based on new information or convincing evidence (Ennis, 2018).

Among the most prominent studies that addressed the topic of educational scaffolding and emphasized its effectiveness, Al-Sayed's (2019) study demonstrated that the educational scaffolding model contributes to developing analytical thinking skills and scientific awareness among middle school students Al-Awaid’s (2020) study emphasized the need to adopt models based on constructivist models, such as educational scaffolding, which may contribute to enhancing the comprehension of scientific concepts and developing learners' critical thinking skills.

The National Science Education Standards and the National Science Teacher Association have emphasized the importance of enabling students to understand the nature of science, acquire scientific concepts, and develop their skills in various scientific processes. Educational studies indicate that difficulties in learning chemistry are related to several factors, including abstract chemical concepts, weak connections to practical applications, and the adoption of traditional teaching methods that do not account for individual differences among learners (Khawaji, 2022).

This traditional teaching approach, which focuses primarily on specific aspects such as memorization and retrieval, may pose challenges for students' ability to connect scientific concepts and apply them in diverse situations. This may indirectly affect the development of certain skills, including critical thinking, which may in turn affect their readiness to acquire more advanced skills in the future. As (Alsafasfeh, Alsmadi, 2025), after publishing Jordan's results in the TIMSS (2023) Trend in International Mathematics and Science Study, Jordan ranked sixth, especially in science, at the level of the participating Arab countries, which numbered (8) countries, and ranked 53rd out of 65) countries participating in the study.

The study emphasizes both theoretical and practical significance regarding the educational scaffolding model in teaching chemistry. Theoretically, it contributes to the educational literature by exploring the relationship between this model and the development of critical thinking skills among ninth-grade students, framed by Vygotsky's theory (Vygotsky, 1978). In practice, it offers a test to assess critical thinking skills, encouraging chemistry teachers to use the educational scaffolding model. This approach promotes active learning and self-reflection, providing educators with resources and training to enhance the teaching of the Metals' reactivity unit.

There is a need to investigate the effectiveness of the educational scaffolding model in teaching chemistry to enhance critical thinking skills in ninth-grade students. This research compares outcomes for students taught with this model with those taught using traditional methods. Observations from a Jordanian chemistry classroom indicate that many students struggle with critical thinking, problem-solving, and the application of reasoning in chemistry. Additionally, current teaching practices may contribute to poor academic performance by emphasizing memorization over a deep understanding of scientific concepts and inquiry.

Therefore, the need arose to employ modern teaching models to raise academic achievement and develop critical thinking and problem-solving skills among students. This study was conducted to assess the effectiveness of the educational scaffolding model in teaching chemistry in developing and enhancing critical thinking and problem-solving skills among ninth-grade students.

The purpose of this study is to assess the effectiveness of the educational scaffolding model in enhancing critical thinking skills in ninth-grade chemistry students. It sought to answer a pivotal question regarding the impact of this model compared to traditional teaching methods. The hypothesis posited that there would be no statistically significant differences ($\alpha = 0.05$) in the critical thinking skill scores between these two groups, which led to the evaluation of arithmetic means and standard deviations from both pre- and post-tests of the experimental group (using the scaffolding model) and the control group (using traditional methods).

3. Literature Review

An in-depth review of past studies has been conducted to examine the effectiveness of the educational scaffolding model in chemistry teaching, with a focus on its impact on students' critical thinking development. The review emphasizes the model's role in improving students' learning patterns, specifically within the context of chemistry education. The analyzed studies are organized chronologically from the oldest to the most recent.

3.1. The effectiveness of the educational scaffolding Model and its impact on various variables

In a study conducted by Mohammed (2019) in a secondary school in Nigeria, the effect of educational scaffolding on the development of deductive skills among biology students was investigated. The study used a quasi-experimental design, with 80 students divided into two groups: the experimental group (40 students) received instruction supported by educational scaffolding, and the control group (40 students) received instruction using conventional methods. The researchers used analytical tests to measure students' deductive skills before and after the intervention, in addition to questionnaires to gather students' opinions on the approach's effectiveness and interviews with teachers to explore the impact of the model on teaching methods. The results showed that the experimental group made significant progress in deduction skills compared to the control group, indicating the potential impact of educational scaffolding on the development of analytical thinking among students.

Szalay et al. (2023) conducted a study to identify the effect of educational scaffolding on students' performance in chemical experiments. The study used a quasi-experimental approach with a longitudinal research sample that lasted 4 years to develop experimental design skills. Nine hundred and thirty-one (931) students participated in the study, all of whom were between 12 and 13 years old at the beginning of the study (September 2021) in Manhattan, USA. ANCOVA analysis showed that these effects are due to a set of factors (most importantly, educational scaffolding and prior knowledge) in developing students' ability to conduct experiments in chemistry.

3.2. Educational scaffolding Model and its impact on critical thinking skills

Youssef (2016) conducted a study to examine the interaction between the educational scaffolding model and critical thinking, and its impact on achievement and mathematical self-efficacy among students in the College of Education specializing in the first grades. The study used a quasi-experimental design, and the sample consisted of 58 students at the College of Education specializing in first grades in Dammam, of whom 28 were in the experimental group and 30 in the control group. The researcher used an achievement test and a mathematical self-efficacy scale as tools for the study. The results showed the effectiveness of the educational scaffolding model in developing achievement and raising mathematical self-efficacy, the effect of the level of critical thinking on achievement and the level of mathematical self-efficacy, and the presence of a statistically significant interaction between the educational scaffolding model and the level of critical thinking on achievement and mathematical self-efficacy.

Al-Sayed (2019) conducted a study to identify the effect of using educational scaffolding models based on the self-regulation model to develop analytical thinking skills and scientific sense in the science subject among middle school students. The study used the quasi-experimental approach. The study sample consisted of 62 male and female students from the second year of middle school at the Arab National School in Sharkia Governorate. The researcher prepared two tools for the study: the analytical thinking test and the scientific sense scale. The results showed statistically significant differences for the analytical thinking test and the scientific sense scale in favor of the experimental group that studied using educational scaffolding.

Alrawili et al. (2020) conducted a study to explore the impact of scaffolding strategies on HOTs among intermediate science students in the Kingdom of Saudi Arabia. To achieve the research objective, a quasi-experimental design was used, with multiple-choice questions distributed across four skills: application, analysis, evaluation, and creativity. The total number of research students was 84 ninth-grade students who sat for the pre- and post-tests. A convenience sample was chosen as a sampling method that typically fits both the experimental group (42 students) and the control group (42 students). Statistical metrics indicated a notable increase in post-test scores: the experimental group ($M = 11.50$, $SD = 3.63$) outperformed the control ($M = 9.59$, $SD = 3.69$) following the application of scaffolding strategies, with pre-test averages being $M = 10.09$ ($SD = 3.83$) for the former and $M = 10.54$ ($SD = 3.76$) for the latter. The results showed that scaffolding strategies had a statistically significant impact on the four skills. This research could contribute to improving students' active learning skills when scaffolding strategies are applied in science classes. From a research perspective, it will serve as a reference for researchers interested in scaffolding strategies in the Kingdom of Saudi Arabia and other countries.

Al-Anwar et al. (2024) conducted a study in Egypt that revealed enhanced scientific and life skills among first-grade secondary school students through the implementation of educational scaffolding. The study was conducted with a group of Azhari students enrolled at Hussein Rushdie Girls Secondary Institute. To evaluate the effectiveness of this educational strategy, a scientific thinking skills test and a life skills scale were administered to the participants both before and after the application of educational scaffolding. The results demonstrate a significant improvement in performance for the experimental group, with the statistical measurement "T" values recorded at 8.962 for scientific thinking skills and 48.682 for life skills. The impact of the educational scaffolding on scientific thinking skills is represented by an ETA squared value of 0.93, while for life skills, the ETA squared value is 0.95. These findings confirm the effectiveness of educational scaffolding in biology instruction in fostering the development of scientific thinking and essential life skills among first-grade secondary students.

Yana et al. (2025) conducted a study in Indonesia at a high school to determine how the instructional scaffolding system affects high school students' scientific thinking when integrated into inquiry-based flipped physics classrooms (E-IFPC) compared with non-inquiry flipped physics classrooms (IFPC). This study is a quasi-experimental educational research. Students' scientific thinking was assessed using a two-level scientific reasoning test on a sample of 90 students. The results showed significant differences in scientific thinking between the E-IFPC and IFPC groups. Students in the instructional scaffolding group showed a gain score of 0.43, approximately 5 times higher than the 0.09 observed in the regular group. This contributes to the field of physics education by providing empirical evidence on the impact of instructional scaffolding on high school students' scientific thinking in physics, especially in the context of post-pandemic learning innovations.

The study contributes to science education by demonstrating the effectiveness of the educational scaffolding model in enhancing critical thinking skills among ninth-grade chemistry students in Jordan. It shows a significant effect ($\eta^2 = 0.525$) on students' abilities to infer, evaluate, and predict scientific phenomena. Unlike previous studies focused on general science or mathematics, this research specifically applies scaffolding to the "Metal Reactivity" unit in chemistry. It details how scaffolding techniques can be integrated into complex subjects, fostering a dynamic learning environment through multimedia tools, group inquiry, and tailored teacher support. Finally, it proposes a contextually adapted scaffolding implementation model for Jordanian public schools, providing a framework for teachers and curriculum designers to improve science teaching.

4. Methodology and design

To achieve the study objectives, a quasi-experimental design was implemented involving two groups: an experimental group and a control group. The study sample was created using a readily available sampling method, with teaching methods randomly assigned. A critical thinking skills test was applied to both groups prior to the intervention. The experimental group received instruction through the educational scaffolding model, while the control group was taught using a traditional method.

4.1. Study Population

The study population comprised all ninth-grade students at public boys' schools affiliated with the Ajloun Governorate Education Directorate during the second semester of the 2024/2025 academic year. According to statistics from the Directorate's Planning Department, the study population totalled 1,746 students. The sample was intentionally selected.

4.2. Study Sample

The study participants were selected from ninth-grade students at Baoun Secondary School for Boys, affiliated with the Ajloun District Education Directorate, during the second semester of the 2024/2025 academic year. This semester marked a significant turning point, as chemistry was being taught independently from other scientific subjects such as physics, earth science, and biology. A total of 50 students were divided into two groups. One group, consisting of (25) students, was randomly selected as the experimental group (taught using a scaffolding model), while the other group, also consisting of (25) students, served as the control group (taught using the traditional method).

Baoun Secondary School for Boys was chosen for a study due to its readiness and available resources. Fifty students were selected based on inclusion and exclusion criteria, including regular attendance and lack of experience with scaffolding methods. Students were randomly assigned to a control group using conventional instruction and an experimental group using an educational scaffolding model. A pre-test showed no significant differences in critical thinking and chemistry readiness between the groups, although the control group had slightly higher mean scores. To mitigate readiness impacts, the experimental group received pre-intervention training, with these limitations addressed in the study's limitations section.

4.3. Study tool

Critical Thinking Skills Test

A critical thinking skills test for ninth-grade students in the "Metal reactivity" unit of the chemistry textbook was developed in its initial form, consisting of 25 items, according to the following steps:

- A number of previous studies and research papers addressing critical thinking skills were reviewed.

- Determining the objective of the test: to measure the level of critical thinking skills (inference, prediction, evaluation, deduction, and interpretation) among ninth-grade students.

- Preparing the test specifications table and relative weights by analyzing the content of the study topics in the "Metal reactivity" unit included in the ninth-grade chemistry textbook to determine the concepts contained in the content.

- Formulating objective multiple-choice questions covering the subject matter, totaling 25 items, each with four answer options, distributed across five areas: inference, prediction, evaluation, deduction, and interpretation.

Critical Thinking Skills Test Validity

The apparent validity of the Critical Thinking Skills Test was verified by presenting it in its preliminary form to a group of specialized arbitrators from Jordanian university faculty members from various disciplines in curricula, science teaching methods, measurement, and evaluation, in addition to 10 science teachers and supervisors from the Ministry of Education in the Hashemite Kingdom of Jordan. The aim was to express their opinions on the validity of the test's content and its suitability for the study's target sample in terms of: the degree to which the item measures the trait, the clarity of the linguistic formulation of the items, and the addition, modification, or deletion of any areas or items they deemed appropriate. In light of the arbitrators' observations, the linguistic formulation of paragraphs (16, 9, 7, 4, 2) was modified, and the standard adopted for accepting or excluding paragraphs was that the paragraphs obtained the arbitrators' consensus at 80%. Thus, the test after arbitration consisted of 25 paragraphs, distributed over five areas, which are: inference, which has 5 paragraphs; prediction, which has 5 paragraphs; evaluation, which has 5 paragraphs; deduction, which has 5 paragraphs; and interpretation, which has 5 paragraphs.

Difficulty and Discrimination Coefficients for Critical Thinking Skills Test Items

The difficulty and discrimination coefficients for the test items were calculated to determine their degree of difficulty and discriminating power. The test was administered to a pilot sample from within the study community and from outside the sample, totaling 20 ninth-grade students at Osarah Secondary School for Boys, as shown in Table 1, using the following equations:

$$Difficulty\ factor = \frac{Total\ marks\ obtained\ for\ the\ question\ (item)}{(Number\ of\ students\ x\ question\ mark)} \times \%100$$

$$discrimination\ coefficient = \frac{Total\ marks\ for\ the\ upper\ category\ on\ the\ question - Total\ marks\ for\ the\ lower\ category\ on\ the\ question}{Number\ of\ students\ in\ one\ class \times question\ mark} \times \%100$$

Table 1. Difficulty and discrimination coefficients for the critical thinking skills test items

Paragraph number	Difficulty factor	Discrimination factor	Paragraph number	Difficulty factor	Discrimination factor
1	0.65	0.51	14	0.75	0.41
2	0.60	0.59	15	0.60	0.57
3	0.75	0.44	16	0.70	0.47
4	0.45	0.53	17	0.50	0.56
5	0.55	0.55	18	0.60	0.43
6	0.60	0.72	19	0.75	0.65
7	0.70	0.57	20	0.55	0.64
8	0.60	0.54	21	0.75	0.40
9	0.55	0.57	22	0.70	0.57
10	0.65	0.64	23	0.60	0.60
11	0.50	0.70	24	0.45	0.62
12	0.65	0.45	25	0.55	0.68
13	0.45	0.68			

It is clear from Table 1 that the values of the difficulty coefficients for the paragraphs ranged between 0.45-0.75, and the values of the discrimination coefficients ranged between 0.40-0.72, and these values are considered acceptable for keeping the paragraphs within the test according to the (Woodrow, 1936) criterion which indicates keeping the paragraph whose difficulty ranges between (0.20-0.80), and has a discrimination coefficient higher than 0.93, and thus none of the paragraphs were deleted based on the difficulty coefficient or the discrimination coefficient, and the test remained in its final form consisting of 25 paragraphs.

Reliability of the Critical Thinking Skills Test

To estimate the internal consistency reliability of the Critical Thinking Skills Test, with its overall significance and subdomains, according to Horst (1953), the Kuder-Richardson 20 (KR-20) equation was used on the data of the first application of the exploratory sample of 20 students from Osarah Secondary School for Boys, as shown in Table 2.

Table 2. Internal consistency coefficients for the critical thinking skills test, with its overall significance and subdomains

The test and its areas	Internal consistency stability	Number of paragraphs
Conclusion	0.87	5
Prediction	0.88	5
Evaluation	0.86	5
Interpretation	0.87	5
Deduction	0.87	5
Critical thinking skills (as a whole)	0.90	25

It is clear from Table 2 that the internal consistency stability coefficients for the test's sub-domains ranged from 0.86 to 0.88, and for the test as a whole, they reached 0.90.

Determining the Appropriate Time for the Test

The time required to complete the test was determined. The results showed that the first student took 25 minutes to answer the paragraphs, while the last student took 45 minutes. The estimated 10-minute period was taken into account to organize the students, distribute the test papers, and read the instructions before the actual test began.

To calculate the total time required for the students to complete the test, the average of the two times determined (the time taken by the first student and the time taken by the last student) was calculated. Using this method, the researcher was able to determine the optimal time for the critical thinking skills test, which was set at 45 minutes, using the following equation:

$$x = \frac{25 + 45}{2} = \frac{70}{2} = 35$$

By adding 10 organizational minutes, the final approved time for the test becomes 45 minutes.

Test Application

The pretest was administered to the study sample at the beginning of the second semester. The posttest was administered after completing the unit on Metal reactivity. The unit was taught using the educational scaffolding model for the experimental group and the traditional method for the control group. The school's chemistry teacher administered this.

Test Correction

The test was prepared on paper. A score of 0 was given for an incorrect answer, and 1 for a correct answer. Thus, the minimum score on the test was 0, and the maximum was 25.

Verifying the Equivalence of the Two Study Groups in Critical Thinking Skills

To verify equivalence between the two study groups in the pre-test of critical thinking skills, the arithmetic means and standard deviations of the study sample's pre-test performance were calculated by study group (control, experimental). An independent-samples t-test was also used to determine the significance of the differences between the arithmetic means, as shown in Table 3.

Table 3. Results of the Independent Samples T-test to reveal the significance of the differences between the arithmetic means of the study sample's pre-performance on the critical thinking skills test, with its overall significance and sub-domains, according to the teaching method

Skill	Control group	Mean	Standard deviation	T	Degrees of freedom	Statistical significance
Inference Prediction	Experimental group Control group	2.44 2.96	0.92 1.21	-1.716	48	0.093
Evaluation Deduction	Experimental group Control group	2.88 2.48	1.20 1.29	1.135	48	0.262
Interpretation	Experimental group Control group	1.72 1.20	1.21 0.87	1.749	48	0.087
Skill Inference	Experimental group Control group	1.64 1.92	1.13 1.00	-0.930	48	0.357
Prediction Evaluation	Experimental group Control group	1.20 1.64	1.08 1.29	-1.309	48	0.197
Deduction	Experimental group	10.88 10.20	2.63 3.30	0.805	48	0.425

**Statistically significant at the significance level (α=0.05)*

It is clear from Table 3 that there are no statistically significant differences at the significance level (α=0.05) between the arithmetic means of the pre-study sample's performance on the critical thinking skills test with its overall significance and its sub-domains attributed to the study group (control, experimental), and for further statistical control, analysis of associated variance (ANCOVA) and analysis of associated variance (MANCOVA) were used.

4.4. Educational Material

- Determine the educational unit to be implemented. The first unit from the ninth-grade chemistry textbook, first edition, issued by the Ministry of Education for the 2024/2025 academic year, titled "Metal reactivity," was chosen due to its inclusion of diverse concepts and terminology, in addition to the illustrative drawings that require students to understand and relate them to the lesson outcomes.

- Determine the content of the cognitive material by analyzing the content of the first unit (Metal reactivity) in the ninth-grade chemistry curriculum. This was achieved by identifying the cognitive-behavioral objectives (remembering, understanding, and applying) and then the cognitive structure (including facts and concepts) based on the Ministry of Education's teacher's guide.

- Verify the validity of the content analysis by presenting it to a group of referees comprising faculty members from Jordanian universities, supervisors, and chemistry teachers with extensive teaching experience. The content analysis vocabulary was modified based on their feedback. -Organizing the unit's educational material to achieve the cognitive objectives in accordance with the educational scaffolding model, and preparing a teacher's guide as a guide for implementing the Metal reactivityunit based on the educational scaffolding model.

- Presenting the guide to several curriculum and teaching method specialists to seek their opinion on the validity of the formulation of the objectives contained in the guide's content, the information contained therein, the arrangement of concepts, and the branching of branches from the main idea. Some branches were modified, and thus the method, in its final form, was ready for application to the study sample.

- Determining the timeline for teaching the unit, which took place during the period from February 13, 2025, to March 20, 2025, during the second semester of the 2024/2025 academic year. The number of classes required to implement teaching using the educational scaffolding model was 10, each lasting 40 minutes. This is the same number of classes approved by the Ministry of Education for teaching the unit using the usual method.

4.5. Study Procedures

To achieve the study objectives, the researcher carried out the following procedures:

- Obtaining IRB approval.

- Obtaining a task facilitation letter from the Deanship of the College of Education at Yarmouk University.

- Obtaining a task facilitation letter from the Ajloun Governorate Education Directorate.

- Identifying the study population, which comprised ninth-grade students at Baoun Secondary School for Boys, affiliated with the Ajloun Governorate Education Directorate.

- Verifying the validity and reliability of the final study instrument.

- Applying the study instrument to a pilot sample from the same study population and from outside its sample from the Ajloun Governorate Education Directorate to verify the psychometric properties of the instruments.

- Obtaining approval from the school that was intentionally selected to implement the study instrument, pursuant to a task facilitation letter from Yarmouk University to the Ajloun Governorate Education Directorate, to facilitate the researcher's application of the study instrument.

- Applying the study tool to the study groups before starting to teach the unit "Metal reactivity" from the ninth-grade chemistry textbook (pretest).

- Training the teacher on the teacher's guide and how to use it through a training session. The session introduced the educational scaffolding model for teaching the unit "Metal reactivity," its implementation mechanism, and the roles of both teacher and student within the model.

- Applying the study tool, which consisted of a critical thinking skills test, to the two study groups after completing the unit "Metal reactivity" from the ninth-grade chemistry textbook (posttest).

- Collecting responses to the study tool, transcribing them, and entering them into a computer for statistical processing using SPSS.

- Obtaining acceptance for publication of the research extracted from the dissertation.

4.6. Study Design

The study tool was administered post-test to both groups. Thus, the design was a pre-post design with two groups, with the teaching method variable (scaffolding model vs. traditional method). The study design can be symbolically expressed as follows:

Table 4. A pre- and post-test design for both groups, with a teaching method variable (scaffolding model and traditional method)

Post-measurement	Treatment	Pre-measurement	Assignment	Group
O1	X	O1	R	EG Experimental Group
O1	-	O1	R	CG Control Group

Where:

For example, the experimental group was taught using the scaffolding model.

CG: The control group was taught using the traditional method.

R: The random assignment to the two groups.

X: The treatment using the scaffolding model.

O1: Pre- and post-test of critical thinking skills.

4.7. Study Variables

The study included the following variables:

First: Independent variables, including:

- Teaching method, which has two categories: the educational scaffolding model and the traditional method.

Second: Dependent variables, including:

- Critical thinking skills.

4.8. Statistical Methods Used

The statistical processing of data in this study was carried out using the Statistical Packages for the Social Sciences (SPSS), as follows:

- To answer the first question, the arithmetic means and standard deviations of the study sample members' scores in the pre- and post-tests on the critical thinking skills test, with its overall significance and subdomains, were calculated. ANCOVA and MANCOVA were used.

4.9. limitations

1. Sample Size and Representativeness: Out of the 1,746 ninth-grade students in the Ajloun Governorate, a comparatively small sample of 50 students participated in the study. This limits the applicability of the findings across different contexts and schools.

2. Limitations of the Research Design: Complete control over all external variables is not possible due to the quasi-experimental design. The results may have been affected by confounding variables, such as socioeconomic background, motivation, prior knowledge, and teacher influence.

3. Single-School Context: Because the study was limited to one school, it might not accurately reflect the variety of learning environments and resources found in other institutions.

4. Temporal Limitation: Because the study only lasted one semester, it might not have fully captured how scaffolding-based instruction affects students' development of critical thinking over the long run.

For future research, it will be guided by acknowledging these limitations. To improve the reliability and generalizability of results, future research is advised to use larger and more varied samples, employ longitudinal designs, and involve multiple schools.

5. Results

The study aimed to reveal the effectiveness of using the educational scaffolding model in teaching chemistry in developing critical thinking skills among students, by answering the following question:

First: Results related to the first question, which stated What is the effectiveness of using the educational scaffolding model in teaching chemistry in developing critical thinking skills among ninth-grade students?

To answer this question, the hypothesis of which states: "There are no statistically significant differences at the significance level (α = 0.05) between the average scores of ninth-grade students who studied using the educational scaffolding model and the average scores of students who studied using traditional methods in critical thinking skills," the arithmetic means and standard deviations for critical thinking skills (as a whole) were determined in the pre- and post-tests and the average for members of the experimental and control groups, as shown in Table 5.

Table 5. Arithmetic means and standard deviations of critical thinking skills with their overall significance among members of the experimental and control groups in the pre- and post-test, and adjusted according to the group variable

Group	number	pre		Post		Average	
		Arithmetic mean	Standard deviation	Arithmetic mean	Standard deviation	Average	Standard Error
Control	25	10.88	2.63	13.28	3.03	12.96	0.28
Experimental	25	10.20	3.30	17.56	3.18	17.88	0.28

It is clear from Table 5 that there are significant differences in the arithmetic means of critical thinking skills between the experimental and control groups of ninth-grade students at the pre- and post-measurements, as indicated by the group variable. To verify the significance of the apparent differences, one-way analysis of variance (One-way ANCOVA) was used, with pre-measurement scores of critical thinking skills (as a whole) as the accompanying variable, for each of the two groups, as shown in Table 6.

Table 6. Results of one-way ANCOVA for the post-test of critical thinking skills, with their overall significance among the study sample members according to the group variable

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F-Value	Significance Level	Eta Square (η^2)
Pre-test	4.445	1	4.445	2.354	0.132	
Teaching Method	98.048	1	98.048	*51.932	0.000	**0.525
Error	88.755	47	1.888			
Total	191.248	49				

**Statistically significant at the significance level (α=0.05)*

***(Effect size according to Al-Kilani and Al-Sharifain, 2007: weak (less than 0.06), medium (0.15-0.06), large (0.16 and above)).*

Table 6 shows a statistically significant difference at the significance level (α = 0.05) between the arithmetic means of the post-test of critical thinking skills, with their overall significance, for the ninth-grade student sample, depending on the group variable (experimental, control), in favor of the experimental group taught using the educational scaffolding model. The effect of using the educational scaffolding model on raising the level of critical thinking skills (as a whole), as indicated by the value of eta square (η^2), was 52.50%. This value is considered high by Al-Kilani and Al-Sharifain (2007). This generally means that the educational scaffolding model contributed significantly to raising the level of critical thinking skills (as a whole) among ninth-grade students.

The arithmetic means and standard deviations for the pre-test and post-test, as well as the adjusted sub-skills of critical thinking, were calculated by group (experimental, control), as shown in Table 7.

Table 7. Arithmetic means and standard deviations of the critical thinking sub-skills of the experimental and control groups in the pre- and post-tests, adjusted for the group variable

Skill	Group	Num	Pre-test		Post-test		Average	
			Mean	Standard dev.	Mean	Standard dev.	Mean	standard error
Conclusion	Control	25	2.44	0.92	3.08	0.76	3.01	0.12
	Experimental	25	2.96	1.21	4.28	0.74	4.39	0.12
Prediction	Control	25	2.88	1.20	2.92	0.95	2.87	0.14
	Experimental	25	2.48	1.29	3.48	0.77	3.53	0.14
Evaluation	Control	25	1.72	1.21	1.68	0.75	1.67	0.14
	Experimental	25	1.20	0.87	2.64	0.91	2.66	0.14
Deduction	Control	25	1.64	1.13	2.04	0.79	2.06	0.15
	Experimental	25	1.92	1.00	3.48	1.08	3.46	0.15
Interpretation	Control	25	1.20	1.08	2.56	1.08	2.55	0.16
	Experimental	25	1.64	1.29	3.68	0.95	3.69	0.16

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Table 7 shows that there are significant differences in the arithmetic means of the sub-skills of critical thinking between the experimental and control groups at pre- and post-measurement, according to the group variable. To verify the significance of the apparent differences, a one-way MANCOVA was used to determine the effect of the educational scaffolding model on each of the critical thinking skills, after taking into account the pre-measurement scores on the sub-skills of critical thinking for each of the two groups, as an accompanying variable, as shown in Table 8.

Table 8. Results of one-way MANCOVA for the post-test of critical thinking sub-skills among the study sample members according to the group variable

Source of variance	Skill	Sum of Squares	DF	Mean Square	F Value	Statistical Significance	(η^2)
Pre-measurement	Conclusion	0.345	1	0.345	1.142	0.291	
	Prediction	1.179	1	1.179	2.834	0.099	
	Evaluation	0.574	1	0.574	1.251	0.269	
	Deduction	0.561	1	0.561	1.081	0.304	
	Interpretation	0.851	1	0.851	1.465	0.232	
Teaching method	Conclusion	18.880	1	18.880	*62.509	0.000	**0.592
Hotelling's Trace= 6.673	Prediction	4.231	1	4.231	*10.160	0.003	**0.191
F= 22.047	Evaluation	9.646	1	9.646	*21.002	0.000	**0.328
Sig=0.000*	Deduction	19.419	1	19.419	*37.383	0.000	**0.465
	Interpretation	12.630	1	12.630	*21.735	0.000	**0.336
Error	Conclusion	12.987	43	0.302			
	Prediction	17.906	43	0.416			
	Evaluation	19.750	43	0.459			
	Deduction	22.337	43	0.519			
	Interpretation	24.987	43	0.581			
Total	Conclusion	32.212	49				
	Prediction	23.316	49				
	Evaluation	29.97	49				
	Deduction	42.317	49				
	Interpretation	38.468	49				

**Statistically significant at the significance level (α=0.05)*

***(Effect size according to Al-Kilani and Al-Sharifain, 2007: weak (less than 0.06), medium (0.15-0.06), large (0.16 and above)).*

Table 8 shows statistically significant differences at the significance level (α = 0.05) between the arithmetic means of the post-test for critical thinking sub-skills according to the group (experimental, control), in favor of the experimental group taught using the educational scaffolding model.

The effect of using the educational scaffolding model on raising the level of critical thinking sub-skills, as indicated by the Eta square (η^2) value, was 59.20% for the skill of (deduction), 19.10% for the skill of (prediction), 32.80% for the skill of (evaluation), 46.50% for the skill of (deduction), and 33.60% for the skill of (interpretation). This effect was high across all skills, as indicated by Al-Kilani and Al-Sharifain (2007). This means that the teaching model used in this study contributed to the development of all sub-skills of critical thinking among the study sample members. The most influential skill was the inference skill, followed by the deduction skill, followed by the interpretation skill, followed by the evaluation skill, and the least influential skill was the prediction skill.

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6. Discussion

This study examines the effectiveness of the scaffolding model as a pedagogical approach to enhance critical thinking skills among ninth-grade students. Rooted in constructivist theory, the scaffolding model provides incremental support that fosters learner independence. It draws upon Vygotsky's social learning theory, particularly the concept of the zone of proximal development, which suggests that learners can advance their skills with appropriate assistance. Key attributes of instructional scaffolding include offering clear instructions, clarifying goals, providing continuous guidance, posing stimulating questions, and addressing knowledge gaps. These elements are particularly designed to accommodate the diverse needs of learners and to enhance their comprehension of scientific concepts. To assess critical thinking skills, the study utilized the Critical Thinking Skills Test, developed explicitly for the "Metal Interaction" unit in chemistry that evaluates various dimensions of critical thinking, such as reasoning, prediction, evaluation, inference, and interpretation, aimed at gauging the impact of the scaffolding model on students' critical thinking abilities.

The study investigated the effectiveness of the educational scaffolding model in teaching chemistry to ninth-grade students, focusing on its impact on critical thinking skills. Results showed statistically significant differences in critical thinking between students taught with scaffolding (experimental group) and those taught with traditional methods (control group), with the experimental group demonstrating greater skill development. An effect size indicates a substantial impact of scaffolding on enhancing both academic achievement and higher-order thinking skills.

The set of steps in the educational scaffolding model implicitly works to develop higher-order thinking skills, including critical thinking. This was confirmed by Al-Harthi and Al-Attab (2021), who stated that this model contributes to training students in exploration, questioning, and problem-solving skills that are fundamental pillars of critical thinking. Furthermore, a study by Metwally et al. (2023) confirmed that students exposed to gradual, supportive learning situations have a greater ability to distinguish between evidence and opinions, interpret phenomena, and evaluate information—essential skills on which critical thinking is built. The results of Al-Qahtani's (2016) study confirmed that the gradual removal of support in this model enhances learners' mastery of the skills of criticism, analysis, and evaluation.

This result highlights the effectiveness of the educational scaffolding model, which provides gradual support to foster an interactive learning environment. It promotes logical and analytical thinking, particularly in the context of higher-order thinking skills like critical thinking. Each lesson, complemented by a video presentation of the learning outcomes, facilitates group discussions in which students engage in critical questioning and thorough analysis of concepts using multimedia resources, reinforcing their understanding.

The teacher's gradual progression in explaining and clarifying the concept, from simple to complex, and from easy to difficult, enabled students to analyze the concept within each group. The group leader explained the concept to the group members in a simplified manner. Then the group members analyzed it into simpler parts, researched sources to identify information, provided explanations and conclusions, and discussed them critically within the group. This limited individual differences among students and ensured the transfer of learning among them.

The impact of educational scaffolding on ninth-grade students is a pivotal age for cognitive development and discovery. It emphasizes how scaffolding facilitates learning by guiding students toward various sources of knowledge and enhancing their critical thinking skills. The approach helps students develop abilities in inference, prediction, evaluation, deduction, and interpretation through engagement in logical, evidence-based tasks. A one-way analysis of variance (MANCOVA) revealed significant improvements in these critical thinking sub-skills among the experimental group. The noted effect sizes indicated that the most significant enhancement occurred in the inference skill, followed by deduction, interpretation, evaluation, and prediction. This analysis underscores the effectiveness of educational scaffolding in fostering essential cognitive skills during this formative educational stage.

This is due to the fact that the scaffolding model used to teach the Metal reactivity Unit implicitly integrates critical thinking skills into every step of the scaffolding model, including clarifying the general idea of the lesson and the learning objective, identifying students' prior knowledge, and then linking it to existing information to accelerate comprehension. The model also uses hints and provocative questions to stimulate critical thinking among students, giving them time to analyze and interpret information, and discussing some of the lesson's elements with the students.

This may be due to dividing students into small groups and assigning roles. It also involves posing questions, allowing students to answer by analyzing the data or presenting them as a problem. This enhances students' independent thinking by analyzing the question or problem and identifying key points. It also includes presenting images and videos that support the problem or questions. It also involves searching for sufficient information, assessing it based on evidence and supporting it with evidence and proof, and interpreting this information, leading to deductions and finding relationships, linking them to real-life examples, and explaining them.

This is also attributed to the set of activities included in the educational unit, which uses educational scaffolding. These activities reinforce the learning outcomes of the student groups, motivating them to think deeply and understand the topics. They also encourage students to reflect individually, write about their expectations, then collectively within the group, and finally across the groups as a whole. This helps them improve their understanding, share knowledge, take responsibility for their learning, and review their performance to ensure they have reached a proficient level of understanding, can work independently, and think critically.

The learning environment is designed to promote independent student learning through open-ended questions and guidance that encourages critical thinking without directly providing answers. It highlights that prediction skills had the lowest impact within the educational scaffolding model, which was reinforced at every step. This model required images and videos to aid students' brainstorming, providing visual stimuli rather than allowing access to broader resources or firsthand experiences. The enhancement of prediction skills requires well-equipped laboratories and electronic resources. The researcher suggests that the nature of prediction skills, which depend on prior experiences and observations, contributes to this challenge. These findings align with previous studies by Youssef (2016), Al-Sayed (2019), Dawoud et al. (2020), Khawaji (2022), and Sayed et al. (2022).

The control group had somewhat higher mean scores in reasoning, prediction, and interpretation, differences that were close to the 0.05 level. However, the results showed no statistically significant differences between the groups. This was acknowledged as a study limitation. To ensure balanced readiness and reduce its possible impact, the experimental group underwent a brief pre-intervention training session. The study's limitations section specifically acknowledged this limitation and the corrective actions that were taken.

7. Conclusion

Higher-order thinking abilities, such as critical thinking, form the main foundation of the educational scaffolding Model technique employed to teach chemistry, particularly in Metal reactivity. Every course includes learning objectives and videos that demonstrate them, enabling students to critically examine ideas, track their development, and build upon them. By reducing individual variances and ensuring transfer of learning, the teacher's methodical approach to explaining and clarifying concepts enabled students to analyze the idea within each group.

Overall, critical thinking abilities differed significantly between the experimental and control groups, with the experimental group exhibiting greater influence. This is because support is given gradually, fostering an engaging learning environment that encourages critical and logical thinking.

Additionally, the educational scaffolding model helps students develop the three main components of critical thinking: exploration, questioning, and problem-solving. Students who experience gradual, supportive learning environments are better able to evaluate information, analyse phenomena, and distinguish between opinions and evidence.

Inference, prediction, appraisal, deduction, and interpretation were among the targeted skills where a one-way analysis of variance (MANCOVA) revealed statistically significant differences favouring the experimental group. This is because the model incorporates critical thinking abilities into each phase, including outlining the lesson and learning goal, connecting previously learned material to new information, employing cues and thought-provoking questions, and creating a setting that promotes independent thought. The model's emphasis on improving prediction skills at every stage may have contributed to the lowest impact rate observed.

The main purpose of this study was to determine how well ninth-grade students' critical thinking could be developed through chemistry instruction using the educational scaffolding model. With a large effect size ($\eta^2 = 0.525$), the results showed statistically significant differences between the experimental and control groups, favoring the experimental group. This suggests that the educational scaffolding model had a substantial positive impact on students' critical thinking abilities. The results showed that scaffolding-based instruction helps students develop their higher-order thinking skills, particularly in inference, deduction, interpretation, evaluation, and prediction, as well as their academic performance. The study also demonstrated how the model's interactive, gradual learning process encourages deeper conceptual understanding and helps students think independently.

Given these results, the study validates the educational scaffolding model's efficacy as a potent teaching strategy in chemistry instruction. Since this model promotes student engagement, analytical thinking, and collaborative learning, it is advised that science teachers use it when instructing complex subjects. To investigate the wider applicability and sustainability of these findings, future research should apply scaffolding strategies across various subjects, educational levels, and cultural contexts.

Finally, the study reveals that the educational scaffolding model, used in teaching Metal reactivity, focuses on higher-order thinking skills. The model includes learning objectives and videos, allowing students to critically examine ideas, track their development, and build upon them. The methodical approach to explaining and clarifying concepts helps students analyze ideas within each group. The experimental group had a greater influence on critical thinking abilities due to gradual support and an engaging learning environment. This is the educational scaffolding model that helps students develop exploration, questioning, and problem-solving skills, enabling them to evaluate information, analyze phenomena, and discern between opinions and evidence. In addition, the experimental group showed statistically significant differences in inference, prediction, appraisal, deduction, and interpretation skills. This is because the model incorporates critical thinking abilities into each phase, promoting independent thought and enhancing prediction skills at every stage. The model's emphasis on improving prediction skills at every stage may have contributed to the prediction skill's lowest impact rate.

8. Suggestion

In light of the findings of this study, the researcher recommends the following:

- Incorporating the educational scaffolding model into the curriculum, especially in scientific subjects such as science and chemistry, given its demonstrated effectiveness in developing critical thinking skills.

- Redesigning the curriculum and teaching plans for the upper primary stage to include strategies based on phased support and active interaction, keeping pace with students' critical thinking requirements.

- Preparing specialized training programs for science teachers on how to employ educational scaffolding within the classroom, with a focus on methods of gradual provision of support and adapting it to students' levels.

- Explicitly integrating critical thinking skills into the objectives of study units and assessment tools, not just listing them as general concepts, but rather making them tangible educational practices upon which students are evaluated.

- Expanding the application of the scaffolding model to include other subjects and different educational levels, particularly in the second cycle of primary and secondary education, to measure its effectiveness in broader cognitive fields and educational contexts. - Proposing a digital scaffolding model based on the use of educational applications or smart content supported by artificial intelligence, and testing it in the basic stages.

Declarations

Author Contributions. Ahmad Tawalbeh: Literature review, conceptualization, review-editing and writing, original manuscript preparation, and designed methodology. Dr. Abdullah Khataybeh: Asset **Data Analysis.** All authors have read and approved the published final version of the article.

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About the Contributor(s)

Ahmad Tawalbeh, a PhD student, Department of Curriculum and Methods of Instruction at Yarmouk University, Irbid, Jordan.
Email: tawalbeh.ahmad92@gmail.com
ORCID: https://orcid.org/0009-0009-9595-4731

Abdullah Khataybeh, Department of Curriculum and Methods of Instruction in Science at Yarmouk University, Faculty of Education, Irbid /Jordan
Email: khataibeh@yu.edu.jo
ORCID: https://orcid.org/0000-0002-7475-9330