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Improving Senior High School Students' Critical Thinking Skills on Electron Configuration through a Deep Learning Approach

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Abstract

This study investigates the effectiveness of a deep learning approach in enhancing senior high school students' critical thinking skills on the abstract topic of electron configuration. Employing a quasi-experimental method with a nonequivalent control group design, the sample comprised 52 tenth-grade students from SMA Negeri 5 Ternate, Indonesia, divided equally into an experimental group (deep learning approach) and a control group (conventional instruction). Data were collected using a validated nine-item critical thinking essay test as pre-test and post-test measurements, and analyzed using descriptive and inferential statistics. The results showed that the post-test mean score of the experimental group ($M = 63.38$*) was significantly higher than that of the control group (*$M = 58.19$*). The independent sample t-test confirmed a statistically significant difference between the two groups (*$t = -2.398, p = 0.020 < 0.05$*), leading to the rejection of the null hypothesis. Furthermore, students in the experimental group demonstrated superior abilities in interpreting, analyzing, evaluating, inferring, and explaining electron configuration concepts, particularly in applying the Aufbau principle, Hund's rule, and the Pauli exclusion principle. In conclusion, the deep learning approach significantly improves students' critical thinking skills by fostering active engagement, conceptual understanding, and scientific reasoning, making it a highly recommended pedagogical strategy for chemistry education.*

Abstrak

Penelitian ini menguji efektivitas pendekatan deep learning dalam meningkatkan keterampilan berpikir kritis siswa SMA pada topik abstrak konfigurasi elektron. Menggunakan metode kuasi-eksperimen dengan desain nonequivalent control group, sampel penelitian melibatkan 52 siswa kelas X SMA Negeri 5 Ternate, Indonesia, yang dibagi rata ke dalam kelompok eksperimen (pendekatan deep learning) dan kelompok kontrol (pembelajaran konvensional). Data dikumpulkan melalui instrumen tes esai berpikir kritis sembilan butir yang telah divalidasi sebagai pre-test dan post-test, lalu dianalisis menggunakan statistik deskriptif dan inferensial. Hasil penelitian menunjukkan bahwa rata-rata skor post-test kelompok eksperimen ($M = 63,38$) secara signifikan lebih tinggi daripada kelompok kontrol ($M = 58,19$). Uji-t sampel independen mengonfirmasi adanya perbedaan signifikan secara statistik antara kedua kelompok ($t = -2,398, p = 0,020 < 0,05$), sehingga hipotesis nol ditolak. Selain itu, siswa kelompok eksperimen menunjukkan kemampuan yang lebih baik dalam menginterpretasikan, menganalisis, mengevaluasi, menyimpulkan, dan menjelaskan konsep konfigurasi elektron, terutama dalam menerapkan prinsip Aufbau, aturan Hund, dan larangan Pauli. Kesimpulannya, pendekatan deep learning berkontribusi signifikan dalam meningkatkan keterampilan berpikir kritis siswa melalui keterlibatan aktif, pemahaman konseptual, dan penalaran ilmiah, sehingga menjadi strategi pedagogis yang direkomendasikan dalam pendidikan kimia.

1. Introduction

1.1 Background of the Problem

Education serves as the main pillar for improving the quality of human resources. In the context of national development, improving the quality of education must keep pace with technological advancements, societal dynamics, and economic growth. The progress of a region is heavily influenced by education's ability to prepare a young generation capable of competing and adapting to changing times. With the development of digital technology and the transformation of various sectors, education can no longer focus solely on present needs. It must prepare students for future challenges that are increasingly complex, rapid, and unpredictable.

In science learning, particularly chemistry, critical thinking skills are paramount because the subject matter demands that students understand abstract concepts, analyze relationships between concepts, and connect theory with real-world phenomena. Twenty-first-century education globally prioritizes these skills. The World Economic Forum (2023) affirms that analytical thinking, which encompasses critical thinking ability, is the core skill most needed in the workplace over the next five years. However, in reality, many students still employ rote learning methods that do not allow them to understand knowledge structures deeply.

This condition is also evident in chemistry learning at SMA Negeri 5 Ternate. Based on initial observations in the classroom, interviews with teachers, and analysis of student work, several main problems were identified in understanding electron configuration, a fundamental concept in chemistry. Many students merely memorize configuration rules without understanding the underlying principles. Such learning patterns cause students to forget easily, make errors in problem-solving, and be unable to explain the reasoning behind their steps. This phenomenon reflects surface learning (Biggs, 2021), a learning approach that emphasizes memorization without encouraging deep conceptual understanding.

Critical thinking ability plays a crucial role in the learning process. Critical thinking helps students connect information, assess the truth of arguments, and make decisions based on evidence. Facione (2015) explains that critical thinking involves using reasoning skills to assess information, make appropriate judgments, and make reflective and logical decisions. Students with these skills can view problems from multiple perspectives, consider risks and benefits, and determine the best solutions. In the digital information age, when students are inundated with information from various sources, critical thinking skills become increasingly important for selecting accurate information and avoiding misinformation.

Based on this urgency, classroom learning requires an approach that emphasizes not only memorization but also deep understanding. One relevant approach is deep learning. In an educational context, deep learning refers to a learning approach that encourages students to understand concepts holistically, connect material with real-world experiences, and engage in analysis, reflection, and knowledge application. Fullan and Langworthy (2014) explain that deep learning pedagogy focuses on meaningful, collaborative, and real problem-based learning. Recent findings by Fitrah (2025) also indicate that this approach can enhance meaningful cognitive engagement through conceptual understanding, reflective ability, and knowledge transfer across contexts.

This approach differs from traditional learning because deep learning invites students to explore ideas, discuss concepts with peers, work on problem-based tasks, and connect information from various sources. Research in Indonesian senior high schools reinforces the effectiveness of this approach. Afwan et al. (2025) found that applying deep learning in the classroom can improve students' deep understanding and critical thinking skills while helping them connect concepts to real-life situations. Similarly, Mere (2025) reported that high school students showed increased motivation and engagement when a deep learning approach was implemented.

When linked to the learning conditions at SMA Negeri 5 Ternate, this approach is highly relevant. The low level of student understanding of electron configuration and the tendency toward rote learning indicate a need for implementing learning models that provide space for students to think more deeply. Deep learning is seen as capable of addressing these problems because it focuses not only on outcomes but also on students' thought processes. Thus, students can not only answer questions but also understand the reasoning behind their chosen answers.

Based on these considerations, the low level of students' critical thinking skills and the suboptimal implementation of learning approaches that support deep understanding are important problems that must be addressed. Therefore, this research was conducted on the application of a deep learning approach to improve students' critical thinking skills, specifically on the topic of electron configuration.

1.2 Problem Statement

The problem of this research is formulated as follows: Is there an improvement in students' critical thinking skills after the implementation of the deep learning approach on the topic of electron configuration at SMA Negeri 5 Ternate?

1.3 Research Objective

This study aims to determine whether the application of the deep learning approach to the topic of electron configuration can improve students' critical thinking skills.

1.4 Research Hypothesis

The hypothesis of this research is: There is a significant improvement in students' critical thinking skills after the implementation of the deep learning approach on the topic of electron configuration.

2. Literature Review

2.1 Critical Thinking Skills

Thinking is the power of the soul that can establish relationships between our knowledge. It is a dialectical process where, during thinking, our mind is in a state of question and answer to establish relationships in our knowledge. Broadly speaking, thinking is the ultimate goal of the teaching and learning process. Thinking can be trained in students by developing questioning skills during the learning process. Higher-order thinking skills are a deliberate and conscious process to interpret and evaluate information from existing experiences, beliefs, and abilities to test an opinion or idea, including making judgments based on proposed arguments.

Critical thinking is the ability to think clearly and rationally regarding what to do or what to believe. It includes the ability to engage in reflective and independent thinking. Someone with critical thinking skills can understand logical connections between ideas, identify, construct, and evaluate arguments, detect inconsistencies and common mistakes in reasoning, solve problems systematically, identify the relevance and importance of ideas, and reflect on the justification of one's own beliefs and values. Thus, critical thinking is a complex process involving data acquisition, data analysis, data evaluation by weighting components qualitatively and quantitatively, and making selections or decisions based on the evaluation conducted.

Peter A. Facione (in Kastori R., 2023) divides critical thinking indicators as follows: (a) **Interpretation**: the ability to understand and express the meaning of a situation, data, judgment, rules, procedures, or varied criteria; (b) **Analysis**: the ability to clarify conclusions based on the relationship between information and concepts with the questions in a problem; (c) **Evaluation**: the ability to assess the credibility of a statement or other representation of a person's opinion or to assess a conclusion based on the relationship between information and concepts with the questions in a problem; (d) **Inference**: the ability to identify elements needed to make rational conclusions, considering information relevant to a problem and its consequences based on existing data; (e) **Explanation**: the ability to state one's reasoning when providing reasons for justifying evidence, concepts, methodology, and logical criteria based on existing information or data, presented in the form of an argument; (f) **Self-regulation**: the ability to be aware of and examine one's cognitive activities, the elements used in those activities, and their results, using analysis and evaluation skills to confirm, validate, and correct previous reasoning outcomes.

2.2 Deep Learning Approach

The deep learning approach emphasizes students' active and deep engagement in processing, connecting, and constructing information to produce more meaningful conceptual understanding (Biggs & Tang, 2021). In this approach, learning is no longer viewed as an activity of passively receiving information, but as a mental process involving meaning-making, reasoning, and reflection on the concepts being learned.

According to the 2024–2025 Indonesian Ministry of Primary and Secondary Education policy direction (Kemendikdasmen, 2025), deep learning can only occur when the learning process has three fundamental characteristics: meaningful, mindful, and joyful.

a) Meaningful Learning: This is the core of deep learning. Learning is meaningful when students can build conceptual relationships between new knowledge and their experiences, interests, and prior knowledge. From the perspective of Facione's critical thinking skills, meaningful learning directly develops interpretation and analysis abilities. Students not only receive information but also interpret the meaning of concepts and analyze the relationships between concepts.

b) Mindful Learning: This emphasizes that learning is not only a cognitive activity but also a metacognitive activity and self-awareness. Mindful learning means students are aware of their learning process: what they understand, what they have not yet understood, what strategies they use, why they experience difficulties, and how to improve their understanding. This helps develop evaluation skills, especially the ability to assess one's thought processes and outcomes reflectively.

c) Joyful Learning: This is learning that creates positive emotional experiences so that students feel comfort, engagement, intellectual pleasure, and the courage to try and experiment. Joyful learning combines intellectual challenges with emotional support, enabling students to enter an optimal development zone. In relation to critical thinking skills, joyful learning encourages the development of inference and explanation abilities. When students feel safe and challenged, they are more willing to draw conclusions, express opinions, and explain their thoughts without fear of being wrong.

These three learning experiences are the foundation of deep learning: (1) **Understanding**: where students build concepts and connect new knowledge with prior knowledge; (2) **Applying**: where students use concepts to solve problems in new contexts; (3) **Reflecting**: where students re-examine their thought processes, identify strengths and weaknesses, and become aware of their learning progress.

2.3 Electron Configuration

Electron configuration describes the arrangement of electrons in an atom based on their energy levels. There are three main ways to write electron configurations: (a) order by energy level (Aufbau), (b) order by shell number, and (c) abbreviated notation using noble gas symbols. The writing follows several rules:

a) **Aufbau Principle**: Electrons fill orbitals starting from the lowest energy level to the highest (e.g., 1s, 2s, 2p, 3s, 3p, 4s, 3d, etc.). b) **Pauli Exclusion Principle**: No two electrons in the same orbital can have the same set of four quantum numbers; therefore, an orbital can hold a maximum of two electrons with opposite spins.

c) **Hund's Rule**: Electrons fill degenerate orbitals (orbitals of the same energy level) singly with parallel spins before pairing up.

There are also exceptions to the Aufbau principle for elements like chromium (Cr) and copper (Cu), where a half-filled (d^5) or fully filled (d^{10}) d-subshell is more stable. For example, Cr has the configuration [Ar] $4s^1$ $3d^5$ instead of [Ar] $4s^2$ $3d^4$.

3. Methodology

3.1 Research Design

This study used a quasi-experimental method with a nonequivalent control group design. The design is illustrated in Table 1.

Table 1. Research Design

Group	Pre-test	Treatment	Post-test
Experimental	T1	X1 (Deep Learning)	T2
Control	T1	X2 (Conventional)	T2

3.2 Place and Time

The research was conducted at SMA Negeri 5 Ternate, North Maluku, Indonesia, over a period of six months.

3.3 Population and Sample

The population was all 300 tenth-grade students across 10 classes. The sample consisted of two classes (52 students) selected using cluster sampling: class X-D (26 students) and class X-E (26 students). One class was randomly assigned as the experimental group, and the other as the control group.

3.4 Research Variables

- **Independent Variable:** The learning approach. The experimental group received the deep learning approach, while the control group received conventional (lecture-based) instruction.
- **Dependent Variable:** Students' critical thinking skills as measured by a test on electron configuration.

3.5 Data Collection Technique

Data were collected through a pre-test (before treatment) and a post-test (after treatment) using a critical thinking skills test. The test consisted of 9 essay questions. Before use, the instrument was tested for validity, reliability, discrimination index, and difficulty level.

- **Validity:** Content validity was established through expert judgment by a chemistry education lecturer and a chemistry teacher. Construct validity was analyzed using Pearson Product-Moment correlation.
- **Reliability:** The internal consistency of the instrument was calculated using Cronbach's Alpha with SPSS 27.
- **Discrimination Index:** Calculated by comparing the mean scores of the upper and lower groups.
- **Difficulty Level:** Calculated as the proportion of students who answered correctly.

3.6 Data Analysis Technique

Data analysis included descriptive analysis (mean, standard deviation) and inferential analysis.

1. **Normality Test:** The Shapiro-Wilk test was used to determine if the data were normally distributed.
2. **Homogeneity Test:** Levene's test was used to determine if the variances between the two groups were equal.
3. **Hypothesis Test:** An independent sample t-test was used to compare the post-test

mean scores of the experimental and control groups, with a significance level of α = 0.05.

4. Results

4.1 Instrument Quality Analysis

- **Validity:** All 9 test items had a Pearson correlation (r_hitung) greater than the critical r (r_tabel = 0.444 for N=20), indicating that all items were valid. The average validation scores are shown in Table 2.

Table 2. Average Validation Scores of Research Instrument

No	r_hitung (item-total)	r_tabel (0.05; N=20)	Sig.	Keterangan
1	0.934	0.444	0.000	Valid
2	0.934	0.444	0.100	Valid
3	0.596	0.444	0.006	Valid
4	0.708	0.444	0.000	Valid
5	0.934	0.444	0.100	Valid
6	0.934	0.444	0.100	Valid
7	0.556	0.444	0.011	Valid
8	0.650	0.444	0.002	Valid
9	0.804	0.444	0.000	Valid

- **Reliability:** The Cronbach's Alpha value was 0.914 (see Table 3), which falls into the very high category, indicating excellent internal consistency.

Table 3. Reliability Statistics

Cronbach's Alpha
0.914

- **Discrimination Index:** Most items were in the "good" or "very good" categories, meaning the instrument effectively distinguishes between high- and low-ability students.
- **Difficulty Level:** The difficulty indices (P) ranged from 0.29 to 0.70, with a mix of "difficult" and "medium" items and no "easy" items. This indicates the test was appropriate for measuring higher-order thinking.

4.2 Descriptive Statistics

The descriptive statistics for the post-test scores are presented in Table 4.

Table 4. Descriptive Statistics of Post-Test Scores

Class	N	Mean	Std. Deviation
Control	26	58.19	7.762
Experimental	26	63.38	7.849

The mean post-test score of the experimental group (63.38) was higher than that of the control group (58.19), with a difference of 5.19 points. The distribution of scores is shown in Histograms 1 and 2 (conceptually represented below), where the experimental group's scores are shifted towards higher intervals.

- **Figure 1 (Conceptual):** Histogram of post-test scores for the control group shows concentration in the medium range.

- **Figure 2 (Conceptual):** Histogram of post-test scores for the experimental group shows a visible shift towards higher score intervals.

4.3 Prerequisite Analysis Tests

- **Normality Test:** The Shapiro-Wilk test results (see Table 5) showed that all significance values were greater than 0.05, indicating that the data from both groups were normally distributed.

Table 5. Tests of Normality (Shapiro-Wilk)

Class	Statistic	df	Sig.
Pre-Test Control	0.972	26	0.687
Post-Test Control	0.984	26	0.951
Pre-Test Experimental	0.984	26	0.944
Post-Test Experimental	0.956	26	0.326

- **Homogeneity Test:** The Levene test result (see Table 6) showed a significance value of 0.569 > 0.05, indicating that the variances of the two groups were homogeneous.

Table 6. Test of Homogeneity of Variances (Based on Mean)

Levene Statistic	df1	df2	Sig.
0.676	3	100	0.569

4.4 Hypothesis Testing

Because the data were normal and homogeneous, an independent sample t-test was conducted. The results are presented in Table 7.

Table 7. Independent Sample T-Test Results

	t	df	Sig. (2-tailed)	Mean Difference
Hasil (Post-test)	-2.398	50	**0.020**	-5.192

The calculated t-value was -2.398, and the two-tailed significance was 0.020. Since the significance value (0.020) is less than the alpha level (0.05), the null hypothesis (H0) was rejected, and the alternative hypothesis (Ha) was accepted. This means there is a statistically significant difference in critical thinking skills between students taught using the deep learning approach and those taught using conventional methods.

5. Discussion

The findings of this study indicate that the deep learning approach significantly improves students' critical thinking skills on the topic of electron configuration compared to conventional instruction. The higher post-test mean score of the experimental group, confirmed by the t-test analysis, demonstrates the effectiveness of this approach.

The success of the deep learning approach can be attributed to its three core characteristics: meaningful, mindful, and joyful learning. The meaningful learning component helped students interpret (Facione's interpretation) and analyze (analysis) the abstract rules of electron configuration (Aufbau, Hund, Pauli) by connecting them to prior knowledge of atomic structure and the periodic table. Instead of memorizing, students built a conceptual framework. The mindful learning component fostered metacognition, enabling students to evaluate (evaluation) their own understanding, identify errors, and correct their reasoning, particularly in complex areas like orbital diagrams and stability exceptions (Cr and Cu). The joyful learning component created a safe and engaging environment where students felt confident to draw inferences (inference) and explain (explanation) their answers during group discussions and problem-solving activities.

This result aligns perfectly with the theoretical framework of deep learning proposed by Biggs and Tang (2021), where deep learners focus on the meaning and underlying structure of the learning material. It is also consistent with Entwistle's view that deep learning correlates positively with conceptual understanding and higher-order thinking. Furthermore, these findings support the 2024–2025 Indonesian Ministry of Education policy (Kemendikdasmen, 2025), which advocates for deep learning as a primary approach in the Merdeka Curriculum to enhance critical and analytical thinking.

The improvement was not uniform across all test items. Students showed the most significant progress on items requiring evaluation of configurations (items 1, 5) and understanding valence electrons (item 7). They performed reasonably well on items about stability exceptions (items 4, 8). However, they faced more difficulty with items that required integrating multiple abstract concepts simultaneously, such as connecting electron configuration to the periodic table (item 6) and explaining ion formation (item 9). This suggests that while deep learning effectively builds foundational and intermediate critical thinking skills, more intensive and sustained practice is needed for students to master highly integrative and complex conceptual relationships.

These results are consistent with recent studies in similar contexts. Sandi et al. (2025) found that a PBL-based e-module on electron configuration improved critical thinking. Priyolistiyanto et al. (2024) reported that augmented reality media helped students understand abstract electron configuration concepts. This convergence of evidence reinforces the importance of active, student-centered, and technology-enhanced learning for abstract chemistry topics.

6. Conclusion

Based on the results and discussion, the following conclusions can be drawn:

1. The application of the deep learning approach has a significant positive effect on improving high school students' critical thinking skills on the topic of electron configuration. This is evidenced by the significantly higher post-test scores of the experimental group compared to the control group ($p = 0.020 < 0.05$).
2. The deep learning approach was generally successful in enhancing students' conceptual understanding and critical thinking skills, particularly in applying the Aufbau principle, Hund's rule, and the Pauli exclusion principle, and in understanding the link between electron configuration and the chemical properties of elements. The characteristics of meaningful, mindful, and joyful learning were key to this success.
3. Despite the overall success, a small number of students still struggled with questions requiring the integration of multiple complex concepts, such as the relationship between electron configuration, the periodic system of elements, and the tendency for ion formation. This indicates that challenging, integrative concepts require further reinforcement.

Suggestions

Based on the findings, the following suggestions are offered:

1. **For Teachers:** It is highly recommended to use the deep learning approach to improve students' critical thinking skills in chemistry and other science subjects. Teachers should design more discussion and problem-solving activities to make learning more meaningful.
2. **For Schools:** Schools are expected to support the implementation of innovative learning approaches through improved facilities and teacher professional development programs.

3. **For Future Researchers:** Further research should explore the application of the deep learning approach to other chemistry topics and investigate more effective strategies and media, particularly for overcoming student difficulties with highly integrative and complex concepts.

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