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The Effect of Deep Learning Approach on Conceptual Understanding and Critical Reasoning among Vocational High School Students

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Abstract

This study was motivated by the low conceptual understanding and critical mathematical reasoning among vocational high school students, largely due to conventional instruction emphasizing procedural memorization, and the limited empirical evidence on deep learning interventions in vocational mathematics. This investigation aimed to examine the effect of the deep learning approach on vocational students' conceptual understanding and critical mathematical reasoning regarding exponential functions. A quasi-experimental posttest-only non-equivalent control group design was implemented. The sample comprised 40 tenth-grade students from SMK Ma'arif 1 Metro, assigned to an experimental group (n=19) receiving deep learning instruction and a control group (n=21) receiving conventional instruction. Data were collected using conceptual understanding and critical reasoning tests (10 multiple-choice items each), validated by four experts using Aiken's V (mean V=0.76, high; mean V=0.67, moderate), with reliability (Spearman-Brown=0.730). Data were analyzed using Multivariate Analysis of Variance (MANOVA). The findings revealed a statistically significant multivariate difference between groups (Wilks' Λ=0.519; F=17.123; $p<0.05$; partial η^2=0.481). Univariate analyses confirmed significantly higher conceptual understanding (F=7.634; $p<0.05$; partial η^2=0.167) and critical reasoning (F=18.937; $p<0.001$; partial η^2=0.333) in the deep learning class. These findings suggest that deep learning pedagogy may foster vocational students' higher-order cognitive skills, encouraging mathematics educators to integrate mindful, meaningful, and joyful learning activities connected to industrial contexts.

Keywords: Deep Learning; Conceptual Understanding; Critical Reasoning; Exponents; Vocational Mathematics

Abstrak

Penelitian ini dilatarbelakangi oleh rendahnya pemahaman konsep dan penalaran kritis matematis siswa SMK yang disebabkan oleh pembelajaran konvensional yang berorientasi pada hafalan prosedural, serta terbatasnya bukti empiris tentang intervensi *deep learning* dalam matematika vokasi. Penelitian ini bertujuan menganalisis pengaruh pendekatan *deep learning* terhadap pemahaman konsep dan penalaran kritis matematis siswa SMK pada materi eksponen. Metode kuasi-eksperimen dengan desain *posttest-only non-equivalent control group* digunakan. Sampel terdiri dari 40 siswa kelas X SMK Ma'arif 1 Metro, terbagi dalam kelompok eksperimen (n=19) yang mendapat pembelajaran *deep learning* dan kelompok kontrol (n=21) dengan pembelajaran konvensional. Data dikumpulkan menggunakan tes pemahaman konsep dan penalaran kritis (masing-masing 10 soal pilihan ganda), divalidasi oleh empat ahli menggunakan Aiken's V (rata-rata V=0,76 kategori tinggi; V=0,67 kategori sedang), dengan reliabilitas Spearman-Brown 0,730. Analisis data menggunakan MANOVA. Hasil penelitian menunjukkan perbedaan multivariat signifikan antara kedua kelompok (Wilks' Λ=0,519; F=17,123; p<0,05; partial η^2=0,481). Analisis univariat mengonfirmasi bahwa kelas *deep learning* memiliki pemahaman konsep (F=7,634; p<0,05; partial η^2=0,167) dan penalaran kritis (F=18,937; p<0,001; partial η^2=0,333) yang lebih tinggi secara signifikan. Temuan ini mengindikasikan bahwa pendekatan *deep learning* berpotensi mengembangkan kemampuan berpikir tingkat tinggi siswa SMK, sehingga mendorong pendidik matematika untuk mengintegrasikan aktivitas pembelajaran *mindful*, *meaningful*, dan *joyful* yang terhubung dengan konteks industri.

Kata kunci: *Deep Learning*; Pemahaman Konsep; Penalaran Kritis; Eksponen; Matematika SMK

Introduction

The educational landscape of the Fourth Industrial Revolution necessitates fundamental pedagogical transformation, particularly within vocational education contexts such as Indonesian Vocational High Schools (*Sekolah Menengah Kejuruan*/SMK). Beyond technical competencies, vocational graduates must possess higher-order thinking skills encompassing profound conceptual understanding and critical reasoning capabilities (López et al., 2023). Mathematics plays a strategic role in cultivating these competencies through logical reasoning, systematic thinking, and analytical processes. However, preliminary observations at SMK Ma'arif 1 Metro and prior studies (Sari, 2025; Septia et al., 2021) indicate that mathematics instruction in vocational schools remains dominated by teacher-centred, lecture-based approaches that emphasize procedural memorization over conceptual understanding (Haq & Prasetiyo, 2025). Consequently, students struggle with non-routine problems and fail to provide mathematical justifications (Purwanto et al., 2023; Zuurmond et al., 2024). Indonesia's low PISA 2022 performance (OECD, 2023) further reflects a deep learning crisis requiring pedagogical reorientation.

Addressing these challenges, the deep learning approach—defined here as a pedagogical framework emphasizing meaningful, mindful, and joyful learning (Orhani, 2024; Rahmandani et al., 2025)—offers a promising alternative. *It is important to clarify that the term "deep learning" in this study refers exclusively to a pedagogical approach (deep approach to learning) and is not related to artificial intelligence or machine learning.* Deep learning aligns with cognitive constructivism, positioning students as active knowledge builders through idea interaction and critical reflection (Zain, 2025). Prior studies have shown its efficacy in enhancing conceptual understanding (Wibowo et al., 2025) and critical thinking (Sudarmono et al., 2025), including in vocational settings (Mandasari et al., 2025). However, most previous investigations focused on single dependent variables and did not examine simultaneous effects on both conceptual understanding and critical reasoning. Moreover, research on deep learning applied to exponential content—foundational for logarithms and growth models—remains scarce, as does its use in vocational education with multivariate analysis.

The present study addresses these gaps. Its novelty lies in: (1) applying MANOVA to simultaneously test the effect of deep learning on two interrelated cognitive outcomes (conceptual understanding and critical reasoning) within a vocational school context; and (2) focusing specifically on exponential content, which is rarely examined in deep learning literature. Instrument validation using Aiken's V and Spearman-Brown reliability follows standard procedures and is not claimed as novelty. Based on this background, we hypothesized that the deep learning approach would produce significantly higher post-test scores in both conceptual understanding and critical reasoning compared to conventional instruction.

Method

The present investigation employed a quantitative approach utilizing quasi-experimental methodology. The selection of this design was predicated on the consideration that within educational research contexts, researchers cannot execute complete randomization of research participants because classes are naturally constituted (Sugiyono, 2021). The design employed was a posttest-only non-equivalent control group design, encompassing two groups: an experimental class receiving deep learning approach instruction and a control class receiving conventional (expository) instruction. This design was selected because the investigation employed only final assessments (posttest) to measure students' conceptual understanding and critical reasoning following treatment administration, without utilizing pretest measures (Putri et al., 2025).

The absence of a pretest is acknowledged as a methodological limitation. Due to school scheduling constraints and the inability to administer additional tests without disrupting regular instruction, baseline equivalence between groups could not be empirically established through pretesting. Instead, the researcher relied on prior daily examination scores and teacher recommendations, which indicated comparable initial abilities ($t(38) = 0.423$, $p > 0.05$). Readers should interpret the findings with this limitation in mind.

The investigation was conducted at SMK Ma'arif 1 Metro, located in Metro City, Lampung, Indonesia, during the odd semester of the 2025/2026 academic year (August to October 2025). The research population comprised all tenth-grade students enrolled at SMK Ma'arif 1 Metro, totaling 124 students distributed across four classes. Purposive sampling was employed with the following operational criteria: (1) both classes possessed relatively balanced student numbers; (2) both classes demonstrated no significant difference in mean previous mathematics daily examination scores based on independent t-test analysis ($t(38) = 0.423$, $p > 0.05$); (3) both classes exhibited comparable socio-economic characteristics and learning facilities according to school data; (4) both classes consented to participate in the entire research protocol. Based on these criteria, the experimental class (X AKL/TB 1, $n = 19$) received deep learning instruction, while the control class (X TKJ, $n = 21$) received conventional instruction.

The concept understanding assessment employed multiple-choice format comprising 10 items constructed according to Bloom's Revised Taxonomy (Trisnani et al., 2025). The critical reasoning assessment utilized multiple-choice format encompassing 10 items designed to require students to engage in critical thinking processes. Both instruments underwent content validation by four experts (two university lecturers and two secondary teachers) employing Aiken's V coefficient, with the criterion $V \geq 0.70$ indicating validity (Astriani & Dhana, 2024). Reliability estimation employed the split-half technique with Spearman-Brown correction administered to 17 students external to the research sample.

Table 1. Instrument Content Validity Results (Aiken's V)

Instrument	Mean V	Category
Concept Understanding Test	0.76	High
Critical Reasoning Test	0.67	Moderate

Table 2. Instrument Reliability Test Results (Split-Half)

Statistic	Value
Spearman-Brown Coefficient	0.730
Interpretation	Reliable (High Category)

The deep learning approach was implemented in the experimental class across six sessions, each allocated 2 × 45 minutes. The instructional content addressed exponential concepts, including powers, exponential properties, elementary exponential equations, and exponential applications. This approach was operationalized through three foundational pillars: mindful, meaningful, and joyful learning (Rahmandani et al., 2025).

During the initial session, the instructor introduced exponential concepts through bacterial growth phenomena within food processing industrial contexts. Students were guided to recognize (mindful) the industrial relevance of exponential functions. The instructor posed stimulating questions designed to activate students' curiosity while connecting abstract concepts with authentic contexts (meaningful). The learning atmosphere was rendered enjoyable (joyful) through numerical estimation games employing power concepts.

Deep learning instruction emphasized concept discovery processes rather than reception of preformulated concepts. Students were not immediately provided with exponential property formulas but were guided to discover relational patterns through numerical exploration. At each session's conclusion, students engaged in learning reflection activities, documenting comprehended content, concepts remaining confusing, and material connections to their vocational specializations.

Data analytical procedures were executed in two stages. The first stage comprised prerequisite assumption testing, including multivariate normality assessment employing Mahalanobis Distance scatter plots and Pearson correlation coefficients, covariance matrix homogeneity examination utilizing Box's M Test, and variance homogeneity evaluation employing Levene's Test. The second stage encompassed hypothesis testing utilizing Multivariate Analysis of Variance (MANOVA) with a significance threshold of $\alpha = 0.05$. MANOVA was selected based on the research objective to examine the simultaneous effect of the independent variable on two correlated dependent variables (Backhaus et al., 2021). All statistical analyses were performed using SPSS version 21.

Results

Descriptive Statistics of Posttest Outcomes

The deep learning approach was implemented in the experimental class across six sessions, each allocated 2 × 45 minutes. The instructional content addressed exponential concepts, including powers, exponential properties, elementary exponential equations, and exponential applications. This approach was operationalized through three foundational pillars: mindful, meaningful, and joyful learning (Rahmandani et al., 2025)

Following completion of the entire instructional sequence, posttests were administered to measure students' conceptual understanding and critical reasoning across both instructional conditions (Wawan, 2023).

Table 3. Descriptive Statistics of Posttest Outcomes

Variable	Class	N	Minimum	Maximum	Mean	Std. Deviation
Concept Understanding	Deep Learning	19	60	95	76.84	9.87
	Conventional	21	45	85	69.05	10.24
Critical Reasoning	Deep Learning	19	55	90	73.68	10.56
	Conventional	21	40	75	59.52	11.23

Table 3 indicates that the mean concept understanding score for the deep learning class (76.84) exceeded the conventional class (69.05), yielding a differential of 7.79 points. Regarding critical reasoning, the deep learning class mean (73.68) likewise surpassed the conventional class mean (59.52), producing a differential of 14.16 points. Relatively balanced standard deviations indicate homogeneous data variation across groups.

The partial η^2 value for the experimental group on conceptual understanding was 0.167, which according to Cohen's (1988) criteria falls within the medium effect category (small = 0.01; medium = 0.06; large = 0.14). For critical reasoning, the partial η^2 value of 0.333 falls within the large effect category.

Multivariate Normality Assessment

The correlation analysis revealed a Pearson correlation coefficient of 0.985 between Mahalanobis Distance and theoretical quantiles ($p < 0.01$), confirming multivariate normal distribution of the data.

Covariance Matrix Homogeneity Assessment

Box's M Test results demonstrated a significance value of 0.641 ($p > 0.05$), indicating that covariance matrices between experimental and control classes were homogeneous, thereby satisfying the MANOVA assumption.

Variance Homogeneity Assessment

Levene's Test results indicated significance values of 0.066 for concept understanding and 0.631 for critical reasoning (both $p > 0.05$), satisfying the variance homogeneity assumption.

Hypothesis Testing with MANOVA

The multivariate test results revealed a Wilks' Lambda value for the group of 0.519 with $F\ (2, 37) = 17.123$ and significance of 0.000 ($p < 0.05$) (wawan, 2020). This finding indicates a statistically significant multivariate difference between the class receiving deep learning instruction and the class receiving conventional instruction across the combined dependent variables of conceptual understanding and critical reasoning. The Partial Eta Squared value of 0.481 indicates that 48.1% of the variance in the linear combination of dependent variables is attributable to instructional approach differences.

Table 4. Tests of Between-Subjects Effects

Tests of Between-Subjects Effects						
Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	Critical Reasoning	3458.954[a]	1	3458.954	7.634	.009
	Concept Understanding	10801.811[b]	1	10801.811	18.937	.000

a. R Squared = ,167 (Adjusted R Squared = ,145)
b. R Squared = ,333 (Adjusted R Squared = ,315)

The univariate test results revealed:

1. Concept Understanding: A statistically significant effect of instructional approach on concept understanding was obtained, $F(1, 38) = 7.634$, $p = .009$, partial $\eta^2 = .167$.
2. Critical Reasoning: A statistically significant effect of instructional approach on critical reasoning was obtained, $F(1, 38) = 18.937$, $p < .001$, partial $\eta^2 = .333$.

Indicator-Level Analysis

Table 5. Mean Scores by Concept Understanding Indicator

Concept Understanding Indicator	Deep Learning	Conventional	Mean Difference
Restating concepts	82.5	75.3	7.2
Classifying objects	79.8	71.6	8.2
Providing examples and non-examples	80.2	72.4	7.8
Presenting in mathematical representations	76.4	68.9	7.5
Developing necessary and sufficient conditions	74.8	64.2	10.6
Employing appropriate procedures	81.3	73.5	7.8
Applying concepts	75.1	61.8	13.3

Table 5 reveals that the largest mean differences between instructional conditions occurred for the indicators of applying concepts (13.3 points) and developing necessary and sufficient conditions (10.6 points). Both indicators necessitate deep conceptual understanding and higher-order cognitive processing.

Table 6. Mean Scores by Critical Reasoning Indicator

Critical Reasoning Indicator	Deep Learning	Conventional	Mean Difference
Identifying salient information	76.8	67.5	9.3
Analyzing inter-concept relationships	73.5	62.8	10.7
Evaluating arguments or solutions	74.2	61.4	12.8
Providing justification (logical reasoning)	71.3	58.6	12.7
Drawing logical conclusions	72.4	60.2	12.2

Table 6 indicates that the largest mean differences between instructional conditions occurred for the indicators of evaluating arguments or solutions (12.8 points), providing logical justification (12.7 points), and drawing logical conclusions (12.2 points)—all components central to critical thinking.

Discussion

The findings of this investigation demonstrate that the deep learning approach exerts a statistically significant effect on vocational students' conceptual understanding and critical mathematical reasoning considered simultaneously. This outcome aligns with research conducted by Wibowo et al. (2025) and Mandasari et al. (2025), who documented that implementing deep learning approaches significantly enhanced students' conceptual understanding relative to conventional instructional methods. The multivariate difference (Wilks' $\Lambda = 0.519$; $F = 17.123$; $p < 0.05$; partial $\eta^2 = 0.481$) indicates that deep learning simultaneously improves both cognitive outcomes, with the large effect size suggesting substantial practical significance beyond mere statistical significance.

The statistically significant difference in conceptual understanding ($F = 7.634$; $p < 0.05$; partial $\eta^2 = 0.167$) suggests that the deep learning approach may have supported the development of more robust cognitive structures among students. The concept discovery process facilitated through exploration and discussion enables students to actively construct knowledge, thereby potentially engendering comprehension that is both deeper and more durable (Rachmawati et al., 2023; Zain, 2025). Indicator-level analysis reveals that the deep learning approach's superiority is most pronounced for the abilities to apply concepts (mean difference = 13.3 points) and develop necessary and sufficient conditions (mean difference = 10.6 points). These competencies demand relational understanding rather than merely instrumental comprehension (Kilpatrick et al., 2001), aligning with research by Septia et al. (2021) emphasizing the significance of meaningful learning for developing vocational students' conceptual understanding.

Regarding critical reasoning, the substantial differential between instructional conditions (mean difference = 14.16 points; $F = 18.937$; $p < 0.001$; partial $\eta^2 = 0.333$) indicates that the deep learning approach appears to support the development of students' higher-order cognitive capabilities. Discussion, presentation, and reflection activities embedded within the instructional design train students to analyse, evaluate, and provide justification for mathematical arguments. This finding corroborates research by Sudarmono et al. (2025), who reported that deep learning approaches stimulate students' analytical, evaluative, and justificatory competencies. The indicators of evaluating arguments or solutions (mean difference = 12.8 points), providing logical justification (mean difference = 12.7 points), and drawing logical conclusions (mean difference = 12.2 points) demonstrate the most substantial improvements. These three indicators represent the highest levels of critical thinking according to Ennis's (2018) framework, and this outcome is inseparable from the instructional design, providing opportunities for students to engage in mutual response, critique, and defence of their positions (Orhani, 2024).

The novelty of this study resides in two aspects. First, the application of MANOVA enables simultaneous testing of two interrelated dependent variables, demonstrating that deep learning's benefits transfer across related competencies (López et al., 2023). Second, this study provides empirical evidence of deep learning's effectiveness specifically for exponential content within vocational education contexts (St Omer et al., 2025; Zhang et al., 2024). The differential effect sizes observed (larger for critical reasoning than conceptual understanding) suggest that deep learning may be especially valuable for developing higher-order thinking skills that employers demand from vocational graduates (Zuurmond et al., 2024). Practically, vocational mathematics educators should integrate deep learning approaches through mindful, meaningful, and joyful activities that connect mathematical concepts with industrial contexts relevant to students' specializations (Rahmandani et al., 2025; Wawan, 2020).

Several limitations warrant consideration. The posttest-only design precluded measurement of individual improvement, and the absence of a pretest meant initial group equivalence could not be empirically verified (Edmonds & Kennedy, 2016). The critical reasoning instrument's validity coefficient fell within the moderate category ($V = 0.67$), below the ideal threshold of 0.70, so findings pertaining to critical reasoning should be interpreted with caution. The sample was restricted to a single institution ($N = 40$), and the intervention duration was relatively brief (six sessions). Future research should employ pretest-posttest control group designs with larger, more diverse samples; develop critical reasoning instruments in essay or mixed formats; and examine deep learning effects across additional mathematical content domains and educational levels over extended intervention durations.

Conclusion

Based on the findings and discussion, it can be concluded that the deep learning approach significantly affects conceptual understanding and critical mathematical reasoning among vocational students studying exponential content. MANOVA results revealed a statistically significant multivariate difference between classes receiving deep learning instruction and those receiving conventional instruction across the combined dependent variables (Wilks' $\Lambda = 0.519$; $F = 17.123$; $p < 0.05$; partial $\eta^2 = 0.481$). Univariate analyses confirmed that the deep learning approach proved more effective than conventional instruction for enhancing both conceptual understanding ($F = 7.634$; $p < 0.05$; partial $\eta^2 = 0.167$) and critical reasoning ($F = 18.937$; $p < 0.001$; partial $\eta^2 = 0.333$). Indicator-level analyses revealed that the most pronounced advantages occurred for applying concepts and evaluating arguments or solutions—competencies reflecting higher-order cognitive processing.

Implications of this study suggest that vocational mathematics educators should consider adopting deep learning approaches to simultaneously develop students' conceptual understanding and critical reasoning capabilities. Such approaches may be integrated through exploratory activities, reflective discussions, and connections with industrial contexts relevant to students' vocational specializations. Limitations of this study include: (1) the posttest-only design that precluded measurement of individual improvement; (2) the absence of a pretest to empirically verify initial group equivalence; (3) a sample restricted to a single institution; (4) the critical reasoning instrument's validity coefficient falling within the moderate category; and (5) a relatively brief intervention duration (six sessions). Future research is advised to employ pretest-posttest control group designs with larger and more diverse samples, develop critical reasoning instruments in essay or mixed formats, and examine deep learning effects across additional mathematical content domains and educational levels over extended intervention durations.

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