

The Effect of The RADEC Model on Students' Conceptual Understanding and Critical Thinking Skills in Animalia Classification

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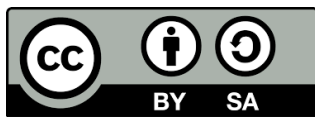
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ABSTRACT

This study was motivated by the prevalence of teacher-centered instruction in biology classrooms, which limits students' conceptual understanding and hinders the development of critical thinking skills. These challenges are particularly evident in animal classification, which involves complex taxonomic concepts and requires systematic reasoning. Therefore, a more structured and student-centered instructional approach is needed. This study aimed to examine the effects of the Read, Answer, Discuss, Explain, and Create (RADEC) learning model on students' conceptual understanding and critical thinking skills in animal classification. A quasi-experimental design was employed, involving 70 tenth-grade students from SMA Negeri 18 Jakarta who were assigned to experimental and control groups. Data were collected using essay-based written assessments designed to measure conceptual understanding and critical thinking skills. Preliminary statistical analyses included the Shapiro–Wilk test for normality, Levene's test for homogeneity of variance, and Box's M test for equality of covariance matrices. The results indicated that the relevant statistical assumptions were satisfied. Subsequently, multivariate analysis of variance (MANOVA) was performed, followed by univariate analyses to examine differences between the groups. The findings revealed statistically significant differences in learning outcomes between the experimental and control groups. Overall, the implementation of the RADEC learning model had a significant positive effect on students' conceptual understanding and critical thinking skills in animal classification.



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INTRODUCTION

Biology education aims not only to enable students to master scientific facts, concepts, and principles but also to develop their ability to explain relationships among concepts and apply scientific knowledge to solve real-world problems. In line with the implementation of Indonesia's Kurikulum Merdeka (Independent Curriculum), biology instruction is expected to develop students' competencies comprehensively through active, meaningful, and student-centered learning processes that foster scientific thinking skills (Rahajirin & Faizah, 2025). Learning strategies that promote deep cognitive engagement have been shown to be more effective in developing durable knowledge structures than rote memorization (Chi & Wylie, 2014; (Santos-Meneses et al., 2023).

One of the most conceptually challenging topics in biology is the classification of living organisms, particularly those belonging to the kingdom Animalia. This topic requires students to understand the distinguishing characteristics of different animal phyla and the evolutionary relationships among organisms. However, the abundance of scientific terminology and the complexity of taxonomic relationships often make the material difficult to comprehend, encouraging students to rely on memorization rather than conceptual understanding (Hizqiyah et al., 2023). A mismatch between instructional strategies and the characteristics of the subject matter may contribute to low student participation (Mardiana & Emmiyati, 2024). Furthermore, limited variation in formative assessment practices may prevent teachers from accurately identifying students' individual learning needs (Cohen, 2020), potentially contributing to reduced student engagement (Nursabila et al., 2025).

Conceptual understanding involves students' ability to interpret, explain, and apply scientific concepts when solving problems (Mahmud et al., 2026). In addition, biology education requires critical thinking skills that enable students to analyze information, evaluate evidence, and formulate logical conclusions (Sapriati et al., 2024). However, previous research has indicated that students' critical thinking skills may remain underdeveloped without appropriate pedagogical interventions (Singhi & Anmol, 2025). This challenge may be exacerbated by reliance on conventional instructional media that provide limited opportunities for independent conceptual exploration (Nurfadilah et al., 2025), despite evidence that appropriate instructional media integration can strengthen students' cognitive structures and conceptual understanding (Nurhasanah & Putri, 2020).

In addition to difficulties in conceptual understanding, the development of critical thinking skills remains a significant challenge in biology education across different educational levels. Students frequently engage in passive information reception rather than critically examining the concepts being studied. Learning activities often emphasize recalling factual information instead of constructing arguments, evaluating evidence, and solving complex problems. Consequently, conventional instructional practices may provide insufficient opportunities for students to develop higher-order thinking skills. These challenges highlight the importance of instructional approaches that actively engage students in inquiry, discussion, reasoning, and knowledge application.

Addressing these challenges requires an instructional model that promotes active student participation while simultaneously strengthening conceptual understanding and critical thinking skills. One promising approach is the Read, Answer, Discuss, Explain, and Create (RADEC) learning model. This model consists of five sequential stages in which students read instructional materials before classroom activities, answer questions based on their reading, discuss their responses with peers, explain their understanding, and create products that demonstrate the application of acquired knowledge (Pratama et al., 2019; Suwartini et al., 2024). These stages encourage students to construct knowledge actively, engage in collaborative reasoning, develop critical thinking skills, and strengthen conceptual understanding through meaningful learning experiences (Rahayu et al., 2021).

Theoretically, the RADEC learning model aligns with the principles of deep learning, which emphasize connecting new information with prior knowledge, engaging in critical reflection, and applying knowledge to solve problems. The sequential stages of RADEC provide structured instructional scaffolding that supports progressively more complex

cognitive activities. Reading and answering questions facilitate initial knowledge acquisition and conceptual processing, while discussion and explanation promote analytical reasoning, metacognitive awareness, and collaborative knowledge construction. The Create stage encourages students to apply their understanding in new contexts, potentially demonstrating knowledge transfer and higher-order cognitive engagement (Salim et al., 2026). Accordingly, the RADEC model offers a systematic instructional framework for integrating conceptual learning with critical thinking development.

Several previous studies have demonstrated the potential effectiveness of the RADEC learning model in improving higher-order thinking skills and conceptual understanding (Pratama et al., 2019; Septiyani & Wilujeng, 2023; (Suwartini et al., 2024). However, these studies were conducted across different educational levels and instructional contexts, leaving questions regarding the model's effectiveness in specific biology topics. In particular, empirical evidence examining the simultaneous effects of RADEC on conceptual understanding and critical thinking skills in animal classification among senior high school students remains limited. Although previous research has explored the benefits of RADEC for individual learning outcomes, further investigation is needed to determine whether the model produces significant differences across these two interrelated cognitive competencies when examined simultaneously. This gap provides the rationale for employing multivariate analysis of variance (MANOVA) to evaluate the effects of the RADEC model on both learning outcomes within a single analytical framework.

The present study therefore focused on the implementation of the RADEC learning model in tenth-grade biology instruction, specifically in the classification of living organisms within the kingdom Animalia. The study examined two dependent variables: students' conceptual understanding and critical thinking skills. The research addressed three questions: whether the RADEC learning model significantly affected students' conceptual understanding, whether it significantly affected their critical thinking skills, and whether it had a statistically significant simultaneous effect on both outcomes. By examining these relationships through MANOVA, the study sought to provide empirical evidence regarding the effectiveness of RADEC as an instructional approach for developing cognitive competencies in biology education.

The findings of this study are expected to contribute to both educational theory and instructional practice. Theoretically, the study may expand empirical knowledge regarding the application of the RADEC learning model in supporting conceptual understanding, critical thinking, and deep learning in secondary biology education. Practically, the findings may assist teachers in designing more participatory and cognitively engaging instructional activities, provide students with opportunities to strengthen conceptual understanding and scientific reasoning, and support schools in implementing innovative learning strategies aligned with the Kurikulum Merdeka and the Profil Pelajar Pancasila (Pancasila Student Profile). Furthermore, the study may provide a foundation for future investigations examining the effectiveness of RADEC across different biological topics, educational levels, and learning environments.

METHOD

This study aimed to measure improvements in students' conceptual understanding and critical thinking skills and examine the effects of the Read, Answer, Discuss, Explain, and Create (RADEC) learning model on these outcomes in animal classification. The research was conducted at SMA Negeri 18 Jakarta, located on Jalan Warakas 1, Tanjung Priok, Jakarta, during the second semester of the 2025/2026 academic year, from March to April 2026.

A quantitative approach with a quasi-experimental design was employed to investigate the effects of instructional models on student learning outcomes. The independent variable was the instructional model, while the dependent variables were conceptual understanding (Y1) and critical thinking skills (Y2). The study adopted a nonequivalent pretest–posttest control group design involving two intact classes: an experimental group and a control group. The experimental group received instruction using the RADEC learning model, whereas the control group was taught using the Discovery Learning model. Both groups completed pretests before the intervention and posttests afterward. The experimental group followed the sequence O1–X–O2, while the control group followed O3–C–O4, where X represented RADEC instruction, C represented Discovery Learning instruction, O1 and O3 represented pretests, and O2 and O4 represented posttests.

Population and Research Sample

The study population comprised 280 tenth-grade students enrolled at SMA Negeri 18 Jakarta during the second semester of the 2025/2026 academic year. These students were distributed across eight classes (X-1 to X-8), each containing approximately 35 students. Cluster random sampling was employed to select two intact classes through a random drawing. Class X-1 was assigned to the experimental group, which received RADEC instruction, while class X-3 served as the control group, which received Discovery Learning instruction. The final sample consisted of 70 students, with 35 students in each group.

Data Collection Techniques

Data collection involved preliminary observations, instructional interventions, and data verification. Preliminary observations were conducted to assess classroom conditions, student characteristics, and the suitability of instructional materials. These observations were supplemented by a review of curriculum documents, including the syllabus and Alur Tujuan Pembelajaran (ATP; Learning Objectives Sequence). Data were collected using validated test and nontest instruments. Essay-based pretests and posttests were administered to assess conceptual understanding at the applying (C3) and analyzing (C4) levels of the revised Bloom's taxonomy (Anderson & Krathwohl, 2001) and critical thinking skills based on the Focus, Reason, Inference, Situation, Clarity, and Overview (FRISCO) framework (Ennis, 1996). The implementation of the RADEC learning model was monitored by an independent observer using a dichotomous observation checklist with Yes/No responses based on the Guttman scale. Data verification involved checking the completeness of students' responses, participant identification, and attendance records across the pretest, intervention, and posttest sessions. Complete datasets were subsequently analyzed using IBM SPSS Statistics, version 25.

Data Analysis Techniques

Quantitative data were analyzed using one-way multivariate analysis of variance (MANOVA) in IBM SPSS Statistics, version 25, to examine the simultaneous effects of the instructional model on conceptual understanding and critical thinking skills. Descriptive statistics, including minimum, maximum, mean, median, range, variance, and standard deviation, were calculated for pretest and posttest scores. Learning improvements were assessed using gain scores and normalized gain (g), calculated as $g = (\text{posttest score} - \text{pretest score}) / (\text{maximum possible score} - \text{pretest score})$. Normalized gain values were classified as high ($g > 0.70$), moderate ($0.30 \leq g \leq 0.70$), or low ($g < 0.30$) (Hake, 1999).

Before conducting MANOVA, statistical assumptions were assessed using the Shapiro–Wilk test for normality, Levene's test for homogeneity of variance, Box's M test for equality of covariance matrices, Pearson's correlation analysis to examine relationships between dependent variables, and linearity assessments. Normality and homogeneity assumptions were considered satisfied when the corresponding p -values exceeded 0.05, subject to the requirements of each test. Correlations between dependent variables were examined to identify potential multicollinearity, with coefficients between 0.30 and 0.90 used as a reference range (Field, 2018; Hair et al., 2022). Linearity was assessed using the deviation-from-linearity test, with $p > 0.05$ indicating no statistically significant departure from linearity.

Multivariate hypothesis testing was performed using Wilks' lambda (Λ) at a significance level of $\alpha = 0.05$. The null hypothesis (H_0) stated that the instructional model had no statistically significant simultaneous effect on conceptual understanding and critical thinking skills, whereas the alternative hypothesis (H_1) stated that a significant multivariate effect existed. The null hypothesis was rejected when $p < 0.05$; otherwise, it was not rejected. When MANOVA indicated a statistically significant multivariate effect, follow-up univariate analyses were conducted using the Tests of Between-Subjects Effects to examine differences in each dependent variable. Effect sizes were estimated using partial eta squared (η^2), with values of approximately 0.01, 0.06, and 0.14 interpreted as small, medium, and large effects, respectively (Fritz, Morris, & Richler, 2012).

RESULTS AND DISCUSSION

Analytical Prerequisite Testing

1. Normality Test

The normality test in this study was carried out using the Shapiro wilk test for a sample size as in this study involving 35 students in each class group. The results of the normality test of critical thinking ability and concept understanding in learning Animalia Classification material in the control and experimental class groups, both pre-test and post-test scores are presented in Table 1.

Table 1. Multivariate Normality Test Results (Shapiro Wilk)

No.	Class Groups	Critical Thinking Skills		Concept Understanding Ability		Ket
		<i>Pretest</i>	<i>Posttest</i>	<i>Pretest</i>	<i>Posttest</i>	
1.	Experiments	0.434	0.642	0.342	0.418	Normal
2.	Controls	0.302	0.502	0.144	0.305	Normal

Based on Table 1, the results of the normality test using the Shapiro-Wilk test show that all variables, namely critical thinking ability and concept understanding ability in both the experimental and control groups, both pretest and posttest data, have a significance value of > 0.05 . This shows that all data are normally distributed, thus meeting the assumption of normality and are suitable for parametric statistical analysis at the next stage (Ghozali, 2021).

2. Varinas Homogeneity Test (Leven's Test)

The homogeneity test in this study was carried out using the Levene test. The results of the homogeneity test of critical thinking ability and concept understanding in learning Animalia Classification material in the control and experimental class groups, both pre-test and post-test scores are presented in Table 2.

Table 2. Results of the Variance Similarity Test (Levene's Test)

<i>Variable</i>	F	df1	df2	Sig.	Ket
Post Test Concept Understanding	0.208	1	68	0.650	Homogeneous
Post Test Critical Thinking	0.908	1	68	0.344	Homogeneous

Based on the results of the Variance Similarity Test (Levene's Test), the significance value (Sig.) for the Critical Thinking Post Test variable was 0.650 and the Concept Understanding Post Test was 0.344. Because the total Sig. value was > 0.05 , the variance between groups was declared homogeneous. Thus, the data met the homogeneity assumption so that it was suitable for future statistical analysis.

3. Variance-Covariance Matrix Homogeneity Test (Box's M Test)

To check whether the variance-covariance matrix of each group is the same in MANOVA, the Box's M test can be used. For MANOVA to be successful, the original population of the groups must have an identical structure of variance and covariance. A significance value (Sig.) greater than 0.05 in the test results indicates that the variance-covariance matrix between groups is homogeneous. This shows that the variance-covariance structure does not differ significantly between the groups tested as shown in Table 3 as shown by the findings of the Box's M test.

Table 3. Variance-Covariance Matrix Homogeneity Test Results

Box's M	F	df1	df2	Sig.
6.744	2.176	3	2320.000	0.089

According to Hair et al. (2022), the data meet homogeneity if the significance value (Sig.) > 0.05 . Based on Table 4.6, a significance value (Sig.) of 0.089 (> 0.05) is obtained, so that H_0 is accepted. This shows that the variance-covariance matrix in the experimental group and the control group is homogeneous so that the MANOVA assumption has been fulfilled (Hair et al., 2022).

4. Correlation Test Between Variables

Correlation tests between dependent variables were conducted to determine the relationship between critical thinking skills and concept comprehension in each research group. Tests using Pearson correlation were carried out separately in the experimental group and the control group. The results of the correlation test are presented in Table 4.

Table 4. Correlation Test Results Between Variables

Groups	N	Pearson Correlation	Sig.
Controls	35	0,726	<0.001
Experiments	35	0,765	<0.001

Based on Table 4, in the control group, a Pearson Correlation coefficient of 0.726 was obtained with a significance value of <0.001, while in the experimental group, a Pearson Correlation coefficient of 0.765 was obtained with a significance value of <0.001. These results show that there is a strong and significant positive relationship between critical thinking skills and concept understanding in both groups. Thus, the assumption of correlation between dependent variables for MANOVA analysis is fulfilled.

5. Linearity Test

The linearity test was conducted to find out whether the relationship between dependent variables, namely concept understanding and critical thinking skills, was linear in each research group. The test was conducted using the Test for Linearity. The results of the linearity test in the experimental group and the control group are presented in Table 5.

Table 5. Results of the Linearity Test

Groups	F	Deviation From Linearity (Sig)	Ket
Controls	1,773	0,139	Linear
Experiments	1,698	0,140	Linear

Based on Table 5, in the control group, the significance value of Deviation from Linearity was 0.139, while in the experimental group it was 0.140. Both values were greater than 0.05, thus indicating that there was no deviation from the linear relationship between conceptual understanding and critical thinking ability. Thus, the assumption of linearity in both groups has been fulfilled so that MANOVA analysis can be performed.

Hypothesis Testing (MANOVA)

This hypothesis test aims to answer the formulation of the problem regarding the simultaneous influence of the RADEC learning model on students' conceptual understanding and critical thinking skills. The test was carried out using Wilks' Lambda statistics. The results of the MANOVA test are presented in Table 6.

Table 6. Wilk' Lambda Manova Test

Effect	Value	F	Hypothesis df	Sig.	Partial Eta Squared
Wilk' Lambda	0.426	45.153	2	< 0.001	0.574

Based on the results of the MANOVA test in Table 6, Wilks' Lambda value of 0.426 was obtained with a value of $F(2,67) = 45.153$ and significance (Sig.) < 0.001 . Because the significance value is much smaller than 0.05 (Sig. < 0.05), H_0 is legitimately rejected and H_1 is accepted. This proves that there is a significant influence of the application of the RADEC learning model on students' critical thinking skills and concept understanding simultaneously.

In addition, the Partial Eta Squared value of 0.574 showed that the RADEC model together contributed a huge influence, namely 57.4% to the variation in the increase of the two cognitive variables simultaneously, while the rest was influenced by other factors outside the study.

Advanced Analysis and Effect Size Measurement

After the main hypothesis is proven to be simultaneously significant, a follow-up analysis (Tests of Between-Subjects Effects) is carried out to examine the effect size of the influence of the RADEC model on each specific bound variable. The results of the follow-up analysis are presented in Table 7.

Table 7. Advanced Analysis of Contributions Per Variable (Tests of Between-Subjects Effects)

Variable	<i>F</i>	<i>Sig</i>	<i>Partial Eta Squared</i>	Categories Influence
Post Test Concept Understanding	76.706	<0.001	0,557	Large
Post Test Critical Thinking	85.619	<0.001	0,530	Large

Based on Table 7, the significance value for both variables is at < 0.001 . This value meets the requirements for a strict significance limit based on the Bonferroni correction (0.025). Analysis of the magnitude of the effect using Partial Eta Squared revealed that the RADEC model contributed 0.557 or 55.7% (large category) to the variation in improving students' conceptual understanding. On the other hand, the contribution to the escalation of critical thinking skills was also recorded at 0.530 or 53.0% (large category). This follow-up analysis data empirically confirms that the RADEC learning model intervention is effective in boosting students' understanding of concepts and critical thinking skills evenly and substantially.

The average score of the critical thinking final test (post-test) which reached 89.77 and concept understanding of 91.34 in the experimental class based on Table 4.1 provides a clear picture of the difference in learning outcomes when compared to the control class which only obtained a score of 77.03 for critical thinking and 78.40 for concept understanding. The high achievement in this experimental class is suspected to be strong because the use of the RADEC learning model is able to provide space for students to construct their own knowledge gradually, which has a direct impact on improving students' analytical power and mastery of material. As in a study conducted by Pratama et al. (2019), it is explained that regular learning steps are very helpful for students to think sharply in solving a problem. The strengthening of this argument is also in line with the findings of research conducted by Hattie & Donoghue (2016) which states that the habit of students being actively involved in the learning process makes the understanding of the material stick in students' memory for much longer.

The initial activity in this learning model starts from reading the material independently at home before face-to-face activities are carried out at school. Based on the first syntax of the RADEC learning model, namely the reading stage, students are trained to explore basic information independently in order to have initial knowledge before discussing it in class. Independence in formulating this initial understanding is factor by the existence of literacy responsibilities that trigger their optimal cognitive readiness. The readiness of this reading stage contributes to a high increase in material mastery, which is evidenced by the N-gain score of Concept Comprehension in Table 4.3 where the experimental class obtained a score of 0.77 (high category), far exceeding the control class which only received 0.39. This is in line with research conducted by Schunk (2020) which explains that learning independence plays an important role in strengthening students' mental readiness before receiving new material. The findings are also strengthened by research conducted by Arends (2012) which states that the habituation of independent literacy is consistently able to build a solid initial thinking framework for students.

The learning process continues at the stage of answering triggering questions which is designed to test students' initial level of understanding of the biology material that has been read before. Based on the syntax of the Answer stage in this RADEC learning model, students are directed to write down answers and note parts of the material that are still not understood. The success of this stage is clear from the average understanding of experimental class concepts in Table 4.1 which shot from 65.57 (pre-test) to 91.34 (post-test). This spike in scores is suspected to occur because the process of answering questions in writing forces students to rearrange information that is still random into a more structured conceptual understanding. In a study conducted by Chi & Wylie (2014), it was explained that interactive constructive activities have been proven to be effective in transforming superficial understanding into meaningful understanding. This reinforcement is in line with the findings of research conducted by (Suwartini et al., 2024) which stated that structured stage-based learning makes it easier for students to grasp abstract science material.

Activities in the class were then focused on the stage of group discussion to decompose the concept of animal taxonomy with peers to solve learning barriers. Based on the syntax of the discussion stage, students exchanged ideas and unified views, which simultaneously strengthened conceptual understanding and trained critical thinking acumen. The effectiveness of this group argument exchange was very well recorded in the increase in Critical Thinking N-gain in Table 4.2, where the experimental class touched a score of 0.77, inversely proportional to the control class which was only at 0.39. This significant score gap is factored by the existence of group dynamics that require students to not only receive information, but to verify, refute, and prove the truth of each other's arguments. As in the research conducted by (Jumanto et al., 2024), it is explained that the process of communicating ideas orally can train courage and sharpen students' logic of thinking. This statement is strengthened by research conducted by (Handayani et al., 2021) which states that interactive discussion activities are able to effectively reduce misconceptions of science materials.

The next stage of the RADEC learning model involves explaining the results of the group work in front of the class to test the overall understanding of the material in front of their peers. Based on the syntax of the explain, students are given the opportunity to articulate

their scientific reasoning openly while getting a straightening of concepts directly from the teacher. The quality of students' oral explanations contributes to the widening of the gap in learning completion, which is evident from the difference in the final achievement of critical thinking in the experimental class (89.77) which outperformed the control class (77.03) by 12.74 points based on Table 4.1. This is because direct exposure in front of the class demands greater academic responsibility, so that students are motivated to develop a more logical and systematic frame of mind. In a study conducted by Paul & Elder (2014), it was explained that logical analysis is formed very strongly when students are accustomed to presenting arguments in public. This is supported by research conducted by (Candraswari & Suniasih, 2024) which states that students' activeness in delivering oral explanations has a major impact on the achievement of their academic competence.

The culmination of this series of RADEC learning models is realized through the stage of creating real products that test the level of creativity and high level of understanding of students of biological materials. Based on the syntax of the Create stage, students are directed to apply the theory of classification of living things into the form of innovative applicative works. Evidence of the success of this product creation stage is validated in the acquisition of N-gain of Concept Understanding in Table 4.3 and Critical Thinking in Table 4.2 which both achieved a score of 0.77 (high category). This maximum achievement is strongly suspected to be derived from the high level of cognitive demands (C6) at the creation stage, which requires students to synthesize all the information that has been learned into a complete and relevant work. As in a study conducted by Anderson & Krathwohl (2001), it was explained that performance-based assignments at a high cognitive level were able to validly measure the level of student understanding. These findings are strengthened by research conducted by (Campbell et al., 2020).

The entire series of syntax of the RADEC learning model has been proven to be able to boost student learning outcomes at large. The integration of all learning stages provides a guarantee that students not only memorize the material, but also really master concepts and analytical reasoning in depth. The achievement of this comprehensive competency is factored by the continuity between RADEC syntaxs that complement each other's weaknesses of conventional learning. In a study conducted by Slavin (2018), it was explained that product-based cooperative learning accelerates the achievement of students' multi-competencies optimally. This reinforcement is in line with research conducted by Sudjana (2005) who stated that the success of a learning method is measured by its ability to achieve competency targets in an integrated manner.

The effect of the application of the RADEC learning model on the concept comprehension variable can be observed in depth through the N-Gain score of the experimental class in Table 4.3 which reached 0.77. This surge in concept understanding is caused by the habit of taxonomic identification which is carried out independently and verified communally, so that knowledge is embedded more precisely in students' long-term memory. As in the research conducted by Panuluh & Fitri (2016), it is explained that univariate instrument calibration ensures accurate mastery of measurable concepts. This is supported by research conducted by Sugiyono (2022).

This considerable increase in conceptual understanding proves that the student-centered learning stage is able to deeply embed the subject matter in the cognitive structure of the

treatment class. This striking difference in learning outcomes is suspected to be because control classes that use Discovery Learning tend to be interrupted at the discovery stage without ending with the product synthesis process as in the final stage of RADEC. In the research conducted by Arikunto (2019), it was explained that a systematic educational research procedure is able to prove the superiority of treatment objectively. The strengthening of this argument is also in line with the research conducted by Ridwan (2015).

The relationship between the stages of the RADEC learning model and the improvement of concept understanding can also be seen from how students are able to relate animal morphological features to the taxon level appropriately. The success of associating physical characteristics of animals is factored by visual and textual stimulation that is constantly provided during the Read and Answer process. As in the research conducted by Trianto (2014), it is explained that innovative learning model design plays an important role in producing a solid understanding of concepts. These findings are strengthened by research conducted by Dahar (2011).

The effect of the application of the RADEC learning model on the critical thinking variable showed very significant results. The N-Gain score of critical thinking in the experimental class in Table 4.2 was recorded at 0.77, which was classified as high and exceeded the control class. This significant increase in reasoning is because students are used to clashing their ideas with the views of other groups, so that their evaluation and analytical powers are naturally honed. In a study conducted by Ennis (1996), it was explained that problem-solving-based assessment instruments are able to measure the increase in reasoning power precisely. This is strengthened by research conducted by Facione (2015).

Critical thinking that is well honed in the experimental class proves that the syntax of the RADEC learning model has succeeded in shaping the logical structure of students in depth. The formation of this logic framework is suspected to be because students are required to account for their final work scientifically, not just to give opinions. As in the research conducted by (Smith, 2020), it is explained that understanding biological taxonomy requires analytical reasoning trained through group investigation. This reinforcement is in line with research conducted by (Oktaviyanti & Fadly, 2023).

This consistency in increasing critical thinking confirms that the stages of problem-solving-based learning make a real contribution to the quality of students' analysis. The resilience of this analytical reason is most likely due to the repetition of cognitive patterns from dissecting abstract concepts into concrete artifacts. In a study conducted by Dimiyati & Mudjiono (2015), it was explained that the analysis of students' motivation and active involvement strengthens the analytical thinking process in the classroom. The findings are supported by research conducted by Gagne (1985).

Before hypothesis testing continues, the distribution of the data from the research must be ensured to meet the basic assumptions of parametric statistics so that the analysis results are avoided. Based on the results of the Shapiro-Wilk test in Table 4.4, the significance value of the critical thinking variables and concept understanding in all test groups is in the range of 0.144 to 0.642. Because all significance values exceed the real level of 0.05, the data is proven to be normally distributed. As in the research conducted by Biggs (2011), it is explained that the constructive alignment of curriculum and statistical data requires a normal

distribution. The strengthening of this argument is also supported by research conducted by Ausubel (1968).

The fulfillment of the assumption of normality in the research data provides certainty that the entire distribution of data is representative of the population. In a study conducted by Joyce & Weil (2009), it was explained that valid statistical modeling requires a normal distribution of data to support further testing. These findings are strengthened by research conducted by Borg & Gall (2003).

The similarity of data variance between sample groups also needs to be verified to ensure fairness in the final comparison process. Based on the Levene's Test in Table 4.5, the significance value of data variance was recorded at 0.650 for the Critical Thinking Post Test and 0.344 for the Concept Comprehension Post Test. Given that the value is above the real level requirement limit of 0.05, the data variance is declared homogeneous. As in a study conducted by Hattie & Donoghue (2016), it is explained that the equalization of the initial conditions of the learning group underlies the accuracy of the educational evaluation.

The homogeneous conditions in the data variance showed that the research subjects in the experimental and control classes came from the background of equivalent cognitive abilities. In the study conducted by Suwartini et al. (2024), it was explained that the equality of variance of the sample groups strengthened the validity of the experimental conclusions. These findings are supported by research conducted by Smith et al. (2020).

The variable covariance matrix bound in this study was tested to ensure the fulfillment of the assumption of multivariate similarity between treatment groups as a whole. Based on the results of the Box's M test in Table 4.6, the significance value obtained was recorded at 0.089, which is greater than the threshold of 0.05. The statistical test decision determined that the covariance matrix is said to be identical if it meets these conditions. As in the study conducted by Chi & Wylie (2014), it is explained that the stability of the multivariate data matrix greatly determines the reliability of educational analysis.

The fulfillment of the assumption of covariance matrix similarity provides full legitimacy for the use of multivariate tests at the next stage of hypothesis analysis. In a study conducted by Paul & Elder (2014), it was explained that the regularity of multivariate data patterns reflects the quality of reliable instruments. These findings are strengthened by research conducted by (Jumanto et al., 2024).

The simultaneous influence of the RADEC learning model on concept understanding and critical thinking together can be proven through advanced multivariate statistical testing. Based on MANOVA's calculations in Table 4.9, Wilks' Lambda value was recorded at 0.426 with an F value of 45.153 and a significance probability of <0.001 which was below the real level of 0.05. This simultaneous success stemmed from the integration of the entire syntax of the RADEC learning model. As in the research conducted by Handayani et al. (2021), it is explained that the application of the integrated learning model is able to boost students' multi-competencies simultaneously.

The success of simultaneous testing through MANOVA confirms that the RADEC learning model is able to unite conceptual and analytical cognitive mastery into a single whole. Based on the multivariate significance value of <0.001 in Table 4.9, the null hypothesis is rejected absolutely. In a study conducted by Anderson & Krathwohl (2001), it

was explained that the achievement of a high cognitive level simultaneously can be achieved through a successive instructional design.

Partial differentiation of learning outcomes in the variables of concept understanding and critical thinking showed a real influence of the treatment given. Based on the results of the Tests of Between-Subjects Effects test in Table 4.10, the significance value for the two variables was recorded at <0.001 each, which proves the rejection of the null hypothesis separately. As in the research conducted by Panuluh & Fitri (2016), it is explained that the partial testing is carefully able to show the specific contribution of a treatment.

The magnitude of the influence of the application of the RADEC learning model on variations in changes in learning outcomes can be evaluated through the influence measure index on the results of multivariate analysis. Based on Table 4.10, the Partial Eta Squared value was recorded at 0.557 for concept understanding and 0.530 for critical thinking, which exceeded the threshold of the large influence category (0.14). This finding proves that the RADEC learning model accounts for more than 50% of the variation in student learning outcomes. In a study conducted by Arikunto (2019), it was explained that the high magnitude of influence indicates the practical effectiveness of a method in the field.

The dominance of the contribution of the RADEC learning model treatment to improving student competence shows that the applied learning syntax has very strong practical implications. Based on the influence size index that exceeds the 50% figure in Table 4.10, this method has proven to be a reliable solution in overcoming science learning obstacles. As in the research conducted by Slavin (2018), it is explained that performance-based cooperative learning provides dominant effectiveness on student learning outcomes.

The entire series of discussions emphasized that the use of the RADEC learning model has a broad, structured, and comprehensive impact on improving student learning outcomes. This model intervention has succeeded in uniting concept understanding and critical thinking into a fully integrated learning ecosystem through the syntax of reading, answering, discussing, explaining, and creating. In the research conducted by Trianto (2014), it was explained that the success of innovative learning methods is measured by their ability to achieve comprehensive competency targets. These findings are strengthened by research conducted by Dahar (2011) which states that the integration of cognitive learning theory and modern learning practices is able to answer the pedagogical needs of students well.

CONCLUSION

Based on the findings, this study concluded that the implementation of the Read, Answer, Discuss, Explain, and Create (RADEC) learning model had a statistically significant effect on students' conceptual understanding and critical thinking skills in animal classification. The results demonstrated significant effects on each learning outcome individually, as well as a significant simultaneous effect on both outcomes. These findings suggest that the RADEC learning model is a promising instructional approach for enhancing students' conceptual understanding and critical thinking skills in biology education.

The RADEC learning model is recommended as an innovative instructional approach for teaching animal classification. Beyond improving conceptual understanding and critical thinking skills, the model has the potential to support three dimensions of deep learning: cognitive development through conceptual mastery and analytical reasoning, intrapersonal

development through independent reading and metacognitive reflection, and interpersonal development through collaborative learning, critical discussions, and the creation of shared learning products.

Biology teachers are encouraged to integrate the RADEC learning model into instructional practices, particularly when teaching complex topics such as animal classification, to promote active participation and meaningful learning. Schools and educational policymakers should support its implementation through professional development programs, appropriate instructional resources, and supportive learning environments. Future research should examine the effectiveness of the RADEC model across different biological topics, educational levels, and learning contexts, including its integration with interactive technologies and personalized learning strategies. Students are also encouraged to participate actively in RADEC-based activities to strengthen their critical thinking, problem-solving, collaboration, and conceptual reasoning skills.

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CONFLICT OF INTEREST

The author states that there is no conflict of interest in the preparation of this article.

AUTHOR CONTRIBUTIONS

All authors contributed to conceptualization, search and synthesis of literature, interpretation of results, manuscript preparation, and critical review of manuscripts. All authors have read and approved the final version of the manuscript.

GENERATIVE AI STATEMENT

The authors declare that Generative Artificial Intelligence (Generative AI) was used solely to assist with language refinement, grammatical correction, and improvement of manuscript readability. All scientific concepts, interpretations, literature synthesis, analyses, and conclusions were developed by the authors. All AI-assisted content was carefully reviewed, verified, and revised by the authors, who take full responsibility for the accuracy, integrity, and final content of the manuscript.

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