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Virtual Laboratory–Assisted RADEC Courseware for Enhancing Conceptual Change in Elementary Teacher Education

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Abstract: Conceptual change is a crucial aspect of science learning, particularly for pre-service primary school teacher students who will become educators at the elementary level. However, science instruction in teacher education programs still faces various challenges, especially in helping students understand abstract concepts and overcome pre-existing misconceptions. This study aims to examine the effect of science courseware based on the RADEC learning model (Read, Answer, Discuss, Explain, Create) assisted by a virtual laboratory on students' conceptual change in excretory system. A quasi-experimental method with a pretest–post-test non-equivalent control group design was employed. The research sample was selected using random sampling, resulting in 39 students from Class A as the experimental group, who received the RADEC model assisted by a virtual laboratory, and 39 students from Class B as the control group, who did not receive the treatment. Data were collected through a conceptual change test and analyzed using a paired-sample *t*-test with SPSS. The results showed that t-count > t-table (2.04 > 1.66) and p-value = 0.015 ($p < 0.05$). It can be concluded that science courseware based on the RADEC learning model assisted by a virtual laboratory has a significant effect on students' conceptual change. The integration of virtual laboratory activities within the RADEC stages effectively facilitates active engagement, reflection, and deeper conceptual understanding.

Keywords: Conceptual change, RADEC learning model, Virtual laboratory, Science learning, Pre-service primary School teachers

Introduction

Elementary science education plays a crucial role in developing students' scientific literacy, which encompasses understanding the nature of science, how scientific knowledge is constructed, and its application in everyday life. Effective teaching methods, such as project-based learning in STEAM, have been shown to enhance both scientific literacy and foundational science concepts while simultaneously supporting language development, which is vital for overall literacy (Gerde & Wasik, 2022; Zuryanty et al., 2019). However, pre-service primary school teachers often encounter challenges in grasping abstract concepts. Those challenges such as the particulate theory of matter and

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energy, leading to persistent misconceptions without proper professional development (Kruse et al., 2020). Additional difficulties include language barriers, reliance on closed-ended questioning techniques, and low self-efficacy in teaching science, all of which can hinder critical thinking development and effective instruction (Christidou et al., 2025; Zuryanty et al., 2019). Research indicates that inquiry-based learning, differentiated instruction, constructivist approaches, and the use of high-quality educational resources, such as interactive read-alouds and nonfiction trade books, can effectively correct misconceptions and promote active scientific thinking (Syofyan et al., 2025).

Misconceptions in science are widespread among students at various educational levels, including pre-service primary school teachers. It is persist despite formal education, often mirroring those held by younger learners (Härmälä-Braskén et al., 2020; Hejnová, 2022). These misconceptions are prevalent in topics such as thermodynamics, mechanics, quantum mechanics, and the particulate nature of matter, with students frequently misunderstanding concepts like the isobaric process of ideal gas and mechanical equilibrium (Guerra-Reyes et al., 2024; Sutarja & Wulandari, 2021). The sources of misconceptions include prior knowledge, everyday experiences, inadequate teaching methods, and the inherent complexity of scientific concepts, exemplified by students anthropomorphizing electrons in semiconductor drift phenomena. Such misconceptions negatively impact scientific understanding and application, leading to persistent errors, confusion in new contexts, and potential propagation of incorrect knowledge when pre-service teachers instruct future students (Correia & Baptista, 2022; Herak et al., 2025; Jean-Pierre, 2022; Ruiz-Gallardo & Reavey, 2019; Topalsan & Bayram, 2019). Addressing misconceptions requires effective diagnostic tools, such as multiple-choice and three-tier tests, alongside instructional strategies including active learning, counterfactual reasoning, immersive simulations, and blended learning models, all of which have been shown to improve conceptual understanding and correct persistent misunderstandings (Gadbury, 2024; Hejnová, 2022; Hermita et al., 2024; Wahyuni & Saputra, 2023). Overall, targeted interventions using these approaches are critical for enhancing conceptual clarity, fostering accurate scientific reasoning, and supporting effective science teaching among pre-service primary school teachers.

The RADEC learning model (Read, Answer, Discuss, Explain, Create) has been introduced as a structured strategy to enhance students' Higher Order Thinking Skills (HOTS) and scientific understanding by guiding learners through five stages: reading, answering, discussing, explaining, and creating (Handayani et al., 2019). This model promotes active learning and cognitive engagement by encouraging students to explore information, critically evaluate alternatives, collaborate in discussions, and develop innovative solutions, which also facilitates conceptual change by addressing misconceptions (Fuadi dkk., 2021; Sukardi dkk., 2025a; Sukmawati dkk., 2023). Integration with technology further enhances the RADEC model by increasing interactivity, engagement, and personalization through tools such as learning management systems, virtual reality, gamification, and hybrid learning environments, which support immersive and collaborative learning experiences (Arvind, 2024; Cabalbag, 2025; Das & Malaviya, 2025; Gierhart, 2024).

Moreover, effective implementation of the RADEC model requires ongoing professional development for educators to ensure seamless integration of digital tools and learner-centered pedagogical strategies, allowing teachers to maximize active learning, cognitive engagement, and conceptual understanding in contemporary science education. Overall, the RADEC learning model, when supported by technology, offers a comprehensive framework for fostering critical thinking, conceptual mastery, and student-centered learning, which is essential for preparing students to navigate complex scientific concepts and modern educational environments. One of the technologies that can be used to enhance conceptual change is virtual laboratory.

Virtual laboratories (VLs) have emerged as significant tools in science education, providing interactive and flexible platforms that enhance students' conceptual understanding, critical thinking, and motivation while overcoming the limitations of traditional laboratories (Alnaser & Forawi, 2024; Tatira & Mshanelo, 2024; Yan et al., 2025). Research demonstrates that VLs improve performance on complex topics such as impulse and momentum, foster reflective thinking in higher education chemistry courses, and promote positive attitudes and intrinsic motivation among students across grade levels (Alnaser & Forawi, 2024). VLs also increase accessibility, particularly in resource-limited or rural schools, and their integration with artificial intelligence can simulate real-world scenarios to further develop problem-solving skills (Murali et al., 2024; Shambare et al., 2022; Sypsas et al., 2024). However, successful implementation requires overcoming technical and infrastructural challenges, ensuring adequate teacher knowledge, and aligning VL content with course objectives (Athauda et al., 2018). Combining VLs with hands-on experiments has been shown to enhance learning outcomes, as students benefit from the complementary strengths of virtual and physical labs (Tsutsui et al., 2020). Overall, VLs represent a powerful pedagogical tool that, when properly integrated, can transform science education by improving conceptual mastery, engagement, and accessibility.

Although there is limited direct research combining the RADEC learning model (Read, Answer, Discuss, Explain, Create) with virtual laboratories to address misconceptions among pre-service primary school teacher students, existing studies suggest substantial potential for this integration to facilitate conceptual change. Research on virtual laboratories indicates they effectively enhance conceptual understanding, engagement, and attitudes toward science across domains such as direct current circuits, chemistry, and life sciences (Alhashem, 2023; Alhashem & Alfailakawi, 2023; Penn & Mavuru, 2020), while RADEC has been successfully applied to improve digital literacy, creative thinking, and structured problem-solving skills (Anggraeni et al., 2024; Maspiroh et al., 2025; Sukardi et al., 2022). Integrating virtual lab activities within the RADEC framework could provide students with interactive, reflective, and collaborative opportunities, allowing them to engage in reading, answering, discussing, explaining, and creating while directly confronting and correcting misconceptions. Effective courseware development should follow an iterative process of analysis, design, trial, improvement, and reflection, and its impact can be measured using pre- and post-tests to assess conceptual change. Overall, leveraging the complementary strengths of RADEC and virtual laboratories offers a promising pathway for designing innovative instructional strategies that enhance conceptual understanding and support meaningful learning outcomes in pre-service primary school teacher students.

This study plays a crucial role in the development of effective science teaching strategies at the primary teacher education level, as it provides a more systematic and interactive approach to building pre-service teachers' understanding of basic science concepts. By integrating the RADEC learning model with a virtual laboratory, this research is expected to serve as a reference for developing courseware that emphasizes not only theoretical knowledge but also practical application and critical reflection, enabling students to better comprehend abstract and complex scientific concepts. Moreover, this study contributes to enhancing the quality of courseware, the mastery of science concepts, and students' ability to design and implement classroom instruction more effectively and innovatively. The results are expected to positively impact the professional competencies of future teachers, enabling them to address misconceptions, promote students' critical thinking, and apply creative, technology-based teaching strategies in the future.

Literature Review

Science Misconceptions among Elementary School Students in Indonesia

Recent research on science misconceptions among elementary school students in Indonesia indicates that misconceptions are prevalent among both teachers and students, particularly in science. In science, studies reveal that 87% of teachers shifted from holding misconceptions to achieving understanding after remediation, and the development of standardized instruments confirms that misconceptions are widespread and need to be addressed (Desstya et al., 2025; Ibrahim & Mariati, 2024). Misconceptions regarding photosynthesis and plant respiration are influenced by students' thinking styles, with impulsive and slow-precise thinkers showing higher rates of misconceptions (Pamungkas et al., 2019). Various diagnostic tools, including three-tier and four-tier tests, have been validated and proven effective in detecting misconceptions, while remediation strategies such as the Cognitive Conflict Strategy have successfully reconstructed preservice elementary teachers' understanding (Anggoro et al., 2019; Ningroom & Yamtinah, 2025).

The RADEC Learning Model in Science Teaching

Recent research on the RADEC learning model in science education highlights its structured approach—Read, Answer, Discuss, Explain, and Create—which is designed to foster higher-order thinking skills (HOTS) and student engagement. The "Read" stage encourages students to gather information from diverse sources, while "Answer" emphasizes exploring multiple solutions to problems. "Discuss" promotes collaborative learning through idea sharing and debate, "Explain" involves presenting findings and receiving feedback, and "Create" engages students in applying knowledge creatively to solve problems (Handayani et al., 2019). Studies have shown that RADEC significantly enhances cognitive engagement and critical thinking skills; for example, online mentoring in RADEC implementation improved elementary school teachers' competence in fostering students' critical thinking (Lestari et al., 2021), and RADEC implementation in natural science learning promoted students' critical thinking (Satria & Sopandi, 2019).

The model also develops analytical skills through its iterative process of problem-solving and structured HOTS activities, ensuring continuous refinement of understanding. Furthermore, RADEC has been effective in reducing learning anxiety and enhancing conceptual mastery supporting deeper comprehension and conceptual change (Sukardi et al., 2025). Additionally, teacher training in RADEC-based programs has improved competencies in teaching multi-literacy and 21st-century skills, further contributing to students' conceptual understanding (Imran et al., 2021). Overall, the RADEC learning model offers a robust framework for promoting cognitive engagement, critical thinking, analytical skills, and deeper conceptual understanding in modern science education.

Virtual Laboratory as a Science Learning Media in Indonesia

Virtual laboratories have emerged as a crucial tool in science education in Indonesia, providing simulated environments that allow students to conduct experiments when physical laboratories are limited or unavailable. For example, the "VLab-little scientist" enables elementary students to practice basic experiments, enhancing their science process skills and preparing them for hands-on experiments (Pramono et al., 2019), while virtual labs like Wokwi for IoT courses offer interactive platforms that increase engagement and motivation (Wahyudi et al., 2025). Virtual labs address limitations of physical laboratories by offering cost-effective, safe, and scalable alternatives, improving conceptual understanding and practical skills, as evidenced in inorganic chemistry education during the COVID-19 pandemic (Tatenov et al., 2025) and in Indonesia, where virtual labs have shown comparable or superior effectiveness to physical labs for complex concepts and scientific inquiry self-efficacy (Husnaini & Chen, 2019).

Moreover, the interactive features of virtual labs, including simulations, animations, and video tutorials, enhance student motivation and attention, contributing to improved learning outcomes (Horton & Wei, 2024; Prawira et al., 2023; Rizkiansyah et al., 2023). Research indicates that students using virtual laboratories achieve higher conceptual understanding and inquiry skills than those using traditional methods, with studies in Indonesian physics classes demonstrating significant improvement (Gunawan et al., 2018; Kapıcı & Coştu, 2023). While the direct integration of virtual labs with the RADEC (Read, Answer, Discuss, Explain, Create) model has not been extensively studied, the alignment between virtual labs' interactive and reflective learning principles and RADEC's emphasis on active learning and critical thinking suggests potential for enhancing higher-order thinking skills and conceptual understanding (Yan et al., 2025). Overall, virtual laboratories in Indonesia provide interactive, flexible, and effective science learning experiences, with promising applications for integration with pedagogical models like RADEC to further improve educational outcomes.

Method

Research Design

This study employed a quasi-experimental design using a nonequivalent control group model. The effectiveness of the learning intervention was evaluated by comparing the pretest and posttest results of the experimental group, which received the specialized treatment, with those of the control group, which followed conventional instruction.

Population and Sample

The population targeted in this study consisted of students enrolled in the Elementary School Teacher Education Study Program at Universitas PGRI Palembang, Indonesia. A total of 80 students were selected as the research sample through random sampling and were divided into two groups:

1. Experimental group: 39 students from Class A, who received the basic science courseware intervention based on the RADEC learning model supported by a virtual laboratory.
2. Control group: 39 students from Class B, who participated in conventional learning activities.

Research Instruments

Conceptual change was assessed using a multi-tier test, designed to detect student misconceptions more precisely. The science topic examined in this study was excretory system. The employed instrument was a four-tier test, consisting of: (1) multiple-choice questions with distractors based on common misconceptions, (2) confidence levels in the selected answers, (3) reasoning provided to justify the answers, and (4) confidence levels in the reasoning. This format enables a more comprehensive mapping of misconceptions. Prior to implementation, the courseware and assessment instruments underwent validation by experts in the subject matter, media, and language. The basic science courseware for elementary students included teaching materials, student worksheets, and the virtual laboratory, while the assessment instrument consisted of the conceptual change test.

Data Collection Techniques

Data were collected using the same assessment instrument during both the pretest and posttest phases for the experimental and control groups. The pretest was conducted before the learning intervention, and the posttest was administered after the completion of the learning activities. Informed consent was obtained from all participants, and ethical approval for the study was granted by the institutional ethics committee.

Data Analysis Techniques

Data analysis was performed in several stages. Initially, the normality of the data was assessed using the Kolmogorov-Smirnov test and the homogeneity of the data was assessed using the Levene Test. Hypothesis testing used in the study was the paired sample t-test on data between the experimental class and the control class.

Results and Discussion

The Prerequisite Test of Students' Conceptual change

The prerequisite tests were conducted on the pretest and posttest data of both the experimental and control groups. The normality of the data was examined using the Lilliefors test through the Kolmogorov–Smirnov procedure, while homogeneity was tested using Levene's test. The normality test was applied to determine whether the data were normally distributed, whereas the homogeneity test was used to assess whether the data originated from populations with equal variances. The results of the normality and homogeneity tests are presented in Table 1.

Table 1. Normality and homogeneity tests

Class		Normality			Homogeneity			
		Statistic	df	Sig	Levene	df1	df2	Sig
Pretest	Experimental	0.177	39	0.145	0.725	1	76	0.232
	Control	0.732	39	0.130				
Posttest	Experimental	0.164	39	0.187	0.085	1	76	0.650
	Control	0.157	39	0.072				

As shown in Table 1, the Kolmogorov–Smirnov normality test yielded significance values of 0.145 for the pretest and 0.187 for the posttest in the experimental group. In the control group, the significance values were 0.130 for the pretest and 0.072 for the posttest. Since all significance values exceeded 0.05, the data can be considered normally distributed. Furthermore, the results of Levene's homogeneity test for the pretest and posttest data showed significance values of 0.232 and 0.650, respectively. These values are also greater than 0.05, indicating that the pretest and posttest data in both the experimental and control groups are homogeneous.

The Hypothesis Test

In this research, the t-test analysis was conducted using SPSS software. The degrees of freedom were calculated using the formula df = $(n_1 + n_2) - 2$, resulting in a value of 76 at a 5% significance level, with a corresponding t-critical value of 1.66. The null hypothesis (H_0) was rejected and the alternative hypothesis (H_1) was accepted when the calculated t-value was equal to or greater than the critical t-value and the significance level was below 0.05. The results of the t-test analysis are summarized in Table 2.

Table 2. The result of t-test

	t-test for equality of means		
	t	df	Sig (2-tailed)
Equal variances assumed	2.04	76	0.015
Equal variances not assumed	2.02	66	0.0215

As presented in Table 2, the hypothesis testing yielded a calculated t-value of 2.04 with a significance value of 0.015. These results indicate that the calculated t-value exceeded the critical t-value (2.04 > 1.66) and that the significance value was lower than 0.05. Therefore, H_0 was rejected and H_1 was accepted, indicating a statistically significant difference in students' conceptual change between the experimental and control groups. In other words, the implementation of the RADEC learning model had a significant effect on students' conceptual change.

The results of the t-test analysis demonstrate that the implementation of the RADEC learning model had a statistically significant effect on students' conceptual change. This conclusion is supported by two key indicators: the comparison between the calculated t-value and the critical t-value, and the obtained significance level. The calculated t-value of 2.04 exceeds the critical t-value of 1.66, indicating that the observed difference between the experimental and control groups is not due to random chance. Furthermore, the significance value of 0.015 is lower than the conventional alpha level of 0.05, providing additional evidence to reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1).

These findings suggest that students who were taught using the RADEC learning model experienced greater conceptual change compared to those who received conventional instruction. This can be attributed to the structured stages of the RADEC model—Read, Answer, Discuss, Explain, and Create—which actively engage students in the learning process. Each stage encourages deeper cognitive processing, allowing students to confront their initial misconceptions, refine their understanding through discussion, and reconstruct their knowledge more accurately.

Moreover, the significant difference indicates that the RADEC model is effective in promoting meaningful learning rather than rote memorization. By emphasizing student-centered activities and collaborative learning, the model facilitates conceptual restructuring, which is essential in science education. This aligns with constructivist learning theory, where knowledge is actively constructed by learners through interaction and reflection. In summary, the t-test results confirm that the RADEC learning model significantly enhances students' conceptual change. This implies that incorporating RADEC into instructional practices can be a valuable strategy for improving students' understanding of scientific concepts, particularly in addressing misconceptions and fostering students' conceptual change.

Conclusion

In conclusion, the findings of this study demonstrate that the application of Virtual Laboratory–Assisted RADEC Courseware has a significant positive effect on students' conceptual change. The results of the t-test analysis revealed a statistically significant difference between the experimental and control groups, indicating that students who were taught using Virtual Laboratory–Assisted RADEC Courseware achieved greater conceptual change than those who received conventional instruction. These results suggest that Virtual Laboratory–Assisted RADEC Courseware is an effective instructional approach for promoting deeper conceptual understanding and addressing misconceptions in science learning.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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