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Video-Based Laboratories in Physics: A Quasi-Experimental Study on Rotational Dynamics and Critical Thinking Enhancement

Dzikri Rahmat Romadhon[1*], M Adam Buchori Muslim[2], Iwan Permana Suwarna[1]

[1]Physics Education Study Program, Faculty of Educational Sciences, Universitas Islam Negeri Syarif Hidayatullah Jakarta, Tangerang Selatan, Indonesia
[2]Physics Department, UPTD SMP Negeri 4 Pelaihari, Tanah Laut, Indonesia
*E-mail: dzikri@uinjkt.ac.id

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Abstract: This study aimed to evaluate the effectiveness of Video-Based Laboratories (VBL) in enhancing critical thinking skills among state Islamic senior high school (*Madrasah Aliyah Negeri*) students in Hulu Sungai Tengah, Kalimantan Selatan, specifically in the context of rotational dynamics. Using a quasi-experimental design, we compared the performance of an experimental group that utilized VBL with a control group that followed traditional teaching methods. Data were collected through pretest and posttest assessments on critical thinking skills, and various statistical analyses were performed, including the paired samples t-test, Wilcoxon signed-rank test, and Mann-Whitney U test. The findings indicated significant improvements in critical thinking skills for both groups; however, the experimental group demonstrated substantially greater gains. This suggested that VBL, through interactive and hands-on learning methods, effectively enhanced critical thinking skills in physics education. The results underscored the potential of integrating VBL into physics curricula to foster deeper understanding and reflective reasoning. Future research should explore the long-term impacts of VBL and its application in diverse educational settings.

Keywords: Critical Thinking; Physics Education; Rotational Dynamics; Video-Based Laboratories.

Introduction

Physics, as a discipline, inherently challenges conventional understanding, often prompting learners to re-evaluate their intuitive beliefs [1]. Traditional methods of teaching physics, such as lecture-based approaches and reliance on textbooks, have been criticized for their limitations in promoting deep understanding and critical thinking among students. These conventional methods often fail to fully engage students or encourage the application of theoretical knowledge to practical situations [2]. As a result, students may struggle to develop the critical thinking skills necessary for navigating scientific paradigms and solving complex problems in physics. This situation underscores the need for more effective teaching methodologies to enhance student engagement and foster critical thinking skills more effectively.

Innovative approaches to teaching physics have been explored in various studies to address the shortcomings of traditional teaching methods. For instance, the effectiveness of the flipped teaching methodology in improving learning performance in physics courses has been widely acknowledged in the literature [3–6]. Additionally, research has shown that integrating creativity into physics teaching, especially in a second language context, can enhance student learning outcomes and engagement [7,8]. Moreover, inquiry-based learning has been found to significantly improve students' understanding of complex physics concepts by encouraging active participation and exploration [9,10]. Problem-based learning, which presents students with real-world physics problems to solve, has also been shown to foster critical thinking and collaborative skills [11,12]. These innovative methodologies offer potential solutions to the problems posed by traditional teaching methods, providing a more interactive and engaging learning experience that can enhance critical thinking skills in physics education.

In response to the need for more effective teaching methodologies, Video-Based Laboratories (VBL) have emerged as a promising and novel solution. VBL integrates video content into teaching modules, providing an interactive and flexible learning experience [13,14]. Unlike traditional methods, VBL allows students to visualize complex physics phenomena and processes that might be difficult to grasp through text alone. Moreover, tools like Tracker software within the VBL framework further enhance this experience by enabling real-time analysis and manipulation of video data, thereby bridging the gap between theoretical content and tangible observation [15–17]. This innovative approach engages students more effectively and supports the development of critical thinking skills through interactive and hands-on learning methods, offering a significant advancement over conventional teaching techniques.

This study focuses on several key variables to evaluate the effectiveness of Video-Based Laboratories (VBL) in enhancing critical thinking skills among physics students. Critical thinking skills are measured through pretest and posttest assessments. The experimental group utilizes VBL, incorporating video content and Tracker software to facilitate real-time data analysis and manipulation. The control group follows traditional teaching

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methods, providing a basis for comparison. Previous research has shown that interactive and technology-enhanced learning environments, such as those provided by VBL, can significantly improve student engagement and conceptual understanding [18,19]. Additionally, the context of rotational dynamics is chosen as it is a fundamental topic in physics that requires a solid understanding of theoretical concepts and practical applications, making it an ideal area to test the impact of VBL on critical thinking skills.

This study aims to evaluate the impact of Video-Based Laboratories (VBL) on enhancing critical thinking skills among physics students, specifically in the context of rotational dynamics. By comparing traditional teaching methods with digital strategies, our research seeks to determine if VBL can bridge the gap between theoretical knowledge and practical application, fostering deeper understanding and reflective reasoning. The urgency of this research lies in the demand for innovative teaching methodologies to address the limitations of conventional physics education. As educational institutions adopt digital tools to improve outcomes, assessing their efficacy in cultivating critical thinking skills, essential for navigating complex scientific paradigms is crucial. Traditional methods are increasingly insufficient in fostering the deep, analytical skills required in modern scientific and professional fields. The integration of approaches like VBL is a necessary evolution in educational practice. This study aims to provide empirical evidence of VBL's effectiveness, informing educators, policymakers, and curriculum developers about its benefits. The findings could significantly improve educational practices, better preparing students to tackle real-world problems with a critical mindset.

Research Methods

Using a quasi-experimental approach, this study adopted the Nonequivalent Control Group Design to evaluate the impact of the Video-Based Laboratory on students' critical thinking abilities in rotational dynamics, as shown in table 1 [20]. Conducted from September to December 2021 during the odd semester of the 2021/2022 academic year, the study involved students from two classes at a State Islamic High School in Hulu Sungai Tengah, South Kalimantan. The 60 participants were divided into an experimental group (30 students from one class) and a control group (30 students from another). Purposive sampling ensured that both groups began the study with comparable pre-test scores and similar baseline knowledge.

Table 1. Nonequivalent Control Group Design

Pretest	Treatment	Posttest
O_1	X_1	O_2
O_1	X_2	O_2

The control group learned about rotational dynamics through a video (X_1). Their activities included observation, inquiry, group discussions (supplemented with books and online resources), data processing, and a concluding presentation of their findings. After starting similarly, the experimental group (X_2) engaged in hands-on activities post-observation. They observed and recorded physics phenomena, supplemented their understanding with additional resources, and used tracking tools for data analysis. The process concluded with students presenting their findings.

Data collection utilized an essay test administered before (O_1) and after (O_2) the intervention to gauge students' critical thinking capabilities, validated for both content and construct.

We calculated descriptive statistics for data analysis, including the mean and standard deviation for pretest and posttest scores in both groups, as shown in Figure 1. The Shapiro-Wilk test was used to check if the scores were normally distributed. The data was considered normally distributed if the p-value from this test was greater than 0.05. Levene's test was conducted to check for homogeneity of variances, with a p-value greater than 0.05 indicating equal variances.

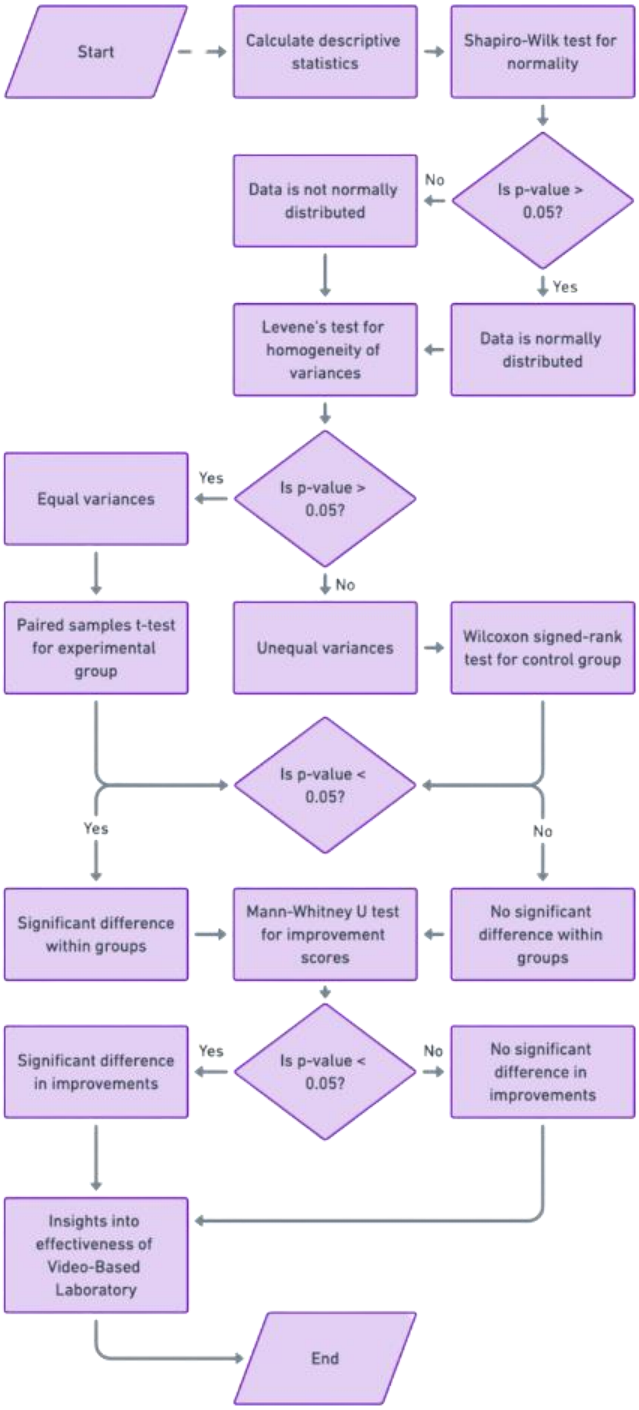

Figure 1. Data Analysis Procedure

To compare pretest and posttest scores within groups, we used a paired samples t-test for the experimental group and the Wilcoxon signed-rank test for the control group due to the non-normal distribution of its posttest scores. A significant p-value (less than 0.05) indicated a significant difference within groups. Finally, we used the Mann-Whitney U test to compare improvement scores between the experimental and control groups, with a significant p-value (less than 0.05) indicating a significant difference in improvements. These analyses provided insights into the effectiveness of the Video-Based Laboratory in enhancing critical thinking skills among physics students.

Table 2. Comprehensive Statistical Test Results

Category		Experiment	Control
Pretest	Mean	13.07	12.23
	Std Dev	7.60	6.88
	Shapiro-Wilk Normality Test	0.946	0.932
	p-value[a]	0.134	0.55
	Levene's Test		0.276
	p-value[b]		0.601
Posttest	Mean	35.10	21.77
	Std Dev	9.09	5.48
	Shapiro-Wilk Normality Test	0.965	0.886
	p-value[a]	0.410	0.004
	Levene's Test		10.299
	p-value[b]		0.002
Statistical test fulfilling the assumptions		Paired Samples t-test	Wilcoxon Signed-Rank Test
Statistical result		-15.255	0.0
p-value[c]		2.17×10^{-15}	1.86×10^{-9}
Mann-Whitney U Test (Improvement)			803.5
p-value[d]			1.75×10^{-7}

[a] p-value of the Shapiro-Wilk Normality test, $\alpha = 0.05$
[b] p-value of Levene's Test for homogeneity of variances, $\alpha = 0.05$
[c] p-value of a statistical test of Paired Samples t-test and Wilcoxon Signed-Rank Test, $\alpha = 0.05$
[d] p-value of a statistical test of Mann-Whitney U Test, $\alpha = 0.05$

Results and Discussion

The analysis of the pretest and post-test scores for the experimental and control groups provides valuable insights into the impact of the intervention on critical thinking assessment scores, as shown in Table 2. The descriptive statistics reveal that the mean pretest score for the experimental group was 13.07 with a standard deviation of 7.60, while the mean posttest score increased significantly to 35.10 with a standard deviation of 9.09. For the control group, the mean pretest score was 12.23 with a standard deviation of 6.88, and the mean posttest score was 21.77 with a standard deviation of 5.48, as shown in Figure 2.

The Shapiro-Wilk normality tests indicated that the pretest and posttest scores for the experimental group were normally distributed, as evidenced by p-values of 0.134 and 0.410, respectively, bigger than the $\alpha = 0.05$, showing that the data is normally distributed. Similarly, the pretest scores for the control group were normally distributed with a p-value of 0.055. However, the posttest scores for the control group were not normally distributed, as indicated by a p-value of 0.004, less than the $\alpha = 0.05$, showing it is not normally distributed, as shown in Table 2.

Levene's test for homogeneity of variances showed that the variances of the pretest scores between the experimental and control groups were equal (p-value of 0.601). However, the variances of the posttest scores were unequal, with a significant Levene's test result (p-value of 0.002).

The paired samples t-test for the experimental group demonstrated a significant increase in scores from pretest to posttest, with a t-statistic of -15.255 and a p-value of 2.17×10^{-15}. This result indicates that the intervention had a substantial positive impact on the scores of the experimental group. For the control group, the Wilcoxon signed-rank test, which is appropriate given the non-normal distribution of the posttest scores, also revealed a significant increase in scores from pretest to posttest, with a Wilcoxon statistic of 0.0 and a p-value of 1.86×10^{-9}.

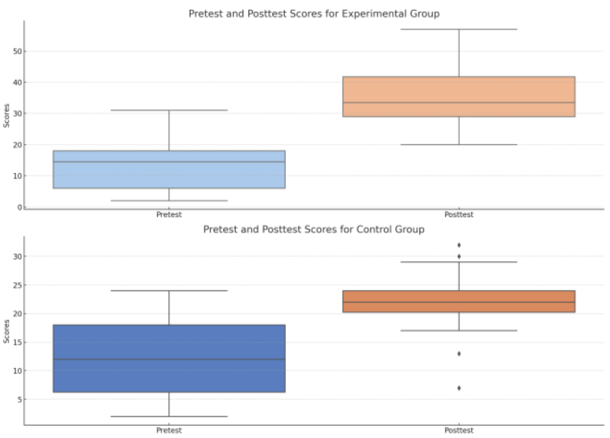

Figure 2. Pretest and Posttest Scores for Experimental (top) and Control (bottom) Groups.

When comparing the improvements between the experimental and control groups, the Mann-Whitney U test showed a significant difference in improvement scores, with a U statistic of 803.5 and a p-value of 1.75×10^{-7}. This finding suggests that the experimental group experienced a greater improvement in scores compared to the control group.

The results indicate that the experimental and control groups significantly improved their critical thinking assessment scores. However, the experimental group, which received the intervention, demonstrated a substantially greater improvement than the control group, underscoring the effectiveness of the intervention.

Video-based laboratories (VBL) have shown significant potential in enhancing physics education and improving students' critical thinking skills. Studies have demonstrated that VBL, particularly using Tracker software, can effectively analyze various physics concepts, including pendulum motion, parabolic movement, simple harmonic motion, and roller coaster dynamics [21–24]. Implementation of VBL in problem-based learning has led to substantial improvements in critical thinking abilities, with one study reporting a 53.9% increase [22]. VBL has also been shown to enhance students' modeling abilities and their capacity to produce coherent explanations of physical phenomena [21]. Furthermore, the development of VBL-based practicum modules has received positive feedback from experts and students, indicating its potential for widespread adoption in physics education [23]. These findings collectively support the integration of VBL as an effective tool for physics instruction and skill development.

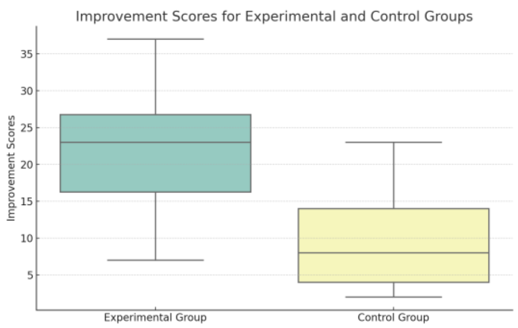

Figure 3. Improvement Scores for Experimental and Control Groups.

Rodriguez and Towns [25] highlighted the importance of engaging students in critical thinking within laboratory settings, which supports our hypothesis that VBL activities can enhance critical thinking skills. This is demonstrated in our study, which focuses on rotational dynamics. Similarly, Nurma'Ardi et al. [26] showed that discovery learning assisted by interactive video effectively improves critical thinking skills in primary school students, further validating our findings.

Key components of VBL that contribute to this improvement include interactive video content, hands-on data analysis with Tracker software, and inquiry-based learning. The interactive videos allow students to observe and analyze real-life applications of theoretical concepts, prompting them to question, hypothesize, and reflect on what they see, fostering critical thinking. Tracker software enables students to perform real-time analysis and manipulation of video data, connecting theoretical equations with tangible observations [17,27,28]. This hands-on approach requires students to interpret data, verify results, and understand the underlying principles, further developing their critical thinking abilities [22].

Additionally, VBL promotes a collaborative learning environment and reflective reasoning through feedback. Collaborative projects involve students working in groups to analyze videos, discuss findings, and present conclusions, fostering critical thinking as they articulate thoughts, challenge ideas, and synthesize different perspectives [12]. Immediate feedback through video reviews and discussions allows students to reflect on their observations, compare analyses with peers, and receive instructor guidance, encouraging critical evaluation of their learning process. These components of VBL—interactive content, hands-on analysis, inquiry-based learning, collaboration, and reflection—collectively contribute to bridging the gap between theoretical knowledge and practical application, ultimately enhancing the overall learning experience and critical thinking skills in physics education.

Our statistical analysis revealed significant improvements in the experimental group's critical thinking skills compared to the control group. Tools like Tracker software allowed students to visualize and analyze physical phenomena in real time, bridging the gap between theoretical concepts and practical observation. This hands-on approach aligns with constructivist learning theories, which emphasize active engagement and reflection as crucial components of effective learning [29].

Constructivist teaching methods, highlighted in various studies, focus on discovery, experimentation, and problem-solving. These approaches foster independent thinking, collaborative problem-solving, and creativity. The positive response from students using Tracker software in physics education [16] supports the notion that such tools enhance the learning experience.

Active engagement in the learning process, a fundamental principle of constructivist teaching, has been shown to improve student success [30]. By involving students actively, constructivist approaches help clarify the logic behind concepts, aiding deeper understanding and knowledge retention [31].

However, this study has some limitations. The sample size was relatively small, and the study was conducted in a specific educational context, which may limit the generalizability of the findings. Additionally, while the study controlled for baseline knowledge through pretest scores, other unmeasured variables could have influenced the results. Future research should consider larger, more diverse samples and explore the long-term impact of VBL on critical thinking skills.

Conclusion

This study concludes that Video-Based Laboratories (VBL) significantly enhance critical thinking skills in physics students compared to traditional learning methods. The experimental group using VBL substantially improved their critical thinking skills from pretest to posttest, far exceeding the gains seen in the control group. Statistical analyses confirmed this significant improvement in the experimental group. These findings highlight the effectiveness of VBL in fostering critical thinking skills in physics education. Future research should investigate the long-term impact of VBL on critical thinking and explore its application in diverse educational contexts.

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