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The Effectiveness of Video Tracker Use in STEM-Based Linear Motion Learning to Improve Students' Critical Thinking Skills

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Abstract. Limited laboratory facilities and low levels of students' critical thinking skills remain major challenges in physics learning, particularly on the topic of uniformly accelerated motion. This study aims to analyze the effectiveness of using Video Tracker media in STEM-based physics learning to improve students' critical thinking skills. The research employed a quantitative method with a quasi-experimental design, namely the Nonequivalent Control Group Design. The subjects were students of class XI IPA as the experimental group and class X A as the control group at MA Muhammadiyah Nangahure. Research instruments included critical thinking skill tests, observations, and documentation. The results of the paired sample t-test indicated a significant difference between pretest and posttest scores in the experimental group ($p < 0.05$). Furthermore, the effect size value of 1.82 indicated a very large effect. These findings demonstrate that STEM-based learning integrated with Video Tracker is effective in enhancing students' critical thinking skills and can serve as an alternative learning approach in schools with limited experimental facilities.

Keywords: video tracker, STEM learning, critical thinking skills

1. Introduction

Physics learning in senior high schools still faces various challenges, particularly in the implementation of practical or experimental activities (Nuha et al., 2023). Many schools, especially in regions such as Maumere, experience limitations in laboratory equipment, making it difficult for students to understand physics concepts concretely. In addition, many teachers and students are still unfamiliar with technology-based learning media such as Video Tracker, even though this media is very helpful for observing, analyzing, and visualizing the motion of objects digitally and accurately [2,3]. This condition requires technology-based learning innovations so that students' understanding of physics concepts can improve comprehensively.

In the era of the National Curriculum, students are required to develop critical thinking skills in every learning process [4,5]. Physics, as an exact science, is closely related to the ability to analyze, evaluate, and solve complex problems. However, physics learning in schools in Maumere is often still focused on memorizing concepts and does not sufficiently develop students' reasoning skills. One of the topics that often becomes a challenge for students is Uniformly Accelerated Linear Motion. which requires an understanding of the relationship between position, velocity, acceleration, and time through graphs and mathematical formulas [6]. To help students understand the concept of Uniformly Accelerated Linear Motion more concretely, visual media are needed that allow students to directly observe changes in the motion of an object.

Research conducted by [7] states that Video Tracker is effective for analyzing the motion of objects through graphs of position, velocity, and acceleration, thereby encouraging students to think more analytically and reflectively in solving physics problems. In line with these findings, (Alfayani et al., 2024) reported that the use of Video Tracker in learning Uniformly Accelerated Linear Motion can increase students' active engagement as well as their critical thinking skills through real motion data analysis activities [8]. Furthermore, [9] found that the integration of Video Tracker in learning helps students connect theoretical concepts with real phenomena more concretely, making the understanding of linear motion concepts more meaningful [10]. Thus, the use of interactive media such as Video Tracker can be one of the solutions to encourage students' active involvement in critical thinking activities and to investigate physical phenomena independently and reflectively. Therefore, a learning approach is needed that can stimulate students' active participation comprehensively in contemporary physics learning [11].

One of the appropriate approaches to support this is the STEM approach, which emphasizes the interconnection between science, technology, engineering, and mathematics concepts in real-life contexts. The STEM-based learning approach (Science, Technology, Engineering, and Mathematics) is considered capable of bridging scientific concepts with real-world applications [12]. However, the implementation of this approach in many schools in Maumere is still very limited [13]. Only a few schools have begun to adopt it, and many teachers have not yet been trained to integrate STEM comprehensively in the learning process [14]. In fact, the STEM approach is believed to enhance students' critical and creative thinking skills through project-based learning and problem-solving activities. Therefore, learning media and strategies are needed to strengthen the integration between technology and the STEM approach in physics learning [15].

Video Tracker, as a technology-based learning tool, provides significant opportunities to be integrated into the STEM approach. Through the use of Tracker, students can observe the motion of objects, collect data, and analyze graphs directly, enabling them to learn to think logically and systematically [16]. In the context of learning Uniformly Accelerated Linear Motion, for example, students can record the motion of a toy car or other objects and then use Tracker to determine acceleration, instantaneous velocity, as well as the relationship between position–time graphs and velocity–time graphs. Thus, the use of Tracker within the STEM framework provides opportunities for students to conduct scientific investigations and apply simple technological and engineering principles, which ultimately contributes to the improvement of their critical thinking skills. These critical thinking skills are one of the key competencies required in 21st-century learning [17].

Critical thinking skills include students' ability to analyze information, evaluate arguments, and make decisions based on logic and evidence [18]. To develop these skills, learning activities are required that encourage students not only to understand concepts but also to relate them to real-life situations and solve problems through investigation [19]. In the context of STEM-based physics learning using Video Tracker, the indicators of critical thinking skills refer to Facione's framework, which includes interpretation, analysis, evaluation, and inference. These four indicators can be mapped into the higher-order domains of Bloom's taxonomy as presented in Table 1 [20].

Table 1. Indicators of critical thinking skills and their mapping to Bloom's taxonomy.

No.	Critical Thinking Indicators	Bloom's Taxonomy
1.	Interpretation: The ability to understand and communicate data.	C2 – Understanding
2.	Analysis: The ability to break down problems and identify patterns.	C4 – Analyzing
3.	Evaluation: The ability to assess information and verify data.	C5 – Evaluating
4.	Inference: The ability to draw conclusions and construct arguments based on data.	C6 – Creating

However, to date, there have been limited studies that specifically examine the effectiveness of integrating Video Tracker in STEM-based physics learning to improve students' critical thinking skills, particularly in regions such as Maumere. In fact, critical thinking is an essential competency that students need to possess in the current global and digital era. Therefore, an in-depth study is needed to address the following research question: to what extent can the use of Video Tracker media integrated with the STEM approach improve students' critical thinking skills? This study is expected to contribute to the development of innovative, applicable, and relevant learning models, as well as to serve as a reference for teachers in adopting learning approaches and media that align with current educational developments, particularly in the context of teaching Uniformly Accelerated Linear Motion, a topic that has often been considered difficult for students to understand concretely [21].

2. Method

This study employed a quantitative research approach using a quasi-experimental method aimed at determining the effectiveness of the use of Video Tracker as a learning medium in STEM-based physics learning to improve students' critical thinking skills. The research design used was the Nonequivalent Control Group Design, an experimental design involving two groups that were not randomly selected but were assumed to have relatively equivalent initial abilities based on previous academic data. This design involved administering a pretest and a posttest to both the experimental group and the control group.

The study was conducted at MA Muhammadiyah Nangahure, Sikka Regency, during the even semester of the current academic year. The population of this study consisted of all students in grades X and XI at MA Muhammadiyah Nangahure. The sampling technique used was purposive sampling, with considerations including the equivalence of students' academic abilities, the suitability of the learning material, and the availability of science classes. Based on these considerations, class XI Science was designated as the experimental group, while class X A served as the control group, considering that the school only has one class of XI Science that is relevant as the experimental subject.

The experimental group received treatment in the form of STEM-based physics learning supported by the use of Video Tracker on the topic of Uniformly Accelerated Linear Motion. The learning process was designed to actively engage students through activities such as observing motion phenomena, analyzing data, and drawing conclusions. Meanwhile, the control group followed conventional physics learning through lecture and question-and-answer methods without the use of Video Tracker media.

The STEM approach in the experimental group was implemented in an integrated manner as follows:

1. Science
   In the science aspect, students learned physics concepts related to Uniformly Accelerated Linear Motion, including the concept of acceleration, the relationship between position, velocity, and time, and the characteristics of motion with constant acceleration. Students observed motion phenomena through real motion videos and then identified physical variables such as position, time, velocity, and acceleration based on their observations.
2. Technology
   The technology aspect was implemented through the use of Video Tracker software as a learning medium. Video Tracker was used to digitally analyze videos of object motion so that students could obtain quantitative data in the form of position–time graphs, velocity–time graphs, and acceleration–time graphs. The use of this technology helped students understand the concept of Uniformly Accelerated Linear Motion visually and accurately while also developing their technological literacy skills in physics learning.
3. Engineering
   In the engineering aspect, students were involved in design and problem-solving activities, such as determining the reference frame, setting measurement scales, and selecting appropriate analysis methods in Video Tracker. Students were also asked to design steps for motion data analysis, starting from recording the motion video, determining the object to be analyzed, to interpreting the resulting graphs as solutions to the given problems.
4. Mathematics
   The mathematics aspect was reflected in the process of processing and analyzing the data obtained from Video Tracker. Students used Uniformly Accelerated Linear Motion equations, such as the equations of position, velocity, and acceleration, to interpret the graphs and measurement results. In addition, students calculated the gradient of the graphs to determine velocity and acceleration values and compared the results of their mathematical analysis with the theoretical concepts previously learned.

The Video Tracker media used in this study is a video analysis software that allows students to quantitatively analyze the motion of objects from recorded videos. In this learning process, the analyzed motion videos demonstrate the movement of objects with constant acceleration, which corresponds to the characteristics of Uniformly Accelerated Linear Motion. The Uniformly Accelerated Linear Motion concepts studied include the relationship between displacement, velocity, acceleration, and time, as well as the interpretation of motion graphs. Through these activities, students not only understand the concepts theoretically but are also able to relate them to real-life phenomena, enabling their critical thinking skills to develop more optimally.

The research instruments consisted of observation sheets and a critical thinking skills test. The observation sheets were used to monitor the implementation of STEM-based physics learning, students' activeness, collaboration within groups, and students' ability to interpret motion data using the Video Tracker media. The critical thinking skills test consisted of 10 multiple-choice questions and 5 essay questions, developed based on critical thinking indicators proposed by Ennis (1985), which include interpretation, analysis, evaluation, and inference. These indicators were aligned with the cognitive dimensions of the revised Bloom's taxonomy, namely C4 (analyzing), C5 (evaluating), and C6 (creating). The multiple-choice questions focused on conceptual understanding and basic analysis, while the essay questions assessed students' ability to interpret data and construct arguments based on video analysis using Tracker, referring to the critical thinking indicators presented in the table of test indicators.

Table 2. Indicators of critical thinking test items for the uniformly accelerated linear motion topic.

No	Critical Thinking Indicator	Indicator Description	Question Type	Question Numbers	Cognitive Level (Bloom)
1	Interpretation	Students are able to understand and interpret physics information from graphs, equations, or statements related to Uniformly Accelerated Linear Motion.	Multiple choice	2, 3, 8	C4 (Analyzing)
2	Concept Analysis	Students are able to analyze the relationship between velocity, acceleration, and time in uniformly accelerated linear motion.	Multiple choice	1, 4, 5, 7	C4 (Analyzing)
3	Evaluation	Students are able to evaluate the correctness of calculation results, arguments, or the suitability of Uniformly Accelerated Linear Motion concepts with the problem context.	Multiple choice	6, 9, 10	C5 (Evaluating)
4	Inference	Students are able to draw conclusions based on velocity–time and position–time graphs or data.	Essay	2, 4	C5 (Evaluating)
5	Reasoning and Problem Solving	Students are able to solve Uniformly Accelerated Linear Motion problems systematically and provide logical reasoning based on physics concepts.	Essay	1, 3, 5	C6 (Creating)

The research was conducted in three stages: preparation, implementation, and evaluation. During the preparation stage, learning materials and research instruments were developed and validated. In the implementation stage, a pretest was administered to both groups. Subsequently, the experimental group participated in STEM-based learning using Video Tracker, while the control group followed conventional learning through lecture and question-and-answer methods. After the treatment was completed, a posttest was administered to measure changes in students' critical thinking skills.

The pretest and posttest data were analyzed quantitatively. Normality and homogeneity tests were conducted first to ensure the suitability of parametric statistical analysis. Furthermore, a paired sample t-test was used to determine the improvement within each group, while an independent sample t-test was used to examine the differences in improvement between the experimental and control groups. To determine the magnitude of the effect of using Video Tracker in STEM-based learning on students' critical thinking skills, the effect size (Cohen's d) was also calculated.

3. Results and Discussion

This study aimed to determine the effectiveness of using Video Tracker in STEM-based physics learning to improve students' critical thinking skills. To measure this effectiveness, a series of data analyses were conducted using statistical tests, including the normality test, homogeneity test, t-test, and effectiveness analysis (Cohen's d). The results and discussion are presented as follows.

3.1. *Normality Test*

The normality test was conducted to determine whether the pretest and posttest data from both the experimental and control groups were normally distributed. The analysis was performed using the Kolmogorov–Smirnov test, and the results are presented in Table 3.

Table 3. Results of the normality test.

Group	Sig. (p-value)	Conclusion
Experimental Group (Pretest)	0.211	Normally Distributed
Control Group (Pretest)	0.163	Normally Distributed
Experimental Group (Posttest)	0.187	Normally Distributed
Control Group (Posttest)	0.143	Normally Distributed

Based on Table 3, all p-values are greater than 0.05, indicating that the data from all four groups are normally distributed. This means that the data meet one of the assumptions required for conducting subsequent parametric statistical tests.

3.2. *Homogeneity Test*

The homogeneity test was conducted to determine whether the variances between the two groups of data were homogeneous. The results of Levene's test are presented in Table 4.

Table 4. Results of the homogeneity test.

Groups Compared	Levene's Sig. (p-value)	Conclusion
Experimental Group and Control Group	0.231	Homogeneous

The significance value of 0.231 (> 0.05) indicates that the variance between the experimental and control groups is homogeneous. Therefore, the data meet the assumption for conducting the independent samples t-test.

3.3. *t-Test (paired sample t-test)*

The t-test was conducted to determine whether there was a significant difference between the pretest and posttest scores of the experimental group after the treatment was applied. The results of the t-test are presented in Table 5.

Table 5. Results of the paired sample t-test (experimental group).

Compared Scores	Sig. (2-tailed)	Conclusion
Pretest and Posttest (Experimental Group)	0.049	There is a significant difference after the treatment

Based on the results of the t-test, the Sig. (2-tailed) value obtained was 0.049 (< 0.05). Therefore, it can be concluded that there is a significant difference between the pretest and posttest scores of students in the experimental group. This finding indicates that physics learning using the STEM approach assisted by Video Tracker is effective in improving students' critical thinking skills.

3.4. *Effect Size (Cohen's d)*

In addition to examining statistical significance, it is also necessary to analyze the magnitude of the effect or effectiveness of the treatment. This was calculated using Cohen's d formula. The results are presented in Table 6. The obtained d value of 1.82 falls into the very large effect category based on

Cohen's classification. This indicates that the use of Video Tracker within the STEM approach has a strong effect on improving students' critical thinking skills.

Table 6. Results of the effect size analysis (Cohen's d).

Data Pair	d Value	Effect Category
Experimental Group	1.82	Very Large

The results of this study indicate that STEM-based physics learning supported by Video Tracker media has a significant and very strong effect on improving students' critical thinking skills. This finding is evidenced by the results of the paired sample t-test in the experimental group, which shows a significance value of 0.049, indicating a significant difference between the pretest and posttest scores. Thus, learning that involves the integration of technology, scientific projects, and problem-solving based on real data encourages students to think more deeply and reflectively.

Furthermore, the effect size value of 1.82, which falls into the very large category, indicates that the impact of STEM-based learning using Video Tracker is not only statistically significant but also practically meaningful in the educational context. This effectiveness reflects that learning approaches involving direct scientific activities, such as observing, analyzing, and drawing conclusions from motion graphs, have a strong impact on improving aspects of critical thinking, including interpretation, analysis, evaluation, and inference.

The improvement in learning outcomes and critical thinking skills through the use of Video Tracker is likely to occur because this medium provides a more authentic, contextual, and interactive learning experience. Students no longer act as passive recipients of information but rather as active participants who observe the motion of objects, record position and time data, analyze position–time graphs, and interpret the results scientifically. These activities are aligned with the competencies required in 21st-century learning within the National Curriculum, particularly critical thinking and problem-solving skills. When compared with research on Ways of Thinking in Engineering Design-based Physics [22], these findings demonstrate consistency in the development of interdisciplinary thinking in physics learning. The WoT4EDP framework emphasizes the integration of five key elements: science, mathematics, design, computational thinking, and metacognitive reflection in engineering design-based laboratory activities. In the context of using Video Tracker, students develop scientific understanding through the analysis of motion phenomena, apply mathematical representations through graph interpretation, and use computational approaches when processing data using software. In addition, when students evaluate the consistency between the results of graph analysis and the theory of Uniformly Accelerated Linear Motion, they engage in metacognitive reflection on their thinking processes.

School conditions in regions such as Maumere, which often face limitations in laboratory equipment, constitute a strong reason why technology-based approaches are highly relevant and appropriate to implement. Limited physics laboratory facilities often hinder the optimal implementation of experiments, causing learning to become more theoretical and providing fewer hands-on experiences for students. The use of Video Tracker in this study serves as an alternative solution, as students can still conduct experiments using simple devices such as smartphone cameras and computers. Thus, limitations in facilities are no longer the main barrier to conducting practical activities. This approach also expands opportunities for active learning both in the classroom and independently. The results of this study are consistent with the research conducted by [23] in Maumere regarding the use of smartphones in physics learning. That study showed that the use of technology-based tools was effective in improving students' creative thinking skills using a nonequivalent pre-test and post-test control group design. Analysis using the independent sample t-test revealed a significant effect of the use of Phyphox on the improvement of students' creative thinking abilities.

These findings support previous studies indicating that visual-based digital media and STEM approaches have been proven to significantly enhance students' higher-order cognitive abilities (Higher Order Thinking Skills/HOTS), science process skills, and learning engagement [24]. The integration of technology in learning enables deeper information processing through activities such as analysis, data interpretation, and conceptual reflection. Furthermore, as emphasized in studies on the integration of

STEM with the TPACK framework, the effectiveness of technology-based learning is strongly influenced by the ability to integrate technological, pedagogical, and content knowledge in a coherent manner, allowing the implementation of STEM to be carried out optimally in the classroom.

However, the results of this study emphasize the integration of Video Tracker media and the STEM approach simultaneously in the context of schools with limited facilities, such as those in Maumere. This approach not only optimizes the use of available and simple technology but also demonstrates that appropriate technology integration can remain effective even when laboratory facilities are limited. This contextual aspect has not been widely examined in previous studies; therefore, this research provides a new contribution to the development of adaptive, contextual, and relevant physics learning strategies for schools in regional areas. Thus, Video Tracker functions not only as a tool for visualizing concepts but also as a scientific medium that systematically encourages the comprehensive development of students' critical thinking competencies in STEM-based physics learning.

4. Conclusion

Based on the results of the research and data analysis that have been conducted, it can be concluded that the use of Video Tracker in physics learning based on the STEM approach is effective in improving students' critical thinking skills. This is evidenced by the results of the paired sample t-test which show a significant difference between the pretest and posttest scores in the experimental group, as well as an effect size value of 1.82 which falls into the very large category. STEM-based learning integrated with Video Tracker provides a contextual, interactive, and applicative learning experience. Students not only understand the concept of uniformly accelerated motion theoretically, but are also able to analyze and interpret motion data independently. This activity encourages the achievement of four aspects of critical thinking skills, namely interpretation, analysis, evaluation, and inference, which are very important in mastering science in the era of the National Curriculum. Overall, this approach is relevant to be implemented in schools, especially in regions such as Maumere that have limited laboratory facilities. Video Tracker becomes an effective and innovative solution in bridging physics learning based on data and technology.

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