JOURNAL OF EDUCATION AND INNOVATION

Journal of Education and Innovation
Vol. 27, No. 4, October – December 2025, pp. 53-64
ISSN: 3027-7019 (Online), DOI: 10.71185/jeiejournals.v27i4.281170

Research Article

ACTIVE LEARNING THROUGH THE STEM PROCESS USING THE FRAMECOUNT APPLICATION TO INCREASE LEARNING ACHIEVEMENT IN FREE FALL MOTION

Received: February 1, 2025 **Revised:** April 14, 2025 **Accepted:** April 24, 2025

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Abstract

This research examined the integration of high-speed video analysis with the Framecount application to enhance Mathayomsuksa 4 students' understanding of free fall motion. Three objectives were pursued: 1) to study free fall motion using high-speed video analysis, 2) to develop supplementary learning activities based on this technique, and 3) to assess the impact of these activities on students' conceptual understanding and academic achievement. A high-speed video camera (using a smartphone at 60 fps) and the Framecount application were employed to record and analyze free fall experiments. The results demonstrated the feasibility of determining gravitational acceleration with an error of less than 5%. Furthermore, students who engaged in the developed learning activities exhibited significantly improved problem-solving skills and academic achievement compared to a control group ($p < .05$). This study highlights the potential of combining active learning strategies with technology-enhanced analysis to deepen students' conceptual understanding of physics.

Keywords: Active Learning, STEM Education, Free Fall Motion

Introduction

The concept of free fall motion, a fundamental principle in physics, is often difficult for secondary students to grasp due to its abstract nature and the difficulty of directly observing such motion in daily life. Traditional teaching methods, relying heavily on textbook explanations and lectures, may not be sufficient to foster a deep understanding of this phenomenon (McDermott, 1991; Chuang, 2020). Students often fail to connect theoretical formulas with real-world observations, leading to misconceptions and shallow understanding.

In recent years, educational approaches have increasingly emphasized active learning and STEM (Science, Technology, Engineering, and Mathematics) integration to address such challenges. Active learning, which promotes student engagement and participation, enhances conceptual understanding, problem-solving skills, and critical thinking (Michael, 2006; Freeman et al., 2014; Prince, 2004). Studies have consistently shown that active learning strategies can lead to higher academic achievement and greater retention of scientific knowledge among students (Su, 2006; Kolodner et al., 2003).

The STEM approach further supports this engagement by incorporating real-world problem-solving through interdisciplinary applications (Honey et al., 2014; Kelley & Knowles, 2016). A key advantage of STEM integration is its ability to contextualize abstract concepts within engineering design challenges, promoting both conceptual understanding and motivation (Fortus et al., 2005; Sadler et al., 2000).

Integrated STEM education allows students to connect scientific inquiry with engineering design, mathematical reasoning, and computational thinking (Li et al., 2019a; Berlin & Lee, 2005). Such interdisciplinary environments enable students to develop versatile problem-solving skills (Allen, 1993; Elliott et al., 2001), while supporting knowledge transfer across domains (Judson & Sawada, 2000; Venville et al., 2000).

In the context of physics education, video analysis technology has emerged as a promising tool for enhancing conceptual understanding. High-speed video, when combined with analysis applications such as Framecount, provides an effective means of capturing rapid motion phenomena like free fall, enabling students to engage in precise measurement and data analysis (Hjalmarson et al., 2020; Hoban et al., 2015). In this study, a smartphone was used as the high-speed video recording device. This choice was based on practicality, as smartphones with cameras capable of recording at 60 fps are widely available and already owned by most students. This approach ensures that the activity can be implemented in typical classroom settings without the need for expensive or specialized equipment. By slowing down physical events, students can make detailed observations that are otherwise missed, thus reinforcing scientific principles (Childress, 1996; Riskowski et al., 2009).

Despite these advances, there remains a gap in research regarding the integration of high-speed video analysis tools with active STEM-based learning activities, particularly in the context of secondary physics education in Thailand. Few studies have examined how combining real-time video analysis with interdisciplinary STEM design activities can improve both conceptual understanding and academic achievement (Apedoe et al., 2008; Norton, 2007).

This study seeks to address this research gap by investigating the effectiveness of combining high-speed video analysis, the Framecount application, and STEM learning activities in teaching free fall motion. The study aims to determine whether such an approach can significantly improve conceptual understanding, problem-solving skills, and academic achievement among Mathayomsuksa 4 students. The results aim to inform instructional design and STEM curriculum integration in Thai classrooms, consistent with the goals of the National Education Plan (Office of the Education Council, 2017; Ministry of Education, 2008).

Objectives

1. To investigate free fall motion using high-speed video analysis: Capture and analyze high-speed video of objects in free fall to examine the relationships between distance, time, and velocity, and to determine the acceleration due to gravity.
2. To develop supplementary learning activities on free fall motion using high-speed video analysis: Design and implement engaging learning activities that leverage high-speed video analysis and the Framecount application to deepen students' understanding of free fall concepts.
3. To assess the impact of the developed learning activities on Mathayomsuksa 4 students' conceptual understanding and academic achievement in free fall motion: Evaluate the effectiveness of the learning activities in improving students' scientific conceptual understanding, problem-solving skills, and academic performance related to free fall motion.

Hypotheses

1. Students using high-speed video analysis and the Framecount application will achieve greater accuracy in identifying free fall relationships and determining gravitational acceleration.
2. Students participating in the STEM-based learning activities will demonstrate significantly greater improvement in problem-solving skills and academic achievement related to free fall motion compared to those receiving traditional instruction.

Population and Sample

The target population consisted of Mathayomsuksa 4 science students at Buengmaluwitthaya School in Sisaket Province during the first semester of the 2020 academic year. Two intact classrooms (M. 4/1 and M. 4/2), with a total of 69 students, were used in the study.

A cluster random sampling technique was employed to assign one classroom (M. 4/1) as the experimental group (n = 35) and the other (M.4/2) as the control group (n = 34). The assignment was performed randomly to ensure that both groups had equivalent academic background and learning environment. This method was chosen to preserve the natural classroom structure and minimize disruption to the school's timetable. Both classrooms were comparable in size, academic background, and prior exposure to the topic, ensuring internal validity for comparison.

Research Methodology

1. Research Design

This study employed a quasi-experimental design with a pre-test and post-test control group structure. This design allows for the comparison of the experimental group, which will receive the intervention (learning activities using high-speed video analysis and the Framecount application), with the control group, which will receive traditional instruction.

2. Participants

The participants will be 60 Mathayomsuksa 4 science students from Bungmalu Wittaya School, Sisaket Province, Thailand. They will be selected using disproportionate stratified random sampling, with 30 students from each of the two science classrooms (M.4/1 and M.4/2). The students will be randomly assigned to either the experimental group (n = 30) or the control group (n = 30).

3. Instruments

High-Speed Video Camera: A smartphone with a high-speed video function capable of recording at 60 frames per second (fps) was used in this study. This approach demonstrates the feasibility of implementing high-speed video analysis in schools using commonly available technology, without the need for specialized equipment.

Framecount Application: This video analysis software will be used to analyze the recorded videos and extract time data.

Conceptual Understanding Test: A multiple-choice and open-ended questionnaire will be developed to assess students' understanding of free fall concepts, such as gravity, acceleration, and the relationship between distance, time, and velocity.

Problem-Solving Tasks: A set of problem-solving tasks related to free fall motion will be designed to assess students' ability to apply their knowledge and skills to solve real-world problems.

Academic Achievement Test: A test based on the Mathayomsuksa 4 science curriculum standards will be used to assess students' overall academic achievement in free fall motion.

4. Procedure

Pre-Test Phase

Both the experimental and control groups were administered the conceptual understanding test, problem-solving tasks, and academic achievement test to establish baseline data prior to the intervention.

Intervention Phase (Experimental Group)

Introduction to High-Speed Video Analysis and Framecount: Students were introduced to the concept and procedures of using high-speed video analysis in conjunction with the Framecount application.

Free Fall Experiments: Students conducted hands-on experiments by dropping objects and recording their motion using a smartphone camera capable of 60 frames per second (fps).

Video Analysis: The Framecount application allowed students to navigate frame-by-frame through their recorded videos. They selected the start frame (just before the object was released) and the end frame (just before the object hit the ground) as shown in Figure 1. a. and b. The application then calculated the time interval t (shown in Figure 2), which was used to determine the gravitational acceleration using the formula $g=2S/t^2$ where S represents the known vertical distance. Students compared the calculated values with the standard value of 9.81 m/s^2 and computed the percentage error for each trial. This process enabled precise, real-time analysis and deepened their understanding of the mathematical relationships in free fall motion.

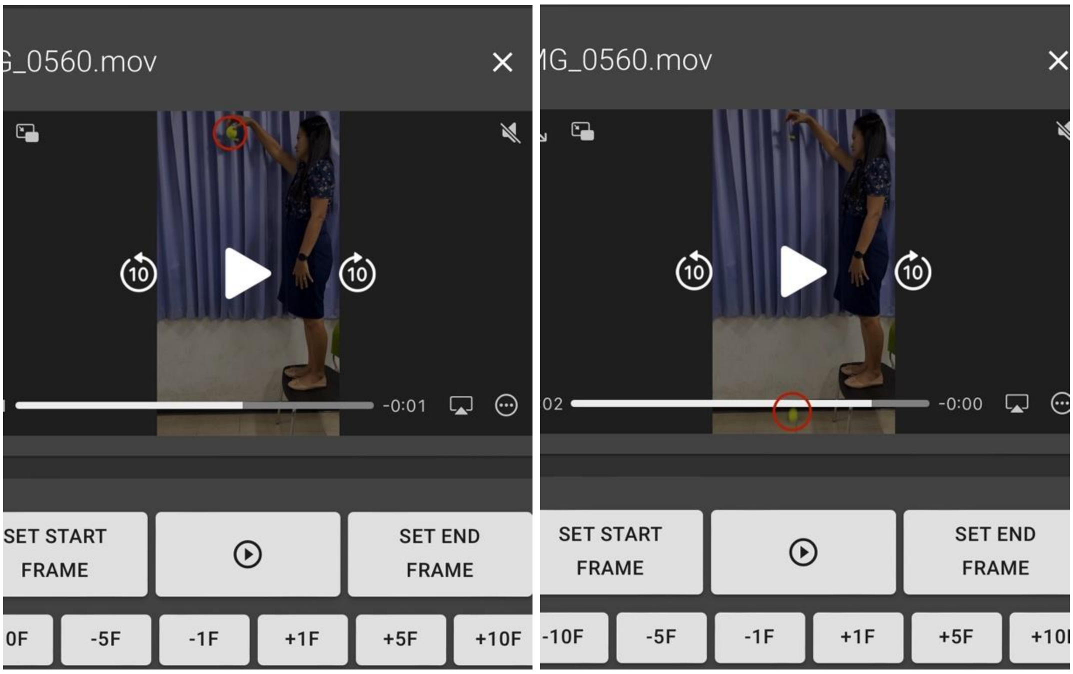

Figure 1 a. Set start frame b. Set end frame

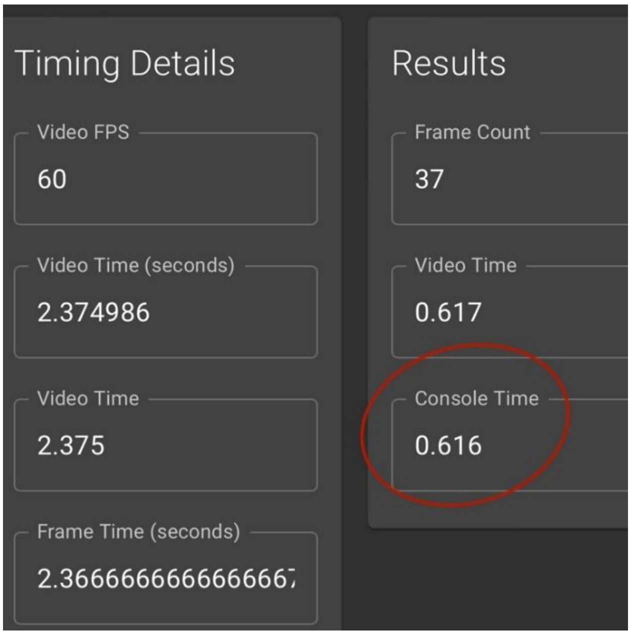

Figure 2 Time value (t) obtained from the Framecount

Instruction for Control Group

Students in the control group received traditional instruction on free fall motion through lectures, textbook readings, and teacher-led problem-solving activities.

Post-Test Phase

After the completion of the intervention, both groups were administered the same set of assessments as in the pre-test phase. These assessments evaluated conceptual understanding, problem-solving skills, and academic achievement in free fall motion.

5. **Normality Test**

To ensure the appropriateness of parametric statistical analyses, the normality of the data was examined using the Shapiro-Wilk test. The test was conducted on the pre-test and post-test scores of both the experimental and control groups. The results indicated that the distribution of the scores did not significantly deviate from normality ($p > 0.05$). Therefore, parametric statistical methods, including paired t-tests and independent t-tests, were deemed suitable for analyzing the effects of the intervention on students' problem-solving skills and academic achievement.

6. **Data Analysis**

Quantitative Analysis: Descriptive statistics (e.g., means, standard deviations) and inferential statistics (e.g., t-tests, ANOVA) were used to compare the pre-test and post-test scores of the experimental and control groups.

Qualitative Analysis: Student responses to open-ended questions and observational notes collected during the learning activities were analyzed to gain deeper insights into students' conceptual understanding and learning processes.

7. **Research Instruments**

Problem-Solving Skills Assessment

A 6-item subjective test was developed and validated by experts, with IOC values ranging from 0.67 to 1.00. Pilot testing with non-sample students yielded discrimination indices (D) between 0.37 and 0.65, difficulty indices (P) between 0.35 and 0.68, and a Cronbach's alpha reliability coefficient of 0.85 for the entire test.

Academic Achievement Test

A 20-item multiple-choice test with four options per item was developed and validated by experts, with IOC values ranging from 0.67 to 1.00. Pilot testing with non-sample students yielded discrimination indices (r) between 0.375 and 0.750, difficulty indices (P) between 0.35 and 0.75, and a Kuder-Richardson 20 (KR20) reliability coefficient of 0.796.

Learning Management Model and Lesson Plan Development

A STEM-based learning management model was developed to support the integration of high-speed video analysis into free fall motion instruction. The model consisted of four key components: principles, objectives, instructional processes, and assessment strategies. To facilitate classroom implementation, a user manual was also created, including example activities and procedures aligned with the experimental design.

A three-hour lesson plan was designed based on this model and aligned with the Mathayomsuksa 4 physics curriculum. The plan was reviewed by experts for content validity, with an Index of Item-Objective

Congruence (IOC) ranging from 0.67 to 1.00. A pilot test with non-sample students was conducted to identify necessary adjustments in activity timing and contextual scenarios. These revisions were incorporated into the finalized lesson plan used with the research sample. The finalized lesson plan emphasized active learning, collaborative experimentation, and the use of digital tools for data analysis.

Measurement and Evaluation

1. **Improvement in Problem-Solving Skills (Within-Group Comparison)**

Table 1 shows the comparison between pre-test and post-test scores of the experimental group on problem-solving skills related to free fall motion. The mean post-test score ($\bar{X}$ = 20.61, SD = 2.37) was significantly higher than the pre-test score ($\bar{X}$ = 14.45, SD = 3.64). The paired sample t-test revealed a statistically significant improvement (t = 45.83, p < .001). The effect size, as measured by Cohen's d, was 2.01, indicating a very large effect of the intervention.

Table 1 Comparison of problem-solving skill scores before and after the experiment of the experimental group (total score 30 points)

Sample	N	Pre		Post		t	p
		$\bar{X}$	S.D.	$\bar{X}$	S.D.		
experimental group	35	14.45	3.64	20.61	2.37	45.83*	.000

*P < .05

2. **Comparison of Academic Achievement (Between Groups)**

Table 2 presents the academic achievement scores of the experimental and control groups after the intervention. The experimental group achieved a higher mean score ($\bar{X}$ = 15.41, SD = 2.67) than the control group ($\bar{x}$ = 9.14, SD = 2.56), with a statistically significant difference (t = 24.78, p < .001). The calculated effect size for this comparison was Cohen's d = 2.40, which also represents a very large effect.

Table 2. Comparison of problem-solving skill scores after the experiment between students in the experimental and control groups (total score 30 points, N = 35)

score	experimental group		control group		t	p
	$\bar{X}$	S.D.	$\bar{X}$	S.D.		
academic achievement	20.61	2.37	15.28	3.41	4.76*	.000

*P < .05

3. Academic Achievement (Within-Group Comparison)

In addition to the between-group analysis, academic achievement was also examined within the experimental group. Table 3 shows that students' scores significantly improved from the pre-test ($\bar{X}$ = 9.14, SD = 2.56) to the post-test ($\bar{X}$ = 15.41, SD = 2.67), with a t-value of 24.78 and p < .001. The effect size (Cohen's d) was 2.01, indicating a strong practical impact.

Table 3 Comparison of academic achievement scores before and after the experiment of the experimental group (total score 20 points)

Sample	N	Pre		Post		t	p
		$\bar{X}$	S.D.	$\bar{X}$	S.D.		
experimental group	35	9.14	2.56	15.41	2.67	24.78*	.000

*P < .05

4. Summary

Both statistical and practical significance were observed in this study. The students who participated in STEM-based learning activities using smartphone video analysis and the Framecount application showed substantial improvement in both conceptual understanding and academic achievement. These results provide strong empirical support for the effectiveness of integrating technology-enhanced analysis with active learning strategies in physics instruction.

Discussion

The results of this study demonstrate that integrating high-speed video analysis, the Framecount application, and STEM-based learning activities significantly enhances students' learning outcomes in physics. Specifically, students in the experimental group showed marked improvements in both problem-solving skills and academic achievement compared to their counterparts in the control group.

These findings are consistent with previous research indicating the benefits of active learning in promoting conceptual understanding and student engagement (Michael, 2006; Freeman et al., 2014). The meaningful increase in learning outcomes can be attributed to the shift from passive reception of content to active exploration and discussion, which allows students to reconstruct their own understanding of abstract concepts (Prince, 2004; Clark & Ernst, 2007).

Moreover, the use of high-speed video analysis in the classroom supported students in visualizing phenomena that are typically difficult to observe in real time. This approach enabled learners to explore the relationships between time, distance, and acceleration through direct measurement and analysis, echoing findings by Chuang (2020) and Hoban et al. (2015), who found that slowed-motion video significantly aids in conceptual retention.

The success of the intervention also supports the value of integrated STEM education in promoting interdisciplinary thinking (Kelley & Knowles, 2016; Li et al., 2019a). By engaging with activities that required the simultaneous application of physics, mathematics, and technology, students experienced the real-world nature of problem solving. This supports the notion that STEM integration nurtures transferable skills and improves students' readiness for complex cognitive tasks (Everett et al., 2000; Hynes & Santos, 2007).

In particular, the structured incorporation of engineering design tasks—as recommended by Apedoe et al. (2008) and Fortus et al. (2005)—provided students with an authentic context for applying scientific principles, thereby enhancing both motivation and depth of learning. The collaborative discussions following each experiment mirrored the goals of problem-based and inquiry-oriented instruction, further supporting knowledge construction and metacognitive development (Kolodner et al., 2003; Dugger & Meier, 1994).

Furthermore, the improvement in academic achievement aligns with studies that show positive outcomes from interdisciplinary science-mathematics integration (Berlin & Lee, 2005; Pang & Good, 2000). This suggests that students benefit not only from the novelty of the technological tools but also from the conceptual coherence provided by cross-disciplinary learning environments (Venville et al., 2004; Allen, 1993).

In the context of Thai education, where traditional instructional practices are still dominant, the findings reinforce the importance of adopting more interactive, student-centered methodologies. This is in line with the National Education Plan (Office of the Education Council, 2017), which advocates for competency-based learning and the incorporation of digital tools to enhance 21st-century skills.

In summary, this study provides empirical support for the integration of high-speed video analysis and STEM activities in secondary physics education. It offers a replicable model for bridging the gap between theoretical instruction and practical application, contributing both to classroom innovation and to the broader discourse on interdisciplinary STEM education (Zubrowski, 2002; Mehalik et al., 2008).

Importantly, the use of a smartphone as the high-speed video camera highlights the practicality and accessibility of this instructional approach, making it feasible for widespread adoption even in resource-limited school settings.

Conclusion

This research investigated the effectiveness of integrating high-speed video analysis, the Framecount application, and STEM-based learning activities to enhance Mathayomsuksa 4 students' understanding of free fall motion. The study employed a quasi-experimental design with pre-test and post-test measures, comparing an experimental group receiving the intervention to a control group receiving traditional instruction.

The findings revealed that the intervention had a significant positive impact on students' learning outcomes. Specifically, the experimental group demonstrated substantial improvements in problem-solving skills and academic achievement related to free fall motion compared to the control group. These results support the hypothesis that active learning approaches, combined with technology tools like high-speed video analysis and the Framecount application, can effectively foster deeper conceptual understanding and improve academic performance in physics.

The study's findings have several implications for science education. First, they highlight the importance of incorporating active learning and STEM approaches into physics instruction. Second, they demonstrate the potential of technology tools like high-speed video analysis and the Framecount application in enhancing student learning. Third, they provide a model for developing and implementing effective learning activities for complex physics concepts.

Limitations and Future Research

This study has some limitations. The sample size was relatively small and limited to a single school. Future research could replicate the study with a larger and more diverse sample to enhance the generalizability of the findings. Additionally, the study focused on free fall motion, but the approach could be extended to other physics concepts. Future research could investigate the effectiveness of similar interventions for other topics in physics or other science disciplines.

Acknowledgements

The researcher would like to express sincere gratitude to Buengmaluwitthaya School for providing support and facilities throughout the duration of this study. Special thanks are extended to Mr. Kobchai Photinaca, the school principal, for his continuous encouragement and facilitation, as well as to the Mathayomsuksa 4 science students who actively participated in the research activities.

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