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Developing the Learning Achievement of Motion and Force and Analytical Thinking of Grade 8 Students Using Integrated STEM Education and Inquiry-Based Learning

Krittaya Narathon[1], Jatuporn Khamsong[2] & Wittaya Worapun[1]

[1] Faculty of Education, Mahasarakham University, Mahasarakham, Thailand

[2] Faculty of Science and Health Technology Kalasin University, Kalasin, Thailand

Correspondence: Wittaya Worapun, Faculty of Education, Mahasarakham University, Mahasarakham, Thailand. E-mail: Wittaya.wo@msu.ac.th

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Abstract

This Study aim to investigate the effects of integrated inquiry-based and STEM education learning management on Thai grade 8 students' analytical thinking and learning achievement. The research employed a one-group experimental design with 37 grade 8 students from a public school in Khon Kaen Province, Thailand, selected through purposive sampling. The instruments used in this study included an inquiry-based STEM education integrated learning management plan, a learning achievement test on motion and force, and an analytical thinking test. Data were collected through pretests and posttests on learning achievement and analytical thinking, and ongoing assessments during the learning activities. The data were analyzed using percentage, mean score, standard deviation, effectiveness index (E1/E2), and a paired samples t-test. The results indicated that the overall effectiveness of the learning management, calculated as the E1/E2 ratio, was 77.20/77.57, meeting the predetermined criteria of 75/75. Furthermore, significant increases in analytical thinking and learning achievement were observed at the statistical level of 0.5. These findings support the effectiveness of integrating inquiry-based learning with STEM education in enhancing students' analytical thinking and learning achievement, contributing valuable insights to educational practices in science education.

Keywords: inquiry-based learning, STEM education, learning achievement, analytical thinking

1. Introduction

The study of science plays a critical role in shaping students' educational journeys, as it not only enhances their understanding of fundamental concepts like motion and force but also sharpens their cognitive abilities and learning behaviors (Alberts, 2022; Harper, 2018; Reiss, 2005). During the formative teenage years, science education guides students toward analytical thinking and problem-solving skills, essential for their overall intellectual development (Harper, 2018). Consequently, achieving learning outcomes in science is a key objective in curricula worldwide, reflecting its importance in preparing students for future academic and life challenges (Tang & Danielsson, 2018).

Analytical thinking is the backbone of scientific inquiry, driving students to explore and understand the world around them in a more profound way (Beno et al., 2020; Hollett & Cassalia, 2022; Limbach & Waugh, 2010; Santos, 2017). Hollett and Cassalia (2022) defines analytical thinking as the ability to break down complex ideas, problems, or systems into smaller, more manageable components, examine each part closely, and then articulate how these parts work together as a whole. In the science classroom, this kind of thinking is indispensable—it empowers students to systematically tackle scientific challenges, uncover patterns, and make informed decisions based on their observations. Fostering analytical thinking, educators help students not only grasp complex scientific concepts but also develop essential skills for lifelong learning and problem-solving.

Motion and force, as core concepts in the science classroom, involve the explanation of how objects move and interact under various influences, such as gravity, friction, and applied forces (Aksit & Wiebe, 2020). These concepts help learners understand real-life events like why cars accelerate or decelerate, how airplanes lift off the ground, and the principles behind the construction of bridges and buildings. Scholars define learning achievement as the progress made toward acquiring educational skills, knowledge, and materials across various disciplines, specifically within academic settings, rather than the broader acquisition of knowledge outside of school environments. Therefore, when students achieve a solid understanding of motion and force, they not only grasp essential scientific principles but also gain the ability to apply these concepts to everyday situations, enhancing their overall problem-solving abilities and preparing them for more advanced scientific learning.

Developing science learning achievement and analytical thinking in students requires instructional methods that actively engage them in the process of thinking critically and analytically (Hollett & Cassalia, 2022). To cultivate these skills, it is essential to incorporate teaching strategies that go beyond traditional lecture-based approaches. Hands-on activities, where students can experiment and observe scientific principles in action, are vital for deepening their understanding. Collaborative learning, where students work together to solve problems, allows them to share perspectives and build on each other's ideas, fostering a more dynamic learning environment. Additionally, connecting classroom concepts to real-life problem-solving is crucial, as it helps students see the relevance of what they are learning and motivates them to apply their knowledge in meaningful ways. However, implementing these methods can be challenging. Teachers often face constraints such as limited resources, time, and the difficulty of designing activities that are both engaging and educational. These challenges can hinder the effectiveness of these approaches, making it difficult to fully realize their potential in enhancing students' learning outcomes (Prajuabwan & Worapun, 2023).

Thai education, the contextual focus of this study, has often been criticized for its passive and teacher-dependent approach, particularly in science education classrooms. In many cases, instruction relies heavily on rote memorization and lecture-based teaching, where students passively receive information without much opportunity to engage in critical thinking or hands-on learning (Lachum & Intasena, 2024; Ranmechai & Poonputta, 2023; Un-udom et al., 2024). This approach limits students' ability to actively participate in their learning process, making it difficult for them to develop analytical thinking skills or deeply understand complex scientific concepts (Smith & Smith, 2014).

As a result, students struggle to acquire the knowledge needed to excel in science, which is evident in national test scores, where Thai students consistently fail to reach 50 percent of the full mark (National Institute of Educational Testing Service, 2022). This issue is further highlighted by Thailand's performance in international assessments like the PISA test, where students often score below the global average, particularly in science and mathematics (OECD, 2022). Compounding this problem is the country's heavy reliance on imported technology and innovation, which reflects a broader issue of insufficient domestic capacity to generate new technologies and scientific advancements. This dependence underscores the urgent need to reform science education, making it more active and student-centered to better equip Thai students with the critical thinking and problem-solving skills necessary for future success.

Inquiry-based learning is a promising instructional method that has the potential to help students develop the desired outcomes and address the challenges within the context of Thai education. Inquiry-based learning is defined as a student-centered approach where learners actively engage in exploring questions, solving problems, and constructing new knowledge through hands-on experiences and critical thinking (Coffman, 2017; Herranen & Aksela, 2019; Meier & Sisk-Hilton, 2013). Coffman (2017) highlighted that inquiry-based learning fosters deeper understanding by encouraging students to investigate and draw conclusions based on evidence, making the learning process more meaningful and engaging. Similarly, Herranen & Aksela (2019) emphasized that this method not only improves content mastery but also enhances students' ability to think analytically and independently. Allowing students to explore scientific concepts through guided inquiry can bridge the gap between theoretical knowledge and practical application, thereby fostering the development of both analytical thinking and learning achievement. Given its focus on active learning and critical thinking, inquiry-based learning holds significant potential for transforming science education and equipping students with the skills needed to excel academically and in real-life problem-solving situations.

STEM education has emerged as an integrated approach that combines science, technology, engineering, and mathematics to enhance learning in educational systems worldwide (Idin, 2018; Martín-Páez et al., 2019; Tytler, 2020). This interdisciplinary method aims to provide students with a more cohesive understanding of these fields by showing how they intersect and apply to real-world problems. Martín-Páez et al.(2019) stated that STEM education encourages students to think critically and creatively, as it emphasizes problem-solving and hands-on learning experiences. According to Idin (2018), integrating these disciplines helps students see the relevance of what they are learning, making education more engaging and applicable to everyday life. Incorporating STEM education helps students engage with scientific and technical concepts in a way that also builds critical skills like analytical thinking, teamwork, and creativity. These experiences not only deepen their understanding but also prepare them for real-world challenges, equipping them to navigate a rapidly changing technological landscape with confidence (Karasah-Çakici et al., 2021; Kazu & Kurtoglu Yalcin, 2021).

Research has consistently highlighted the benefits of inquiry-based learning (e.g., Colclasure et al., 2020; Eroğlu & Bektaş, 2022; Kulapian et al., 2023; Siew & Chai, 2024; Yakob et al., 2020) and STEM education (e.g., Karasah-Çakici et al., 2021; Kazu & Kurtoglu Yalcin, 2021; Prajuabwan & Worapun, 2023; Sawu et al., 2023; Ültay et al., 2020). Findings from these studies demonstrate that both approaches effectively engage learners in problem-solving scenarios that require critical thinking, thereby fostering skills like analytical thinking. Furthermore, the potential for integrating these methods is significant, as they complement each other in promoting active learning and skill development. Previous research has also called for further exploration of these methods across a wider range of scientific concepts and the integration of inquiry-based learning into related studies. In response to this need, the current study combines inquiry-based learning with STEM education to develop a learning management plan aimed at enhancing grade 8 students' understanding of motion and force, as well as their analytical thinking abilities. The purposes of the study were 1) to investigate the effects of integrated inquiry-based and STEM education learning management on Thai grade 8 students' analytical thinking and 2) to investigate the effects of integrated inquiry-based and STEM education learning management on Thai grade 8 students' learning achievement.

2. Methodology

2.1 Research Design

The research employed a one-group experimental design, focusing on assessing students' performance across different stages of the learning process. This involved evaluating their abilities through exercises administered during the pretest, monitoring their engagement and progress during the learning activities, and finally, measuring their achievement through a posttest.

2.2 Participants

The participants included 37 grade 8 students from a public school in Khon Kaen Province, Thailand. They were selected through purposive sampling, with consideration given to their prior academic performance in science and their willingness to participate in the study. Data collection was conducted in strict adherence to ethical standards for human research.

2.3 Instruments

2.3.1 Inquiry-based- STEM Education Integrated Learning Management

The learning management plan was developed using the principles of both inquiry-based learning and STEM education. As such, the learning activities were designed to guide students through constructivist processes, encouraging them to build knowledge by asking questions based on their prior understanding. Additionally, students were tasked with creating projects that integrated science, technology, engineering, and mathematics to solve problems that could realistically occur in everyday life. The content covered during the study included topics such as friction, pressure in liquids, buoyant force in liquids, and rotational equilibrium. Each topic's learning activities incorporated both inquiry-based learning and STEM education principles. An example of a learning activity session is provided below.

Table 1. Inquiry-based STEM education and integrated learning activities

Inquiry-Based Learning Activities	STEM education activities
Exploring the Concept of Friction: Guided Questioning: Start with a guiding question like "What happens when you try to slide different objects across various surfaces?" Allow students to share their initial thoughts. Form Hypotheses: Encourage students to predict which surfaces (e.g., smooth, rough, wet, dry) will create more or less friction when objects like a toy car, a block of wood, or a rubber ball are pushed across them. Conducting simple experiments: Hands-On Exploration: Provide materials like different fabric swatches, sandpaper, plastic, and metal surfaces. Have students slide objects across these surfaces and observe the ease or difficulty with which they move. Data Collection: Students should measure and record how far an object moves on each surface and note the effort required to push it. Discussion: Lead a class discussion to compare results, focusing on why certain surfaces create more friction and others less. Reflecting on Findings: Class Discussion: Students will share what they learned and revisit their initial predictions. Discuss why their predictions were correct or incorrect. Application to Real Life: Ask students to think of everyday examples where friction is important, such as in car tires, braking systems, or the soles of their shoes.	Design Challenge: Problem-Solving: Pose a challenge: "Design a sneaker sole that provides good grip on a wet basketball court." Simple Prototyping: Using cardboard, rubber bands, and other craft materials, students will create a basic model of a sneaker sole. They should focus on patterns and textures that could increase friction. Technology and Simulation: Interactive Tools: Use a simple, age-appropriate online simulation tool where students can experiment with different surfaces and weights to see how friction changes. Visual Learning: Students can visually observe how friction works in different scenarios, reinforcing what they learned through hands-on activities. Basic Mathematical Application: Introductory Calculations: Introduce the concept of friction force using simple formulas like $f=\mu\times N$ in an accessible way. Have students estimate friction by comparing relative values rather than precise calculations. Real-World Connection: Use this calculation to estimate how their shoe sole design might perform. Discuss what changes they could make to improve grip. Collaborative Project Presentation: Group Work: Students will work in small groups to present their shoe designs. They should explain why they chose certain materials and patterns, using their experimental findings to support their choices. STEM Integration: Encourage students to connect their designs to real-life applications, emphasizing how STEM skills helped them solve the problem.

The learning management plan was evaluated by a panel of three experts, including both academic scholars and professional teachers. The evaluation results indicated a very high level of appropriateness ($\bar{x}$ = 4.67). The plan was then adjusted based on their feedback before being implemented.

2.3.2 Learning Achievement Test on Motion and Force

A learning achievement test on motion and force, designed with a focus on inquiry-based and STEM-integrated learning, was administered to grade 8 students before and after the lesson. The test consisted of 20 multiple-choice questions, each with 4 options, covering the following topics: Static Friction and Kinetic Friction, Pressure in Liquids, Buoyant Force in Liquids, and Rotational Equilibrium. The Index of Item-Objective Congruence (IOC) ranged from 0.5 to 1.0, with difficulty levels between 0.68 and 0.80, discrimination indices ranging from 0.20 to 0.80, and a reliability coefficient of 0.78, as tested using the Lovett method.

2.3.3 Analytical Thinking Test

An analytical thinking test was given to grade 8 students both before and after the lesson. The test comprised 10 multiple-choice questions, each offering 4 possible answers, and covered key topics such as importance, relationships, and principles. The Index of Item-Objective Congruence (IOC) for the test items ranged from 0.5 to 1.0. The questions had difficulty levels between 0.40 and 0.68, with discrimination indices from 0.20 to 0.68, and the test demonstrated a reliability coefficient of 0.70, assessed using the Kuder-Richardson method.

2.4 Data Collection and Data Analysis

Data collection began prior to the intervention, with students taking a pretest to assess both learning achievement and analytical thinking. Scores were also recorded during the activities as students engaged with the material. Following the intervention, a posttest was administered to evaluate learning achievement and analytical thinking again. The data were analyzed using percentage, mean score, standard deviation, effectiveness index (E1/E2) compared to the predetermined criteria of 75/75, and a paired samples t-test.

3. Results

Table 2. The effectiveness of the Inquiry-based- STEM education integrated learning management

Outcomes	**N**	**Max score**	**Sum**	$\bar{x}$	**%**
Process (E_1)	37	48	1,371	37.05	77.20
Product (E_2)	37	20	574	15.51	77.57
Effectiveness of the learning management (E1/E2 = 77.20/77.57)					

The results of the study indicate that the overall effectiveness of learning management, calculated as the E1/E2 ratio, is 77.20/77.57 reaching the criteria of 75/75. Specifically, compared to the maximum scores, the participants achieved an average score of 77.20% ($\bar{x}$ = 37.05) during the learning activities, while their average score on the posttest, reflecting product effectiveness, was 77.57% ($\bar{x}$ = 15.51). This indicates that the instructional approach met the expected criteria, demonstrating its effectiveness in enhancing student learning outcomes.

Table 3. The comparison of the participants' analytical thinking

Analytical thinking	N	$\bar{x}$	S.D.	df	t	Sig
Pretest	37	2.76	1.14	36	25.77	< .001*
Posttest	37	7.16	0.87			

A paired samples t-test was conducted to compare the participants' analytical thinking scores before and after the intervention. The results showed a significant increase in analytical thinking scores from the pretest ($\bar{x}$ = 2.76, S.D = 1.14) to the posttest ($\bar{x}$ = 7.16, S.D = 0.87), $t(36) = 25.77$, $p < .001$. This indicates that the inquiry-based-STEM education integrated learning management had a significant positive effect on the participants' analytical thinking abilities.

Table 4. The comparison of the participants' learning achievement

Learning achievement	N	$\bar{x}$	S.D.	df	t	Sig
Pretest	37	6.11	2.41	39	33.51	< .001*
Posttest	37	15.51	1.74			

Likewise, a paired samples t-test was conducted to compare the participants' learning achievement scores before and after the intervention. The results indicated a significant increase in learning achievement from pretest ($\bar{x}$ = 6.11, S.D = 2.41) to posttest ($\bar{x}$ = 15.51, S.D = 1.74), $t(39) = 33.51$, $p < .001$. This suggests that the intervention significantly improved the participants' learning achievement of motion and force.

4. Discussion

The findings of this study demonstrate that the integration of inquiry-based learning and STEM education is an effective instructional approach for enhancing both learning achievement and analytical thinking among grade 8 students. The overall effectiveness of the learning management, as indicated by the E1/E2 ratio of 77.20/77.57, meets the expected criteria of 75/75, confirming that this approach successfully improved student learning outcomes. The significant increase in both analytical thinking and learning achievement, as evidenced by the paired samples t-test results, aligns with previous studies (e.g., Colclasure et al., 2020; Eroğlu & Bektaş, 2022; Kulapian et al., 2023; Siew & Chai, 2024; Yakob et al., 2020), which have highlighted the benefits of inquiry-based learning in fostering deeper understanding and critical thinking skills in science education. Similarly, the positive impact of STEM education on student achievement is supported by research (e.g., Karasah-Çakici et al., 2021; Kazu & Kurtoglu Yalcin, 2021; Prajuabwan & Worapun, 2023; Sawu et al., 2023; Ültay et al., 2020), which has demonstrated how integrating science, technology, engineering, and mathematics can enhance students' engagement and learning outcomes.

The success of this instructional approach can be attributed to several key factors. Inquiry-based learning encourages students to actively engage with the material by asking questions, exploring concepts, and constructing their understanding (Coffman, 2017; Herranen & Aksela, 2019; Meier & Sisk-Hilton, 2013). This active involvement in the learning process fosters deeper comprehension and retention of scientific knowledge. Furthermore, the integration of STEM education provides students with opportunities to apply their knowledge to real-world problems, making the learning experience more relevant and meaningful (Tytler, 2020; Ültay et al., 2020). The method not only enhances students' academic performance but also helps them develop essential skills such as problem-solving, critical thinking, and creativity.

Analytical thinking plays a crucial role in the acquisition of scientific knowledge (Beno et al., 2020; Hollett & Cassalia, 2022; Santos, 2017). Developing analytical thinking skills helped students to understand complex concepts, analyze data, and draw logical conclusions. This cognitive process enables learners to go beyond mere memorization, allowing them to apply their knowledge in practical situations and make informed decisions based on evidence. As a result, the integration of inquiry-based learning and STEM education not only improves students' understanding of motion and force but also prepares them for future challenges in science and beyond.

5. Conclusion

In conclusion, the integrated approach of inquiry-based learning and STEM education has proven to be an effective strategy for enhancing both learning achievement and analytical thinking among grade 8 students in this study. The findings indicate that this instructional method not only improves students' academic performance but also equips them with essential skills necessary for tackling real-world problems. These results align with a growing body of research that advocates for the incorporation of inquiry-based and STEM-focused approaches in science education to foster deeper understanding, critical thinking, and practical application of knowledge.

The positive outcomes of this study have significant implications for educators and curriculum developers. By integrating inquiry-based learning with STEM education, teachers can create a more engaging and meaningful learning environment that encourages students to explore, question, and apply scientific concepts. This approach is particularly relevant in the context of 21st-century education, where the ability to think critically and solve complex problems is increasingly valued. The study suggests that incorporating these instructional methods can help bridge the gap between theoretical knowledge and practical skills, preparing students for future academic pursuits and careers in STEM fields. Therefore, educational institutions should consider adopting these integrated strategies to enhance students' overall learning experiences and outcomes.

Despite the promising results, this study has several limitations that should be acknowledged. Firstly, the research lacks qualitative data, such as student interviews or observations, which could provide deeper insights into the learning processes and student experiences. Additionally, the small sample size of 37 participants limits the generalizability of the findings to a broader population. The absence of a control group for comparison also means that the study cannot definitively attribute the observed improvements to the integrated inquiry-based and STEM education approaches alone. Future research should address these limitations by incorporating qualitative methods, increasing sample sizes, and including control groups to strengthen the validity and applicability of the results.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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