Empowering Analytical Minds: Enhancing Grade 6 Students' Critical Thinking through STEM Education

Siriwan Chatmaneerungcharoen[1*] Noparat Sricharoen[2] Chanadda Eiadjuy[3]

Received: 09-06-2024, Revised: 26-08-2024, 02-10-2024, Accepted: 10-10-2024

Abstract

This study has three main objectives: 1) to examine the analytical thinking skills of Grade 6 students both before and after participating in STEM learning activities, and 2) to design STEM learning activities that effectively promote the development of analytical thinking skills among Grade 6 students. A purposive sampling method was used to select a group of 30 Grade 6 students to participate in a comprehensive 15-hour lesson plan on rocks and the rock cycle. Both quantitative and qualitative data were collected and analyzed to derive the study's findings. The results indicated that Grade 6 students demonstrated significant improvement in their analytical thinking skills after participating in the STEM lessons. The lessons spanned 15 periods and followed 6 STEM steps, including 3 main activities: studying the components of rocks, exploring their origin and formation, and understanding the rock cycle, as well as examining the uses of rocks and minerals. The students' post-learning scores were higher than their pre-learning scores. This conclusion was supported by the students' responses and comments during the learning activities, where teachers used questions in conjunction with real-life scenarios. The students showed enhanced analytical skills in three specific areas: content analysis, relationship analysis, and principle analysis. The continuous recording of the development of these skills highlighted the effectiveness of STEM education in promoting analytical thinking, which is a fundamental aspect of critical thinking.

Keywords: Analytical thinking skill; STEM education; Topic of rocks

[1] Faculty of Education, Phuket Rajabhat University
[2] Faculty of Education, Chulalongkorn University
[3] Faculty of Education, Phuket Rajabhat University
* Corresponding Author, Email: drsiriwankief@pkru.ac.th

Introduction

Global society is evolving rapidly due to advancements in technology, communication, and the economy. Consequently, nations worldwide are heavily investing in human capital to remain competitive in the global economy and labor market. Modern instructional learning plays a crucial role in preparing 21st-century students for learning, innovation, technological progress, information management, life skills, and career development. In today's world, students must exhibit adaptability and flexibility to navigate dynamic global changes and achieve overall well-being. Therefore, passive learning is no longer sufficient. Students should be given opportunities to independently explore knowledge while receiving guidance and facilitation from teachers. 21st-century instructional learning emphasizes developing skills and fostering innovation. This includes cultivating analytical thinking and problem-solving abilities, nurturing creativity and originality, and building communication and collaboration skills. It is the responsibility of teachers to equip students with these essential skills (Panich, 2012).

Recent results from the Programme for International Student Assessment (PISA) and the International Association for the Evaluation of Educational Achievement (IEA) indicate a decline in science learning among Thai students, highlighting a significant gap in scientific excellence. Additionally, the 2018 science instruction for sixth graders in Thailand showed low achievement scores. According to the Ordinary National Educational Test (O-NET) results for the 2020 academic year, the average science score for sixth graders was 38.75 out of 100, below the national average and trending downward (National Institute of Educational Testing Service (National Institute of Educational Testing Service, 2016). This suggests that Thai educational instruction has not effectively prepared students to become competent in science and technology. To develop students' competencies in these areas, teachers should employ instructional strategies that promote 21st-century skills. STEM education integrates knowledge from four fields: Science, Technology, Engineering, and Mathematics. This approach enables students to apply these disciplines to solve problems. The strength of STEM lies in using the engineering design process to create lessons while emphasizing the equal importance of all four disciplines. A STEM classroom is characterized by active, student-centered learning, fostering innovation and invention through physical activities and real-world problem-solving. It supports diverse learning styles and accommodates students with disabilities (Huling & Dwyer, 2018). STEM education encourages creativity, helping students develop essential

21st-century skills such as research, inquiry, critical thinking, analytical thinking, creativity, and decision-making (Hiğde & Aktamış, 2021). Engaging in STEM activities allows students to tackle real-life problems, enhancing their skills in experimentation, design, data collection, analysis, and making connections with natural phenomena. Research has shown that students learning STEM, particularly in chemistry, achieve higher scores and develop better problem-solving skills than traditional methods (Wichiansang, 2017). STEM education promotes self-directed learning and the development of knowledge and products, like constructionism. The Institute for the Promotion of Teaching Science and Technology (IPST) defined five steps of STEM: 1) Identify a challenge, 2) Explore ideas, 3) Plan and develop, 4) Test and evaluate, and 5) Present the solution (IPST, 2014). Effective STEM instructional design should allow students to discover knowledge independently and address real-life problems (Pornpisuthimas, 2013).

This research focuses on enhancing students' analytical thinking in science, specifically on the topic of rocks, the rock cycle, uses of rocks, and changes in rocks over time. This topic is foundational and beneficial for further study. However, teachers often use a teacher-centered approach and neglect experimental practices, possibly due to time constraints or large class sizes. This resonates with a study by (Kanyılmaz & Yücel, 2020) which found that while teachers emphasized the importance of experiments and inquiry in fostering analytical thinking, their classroom practices remained predominantly teacher-centered. Consequently, students struggle to apply learned knowledge to real-world phenomena, leading to a lack of understanding and lower engagement in science classes.

To address these issues, it is essential to design learning experiences that raise achievement scores and enhance critical thinking abilities. Encouraging students to participate in project-based or collaborative activities can facilitate the development of analytical skills (Peter, 2012). This approach should be complemented by instructional modeling of the thinking process, effective questioning techniques, and guidance through critical thinking processes. In conclusion, this research aims to study the impact of using STEM to develop analytical thinking among sixth-grade students. The findings will provide valuable insights into effective instructional strategies for enhancing student learning.

Research Objectives

1. To investigate the analytical thinking skills of sixth-grade students before and after engaging in STEM-based instruction.

2. To develop the analytical thinking abilities of sixth-grade students through the implementation of STEM instructional methods.

3. To evaluate the analytical thinking skills of sixth-grade students following their exposure to STEM instruction.

Research Methodology

This study employed Classroom Action Research within a Pragmatism framework, which emphasizes the practical application of truth and knowledge to achieve life goals and enhance quality of life. This approach values real-life experiences and best practices in teaching, particularly in supporting analytical thinking through STEM education. The research adopted a mixed-methods design, primarily focusing on the collection and analysis of quantitative data. Additionally, qualitative data were gathered to supplement and enrich the interpretation and summary of students' analytical thinking development through STEM instruction

Research instruments

Two research instruments were used to collect data:

1. A fifteen-hour STEM lesson plan designed to improve students' learning, focused on the topic of rocks. The lesson plan details, structured according to STEM steps, are presented in Table 1.

Table 1 The details of activities and time periods in the lesson plans

No.	Learning activities	Class time (hours)
1	Identify a problem	1
2	Explore ideas and gather information - Activity 1 Components of rock -Activity 2 The origin and formation of rock and the rock cycle -Activity 3 Uses of rock and minerals	9

No.	Learning activities	Class time (hours)
3	Design a solution to a problem	1
4	Implementation	1
5	Test, evaluate, and improve products/procedures	1
6	Present ideas	2

2. The data collection instruments for assessing analytical thinking skills include an analytical thinking test and activity worksheets. The analytical thinking test, designed for sixth graders, comprises three open-ended questions and nine multiple-choice questions with four options each. The activity worksheets are integrated into the lesson plans during STEM classes and emphasize critical thinking skills. These worksheets contain questions aimed at measuring analytical thinking, with student responses scored and categorized based on predefined criteria.

Development of research instrument

The development of research instruments involves the creation of STEM lesson plans and an analytical thinking test. For the STEM lesson plans, the process begins with a study of the 2018 core curriculum for the science and technology subject group. This includes an analysis of content, learning standards, and subject group indicators for the sixth-grade level. Relevant documents and research on STEM lesson plans were also reviewed. The STEM learning unit was then designed and submitted to an advisor for review. This review ensured the accuracy of content, the suitability of lesson plans, alignment between content and learning objectives, and the adequacy of study time. The advisor also assessed the learning activities and authentic assessments. Feedback from the advisor was incorporated into revisions. The revised lesson plans were then reviewed by three experts with experience in science, technology, mathematics, and engineering. These experts provided recommendations on content, spelling, and the inclusion of more engaging activities. Following this, the STEM lesson plans on the topic of rocks were tested with sixth-grade students. The researcher personally taught the lesson plans to assess their feasibility and identify any flaws. Results from these trials were used to refine the final version of the lesson plans.

The development of the analytical thinking test began with an inquiry into the 2018 core curriculum for science and technology, as well as a review of documents and theories related to analytical thinking skills and testing and assessment theories. Analytical thinking test items were then created and refined. The test measures three aspects of analytical thinking: 1) content analysis, which involves the ability to distinguish between facts and opinions; 2) recognizing relationships, which involves the ability to determine reasons in a situation or event; and 3) analyzing principles, which involves the ability to identify objectives, attitudes, or viewpoints. The final version of the test consists of two sections. The first section includes three essay questions, each measuring one aspect of analytical thinking, with each question worth three points for a total of nine points. The second section consists of nine multiple-choice items with four options each, with three questions for each aspect of analytical thinking. Correct answers receive one point, while incorrect answers receive zero points, for a total score of nine.

Data collection

Thirty sixth-grade students were selected using purposive sampling. They completed pre- and post-tests to measure their analytical thinking skills. The teacher explained the STEM learning process to ensure students actively participated in the learning activities and achieved the learning objectives. Subsequently, a fifteen-hour lesson plan, structured according to the STEM steps outlined in Table 1, was implemented. The implementation of the lesson plans began with the first step of STEM. Students were asked to read an article about "rock" and engaged in a discussion with questions such as: "What are the characteristics of rock?" (e.g., pattern, color, texture, and hardness), "What is rock?" (Rock is a naturally occurring solid that humans cannot create), and "What are the components of rock?" (Rocks naturally contain minerals). This step directed students towards understanding the problem and the final product they needed to produce.

In the second step of STEM, students were divided into groups to explore and gather information through three activities. In Activity 1, students observed rock collections and recorded their observations in Worksheet 1. They then played a game called "Rocks & Minerals," during which they noted their thoughts and raised questions based on their curiosity. Selected students presented their questions to the class, prompting group discussions and problem-solving. After completing these activities, the students took the analytical thinking test.

Figure 1 Students observed and played a game on rock and minerals in activity 1.

In Activity 2, focused on rock formation and the rock cycle, students first reviewed the instructions for the game "Rocks Dominoes." They played the game to understand its rules and practice their thinking skills. During gameplay, students recorded their observations in Worksheet 2, as shown in Figure 2. Following this, the students completed the analytical thinking test again.

Figure 2 The students were playing the game, Rock Dominoes.

In Activity 3, titled "What are the uses of rock and minerals?" students utilized their knowledge from Activities 1 and 2 to complete Worksheet 3. They engaged in brainstorming and critical thinking, following the steps outlined in the worksheet. Additionally, they discussed the practical uses of rocks and minerals. After completing Worksheet 3, the students took the analytical thinking test. Upon completing all three activities, students participated in a reflective session to summarize their learning. They concluded that in Activity 1, they learned about the components of the three types of rocks and used magnifying glasses to examine rock textures. They also played the "Rocks & Minerals" game to complete Worksheet 1. In Activity 2, they studied rock formation, the rock cycle, rock changes, and metamorphism, and played the "Rocks Dominoes" game. For Activity 3, they acquired knowledge about the uses of igneous, sedimentary, and metamorphic rocks, as well as minerals. This knowledge was essential for creating a unique model of rock cycle.

To create the model, students in each group gathered information, contemplated, planned solutions, and implemented their ideas to illustrate the rock cycle, following the third and fourth steps of STEM. They then summarized and discussed their models to refine their representations, ensuring accuracy and precision as indicated in the fifth step of STEM. In the sixth step, each group presented their models (as shown in Figure 6), shared ideas, and displayed their work on a classroom board. After completing the lesson plans, the students took the post-test on analytical thinking.

Figure 3 The students were presenting and discussing the model.

Research Results

The analytical scores of the sixth-grade students before engaging in STEM learning are presented in Table 2. According to the table, students achieved the highest scores in content analysis, followed by analyzing principles, and recognizing relationships. However, the scores in all three aspects were below the average of the total score.

Table 2 The average scores revealing the students' analytical thinking abilities before learning STEM.

Aspects of analytical skill	Total scores	$\bar{x}$	S.D.
1. Content analysis	6	2.63	1.32
2. Recognizing relationships	6	0.93	0.63
3. Analyzing principles	6	1.43	0.85

The results of developing students' analytical skills during STEM lessons are illustrated in Figure 4. The students' average scores from the three activities-Activity 1: Components of Rocks, Activity 2: Rock Formation and the Rock Cycle, and Activity 3: Uses of Rocks and Minerals-were 1.16, 3.38, and 5.13, respectively. The scores showed progressive improvement through the sequence of activities, with the highest analytical skill scores achieved in the third activity. Students demonstrated similar average scores across the three aspects of analytical thinking skills in Activities 1 and 2. However, in Activities 2 and 3, students showed slightly higher scores in content analysis compared to the other aspects.

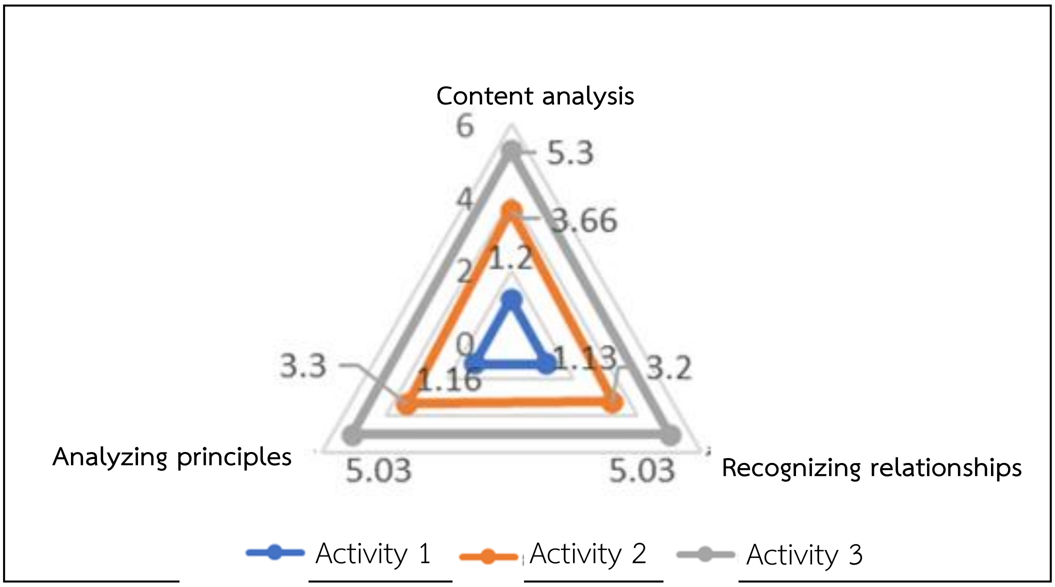

Figure 4 Students' analytical thinking average scores during STEM lessons

The results showing the differences between pre-test and post-test scores are presented in Table 3. According to Table 3, it is clear that after participating in the fifteen-hour STEM lesson plan, the students' average scores in analytical skills improved compared to their scores before the STEM instruction. Additionally, scores in all three aspects of analytical skills-content analysis, analyzing principles, and recognizing relationships-increased after the STEM lessons. In the pre-test, students achieved the highest scores in content analysis, followed by analyzing principles and recognizing relationships. However, in the post-test, the order of scores changed, with analyzing principles ranking highest, followed by content analysis and recognizing relationships.

Table 3 Pre and post scores of the analytical skills before and after the introduction of STEM

Aspects of analytical skill	Total scores	Pretest on the analytical test			Posttest on the analytical test		
		$\bar{X}$	S.D.	Interpretation	$\bar{X}$	S.D.	Interpretation
Content analysis	6	2.63	1.32		5.10	1.02	Excellence
Recognizing relationships	6	0.93	0.63		4.43	1.04	Excellence
Analyzing principles	6	1.43	0.85		5.40	1.03	Excellence
	18	**1.66**			**4.97**	**1.03**	**Excellence**

Students' responses in the open-ended section were analyzed both before and after the STEM lessons. Initially, in content analysis, students struggled to thoroughly analyze the content. However, after participating in STEM lessons, they paid greater attention to the context, were better at identifying conditions within the situation, and demonstrated a more complete understanding. Regarding recognizing relationships, students initially could only partially discern relationships. Following the STEM instruction, they were able to gather relevant information and provide more accurate explanations of the situation. In analyzing principles, students initially showed limited ability to combine principles to support their answers. After the STEM lessons, they demonstrated improved competence in analyzing relevant concepts and integrating them to provide more accurate and substantiated responses.

Research Discussion

The analytical test scores of sixth-grade students showed significant improvement after engaging in STEM activities, surpassing their pretest scores. In this research, the STEM activities were designed to support students' learning through familiar or real-life situations. When students were required to solve problems in such contexts, they felt more connected and paid greater attention to the activities. Consequently, the students’ scores on the analytical thinking test increased significantly at the statistical level of .01 after participating in the STEM activities for the Earth and space science content, specifically the topic of rocks in the sixth-grade science curriculum. This finding aligns with a study indicating that tenth-grade students engaging in a sequence of science activities significantly enhanced their analytical thinking skills, with a statistical significance level of .01, compared to their scores before the learning process (Klinchan, 2009).

The following explanations outline how STEM processes foster the development of students’ analytical thinking. The first process, identifying a problem, helps students think logically, observe, and inquire. The second process, exploring ideas and gathering information, allows students to collect data from various sources and exchange ideas with peers, enhancing their analytical thinking. The third process, designing solutions to a problem, involves students working in groups to construct prototypes, brainstorm, and address issues during implementation. The fourth process, implementation, requires students to summarize information from experiments and discussions to synthesize and propose solutions. (Hiğde & Aktamış, 2021) demonstrated that STEM education, by involving students in designing and collaborating on STEM activities, improved skills such as brainstorming, testing, and presenting creative ideas. The fifth process, testing, evaluating, and improving products or procedures, requires students to apply their knowledge to refine their product until it is complete and successful. According to (Hrbáþková, Hladík, & Vávrová, 2012), analytical thinking proficiency is influenced by metacognitive questions, which impact students' awareness and regulation of their problem-solving knowledge. Finally, the sixth process, presenting ideas, allows students to effectively communicate their investigation results using knowledge gained from all the activities. As a result, STEM processes contribute to science education by fostering analytical and other essential skills.

The development of the analytical skills of sixth graders in three aspects-content analysis, recognizing relationships, and analyzing principles-revealed improvement after participating in consecutive STEM activities. In content analysis, students were inspired to identify significant and high-priority information and conclude it with greater clarity. In recognizing relationships, students gained a deeper understanding by discerning interconnected concepts, cause-and-effect relationships, and distinguishing relevant from irrelevant arguments. In analyzing principles, students integrated related principles to formulate clearer, more accurate, and comprehensive justifications. This aligns with a study by (Chodda, 2017 and Rattanahirun, 2019) on the engineering process of ninth-grade students using STEM in a science camp, which indicated that students demonstrated proficiency in the entire engineering process across the five steps of STEM.

Research Suggestions

For Utilizing Research Results

1. Encourage STEM Integration: This research highlights that STEM activities can boost the analytical skills of sixth-grade students. Therefore, school administrators should encourage teachers to integrate STEM into science topics across different grade levels.

2. Explain STEM Concepts: Prior to integrating STEM into the classroom, teachers should clearly explain STEM instructional concepts to students to help them understand their roles within the STEM framework. Students should then be empowered to think independently under close teacher guidance.

3. Adaptation Period: Teachers should provide students with one semester to adapt to STEM-based learning. This period will enable teachers to identify and address any drawbacks of using STEM instruction and enhance it for the greater benefit of the students.

4. Flexible Learning Duration: STEM instruction requires time for learning activities. Teachers should be flexible regarding the duration of each step of STEM to optimize students' outcomes.

For Future Research

1. Expand STEM Instruction: STEM instruction should be implemented in various disciplines and grade levels to examine its impact on student outcomes.

2. Incorporate Local Wisdom: Local wisdom should be incorporated into STEM education so that students have opportunities to address challenges within their community.

References

Chodda, M. (2017). *A Study of Engineering Design Processes of Grade 9 Students on the Topic of Dissolved Oxygen in Water Using STEM Education Activit*ies. Master's Thesis, Burapha University. https://webopac.lib.buu.ac.th/Catalog/BibItem.aspx?BibID=b00229566

Hiğde, E., & Aktamış, H. (2021). Determination of STEM product-performance levels and opinions of seventh grade students. HAYEE: *Journal of Education*, *18*(2), 220–253.

Hrbáčková, K., Hladík, J., & Vávrová, S. (2012). The Relationship Between Locus of Control, Metacognition, and Academic Success. *Procedia - Social and Behavioral Sciences*, *69*, 1805–1811. https://doi.org/10.1016/j.sbspro.2012.12.130

Huling, M., & Dwyer, J. S. (2018). *Designing meaningful STEM lessons*. National Science Teachers' Association.

Institute for the Promotion of Teaching Science and Technology. (2014). *STEM Education: ST* Bangkok: IPST

Kanyılmaz, B. M., & Yücel, E. Ö. (2020). The evaluation of teachers' in-class practices and opinions for developing analytical thinking skills of primary school students in the course of science. *Education and Science*, *45*(204), 23–39. https://doi.org/10.15390/EB.2020.8876

Klinchan, W. (2009). *A Study of Learning Achievement in Science and Scientific Analytical Thinking Ability of Grade 10 Students Taught Using Science Activity Packages to Promote Analytical Thinking*. [Unpublished master's thesis]. Srinakharinwirot University.

National Institute of Educational Testing Service (Public Organization). (2016). *Summary of the Basic Educational Testing Results (O-NET) for the Academic Year* 2015. https://onetresult.niets.or.th.

Panich, W. (2012). *The Path to Creating Learning for Students in the 21st Century*. Bangkok: Sodsri-Saridwongsa Foundation.

Peter, E. E. (2012). Critical thinking: Essence for teaching mathematics and mathematics problem-solving skills. *African Journal of Mathematics and Computer Science Research*, *5*(3). https://doi.org/10.5897/ajmcsr11.161

Pornpisuthimas, S. (2013). Science Learning Management in the 21st Century. *Journal of Science, Technology, and Environmental Learning Research* Unit, *4*(1), 55-63

Rattanahirun, T. (2019). *STEM Education-Based Learning Management for Developing Scientific Process Skills and Creative Ability in Grade 7 Students*. Master's Thesis in Education, Silpakorn University.

Wichiansang, K. (2017). *The Effects of STEM Education-Based Learning Management on Chemistry Learning Achievement, Problem-Solving Ability, and Learning Satisfaction of Grade 12 Students*. Unpublished Master's Thesis, Prince of Songkla University, Pattani.