ASEAN Journal of Education

Journal homepage: https://so01.tci-thaijo.org/index.php/AJE

Developing Critical Thinking and Learning Achievements in Science of Grade Nine Students Using 5E Learning Cycle with 3D Interactive Model

Gerome Gallato Orteza*, Aree Saripa & Kittisak Jai-on

Faculty of Education, Nakhon Si Thammarat Rajabhat University, Nakhon Si Thammarat, 80280 Thailand

Article info

Article history:
Received: 12 March 2024
Revised: 26 November 2024
Accepted: 6 December 2024

Keywords:
5E learning cycle, 3D interactive model, Critical thinking, Science learning achievement

Abstract

This study aimed to: (1) evaluate students' critical thinking relative to a 75% criterion, (2) assess learning achievement against an 80% criterion, and (3) investigate student satisfaction with the 5E learning cycle and 3D interactive model for the unit on "Electrical Energy". Participants included 60 Grade 9 (M3) students from the English Programme at Benjamarachutit School, enrolled in the second semester of the 2023 academic year. A class of 30 students was selected through cluster random sampling. The study employed a one-group posttest-only design, with a 12-hour intervention using 5E learning cycle lesson plans with 3D interactive models. Data were collected through a critical thinking test, learning achievement test, and satisfaction questionnaire, and analyzed using a One Sample t-test and descriptive statistics to compare mean and standard deviation. Results showed that the intervention significantly enhanced critical thinking and learning achievement, with mean scores of 81.50% and 94.17%, respectively ($p < .05$). Additionally, students reported a "Completely Satisfied" level of satisfaction with the 5E learning cycle and 3D model. These findings suggest that the 5E learning cycle with a 3D interactive model is effective in developing critical thinking components such as inference, recognition of assumption, deduction, interpretation, and evaluation of arguments, as well as the six levels of revised Bloom's taxonomy.

Introduction

Science educators often wonder why students find science particularly challenging, which is reflected in generally low performance on assessments. In today's technology - driven society, UNESCO (2010) emphasizes that science education is essential to achieving global success. Yet, mastering science requires critical thinking as a skill necessary to navigate complex, rapidly evolving information landscapes. Studies of Thai students show a lack of critical thinking skills, which impacts their ability to evaluate situations, make informed judgments, and solve problems (Ploysangwal, 2018). This gap highlights the need to cultivate critical thinking within science education to improve understanding and performance.

Critical thinking is a fundamental skill that enables students to analyze information, evaluate arguments, and solve problems. However, many students struggle with critical thinking, especially in contexts where rote learning predominates, resulting in superficial

* Corresponding Author
e-mail: geromeorteza123@gmail.com

comprehension and limited application of knowledge. Recognizing the importance of this skill, Thai education policy has begun to emphasize reasoning, analysis, and problem-solving. Science learning outcomes are typically assessed through student engagement in activities that require them to apply critical thinking, such as class discussions, debates, and exercises in judgment.

The Thai Ministry of Education's National Education Plan includes objectives aimed at preparing students for the demands of the 21st century. The Programme for International Student Assessment (PISA) (2018) results underscored the need for improvement, showing that Thai students scored below the OECD average in reading, mathematics, and science. In science, Thai students scored an average of 426, compared to the OECD average of 489. Similar results were observed in Thailand's Ordinary National Education Test (O-NET) 2019, with average science scores at 30.1%, indicating a need for stronger critical thinking skills and overall performance improvement. For instance, Benjamarachutit School recorded an average science score of 45.26% for grade 9 students, further signaling the need for enhanced educational strategies.

Research on common challenges in high school science classrooms suggests that teachers often struggle to encourage deep learning and conceptual understanding (Lainez et al., 2021). Many students fail to grasp fundamental scientific concepts, which is crucial for developing critical thinking and achieving better learning outcomes. In Benjamarachutit School's English program, where a 70% passing criterion is set, students' limited conceptual understanding and lack of evidence-based reasoning have motivated this study into students' critical thinking and academic performance.

To address this, inquiry-based learning models like the 5E Learning Cycle are gaining traction in science education. This model—comprising Engagement, Exploration, Explanation, Elaboration, and Evaluation—offers a student-centered framework aligned with natural learning processes and promotes higher-order thinking. Studies indicate that the 5E model can foster critical thinking, increase student engagement, and improve learning outcomes by encouraging exploration, questioning, and active participation (Sumarni, 2010; Maskur et al., 2019; Widodo et al., 2020).

Integrating digital tools, such as 3D visualization, with the 5E Learning Cycle further enhances learning by providing interactive experiences that clarify complex concepts. Research shows that 3D models improve engagement, imagination, and critical thinking by presenting information in dynamic, easily interpretable formats (Astuti et al., 2020). In classrooms, 3D tools can offer experiential learning and help students understand scientific concepts that are otherwise abstract or difficult to visualize.

Building on these findings, this study investigates the use of a 3D interactive model combined with the 5E Learning Cycle to enhance critical thinking and academic achievement of students in grade 9 science, which focused on studying a unit on "Electrical Energy." The study also explores students' satisfaction with this blended teaching approach, aiming to identify its impact on both critical thinking and learning outcomes.

Objectives

1. To evaluate students' critical thinking relative to a 75% criterion after learning through 5E Learning Cycle with 3D Interactive Model.
2. To assess learning achievement against an 80% criterion after learning through 5E Learning Cycle with 3D Interactive Model based.
3. To investigate student satisfaction with the 5E learning cycle and 3D interactive model for the unit on "Electrical Energy."

Literature review

5E Learning Cycle

The 5E learning cycle is a structured framework used to implement inquiry - based learning in science classrooms. It encompasses five sequential stages—Engagement, Exploration, Explanation, Elaboration, and Evaluation—that guide students through an active learning process. Each phase serves a specific purpose in fostering comprehension and retention: Engagement helps students focus and connect with the topic, often by addressing prior knowledge and misconceptions to stabilize cognitive understanding. The lesson aims to bridge previous knowledge with current objectives, setting the stage for meaningful exploration.

During Exploration, students engage in activities that encourage hands-on investigation, allowing them to make connections, observe patterns, and form questions. This phase provides foundational experiences upon which teachers can later build formal explanations. The Explanation phase is crucial, as the teacher focuses students' attention on particular elements of their explorations, often by prompting student explanations before delivering scientific insights. This approach

ensures that the students' perspectives and initial findings inform the learning process, facilitating deeper understanding. Finally, Evaluation gives students a structured opportunity to assess their comprehension and receive feedback, helping consolidate their learning.

The 5E model is notably student-centered and flexible, supporting different learning styles and encouraging active engagement (Sumarni, 2010; Soeprodjo et al., 2008). Research shows that this model, by aligning with inquiry-based principles, effectively supports learning across STEM fields, as it mirrors natural cognitive processes and fosters scientific thinking (Cavallo & Laubach, 2001; Dass, 2015). By following these phases, students tend to approach learning more enthusiastically, develop critical skills, and become better equipped for problem-solving in scientific contexts. Implementing the 5E model has proven beneficial across diverse settings. For instance, Maskur et al. (2019) reported that it enhances student engagement and judgment, while Widodo et al. (2020) demonstrated that it promotes student participation, aids in developing scientific skills, and is adaptable to science instruction. Integrating local context into 5E - based activities further motivates active participation, allowing students to analyze and relate science concepts to everyday experiences.

Technology Integration

Technology - aided learning is another important theme emerging from the literature related to student-centered approach in teaching and learning. It simply means the incorporation of technology in learning to engage students while guiding their access to electronic platforms promoting self-directed learning allowing students to get support and teachers to respond to students' needs effectively (Chen & Tsai, 2021; Knorn et al., 2022).

Integrating digital technology in the classroom enhances the 5E model's impact by fostering essential 21st-century skills such as critical thinking, creativity, and communication (Asrizal et al., 2022; Lubin & Ge, 2012).

Given the level of technology infiltration in education, particularly in relation to the changing learning environment, demand for flexibility in methodology, and need to enhance creativity and innovations in learning, educators no longer have a choice but to integrate emerging technologies into teaching and learning processes. Emerging technology use in the classroom has grown so compelling that it is altering how instruction is planned and carried out as well as how educators function in their roles. Utilizing developing technologies helps teachers and students interact more outside of the classroom and hold classes wherever they are.

The shift toward digital technology has been catalyzed by advances in information technologies since the early 2000s, making real-time access to information more achievable (Burgess & Sievertsen, 2020). This shift encourages educators to incorporate tools like interactive 3D models, which can enhance visualization and support experiential learning.

Use of 3D models

Interactive 3D models are particularly valuable in science education. By transforming abstract concepts into tangible, visual representations, 3D models can improve student comprehension, especially for complex scientific topics. Studies show that these models promote motivation, active learning, and engagement by providing a realistic, immersive environment that encourages students to explore and interact (Squire & Jenkins, 2004; Brasil et al., 2011). In particular, 3D animations offer an effective alternative to traditional instructional methods by enhancing visualization and supporting real-time collaborative learning (Lowe, 2004).

The benefits of using 3D models in education extend to cognitive development and engagement. Research by Teplá et al. (2022) indicates that 3D animations can improve students' visual skills and their ability to comprehend dynamic scenarios, while Astuti et al. (2020) found that 3D visualization improves critical thinking and scientific attitudes. Compared to static images or text, 3D models provide a clear, structured presentation that aids in understanding abstract or challenging scientific concepts. The development of 3D visualization tools is therefore essential for enhancing critical thinking and imagination, helping students tackle complex ideas with increased clarity and engagement.

Research methodology

This study employs a quasi-experimental, one-group post-test design consisting of two primary stages: treatment (X) and post - test (O). Ninth-grade (Mattayom 3) students received treatment (X) involving a 5E learning cycle with a 3D interactive model in science subjects, followed by a post - test (O) to evaluate student performance against a set criterion. After the post - test, a satisfaction questionnaire was administered to gauge the students' satisfaction with the 5E learning cycle and 3D integration in their science curriculum.

Population and samples

The population consisted of 60 students from two classes (M3/7 and M3/8) enrolled in the English Program at Benjamarachutit School, Nakhon Si Thammarat, who attended the core science course Code number: SCI23102, focusing on the "Electrical Energy" unit. Both classes shared similar characteristics regarding academic achievements, thinking abilities, and learning behaviors. A cluster random sampling technique was used to select 30 students from class M3/7 as the sample, comprising 11 males and 19 females in the second semester of the 2024 academic year.

Research Instruments

Following Ary et al. (2010), the researcher developed the following instruments to ensure a thorough investigation of the research objectives:

1. 5E Learning Cycle with 3D Interactive Model Lesson Plans

Twelve lesson plans incorporating six 3D interactive models were developed and implemented in science classes to assess student achievement and critical thinking. Using the Tinkercad application, the teacher provided QR codes for students to access 3D models, which were incorporated into three phases of the 5E learning cycle—exploration, explanation, and elaboration—facilitating students' understanding and visualization of science concepts. The lesson plans were evaluated by three experts on a 5-point Likert scale and achieved mean scores ranging from 4.82 to 4.96, interpreted as "very good" (Nyutu, Cobern, & Pleasants, 2021).

2. Critical Thinking Test

A 20-item test, adapted from the Watson-Glaser Critical Thinking Appraisal (Watson & Glaser, 2002), assessed skills in inference, assumption recognition, deduction, interpretation, and argument evaluation. Each item was rated by experts using the Index of Item-Objective Congruence (IOC) for content relevance, with all items achieving IOC indices between 0.67 and 1.00, signifying acceptability. Item analyses based on Difficulty and Discrimination Indices (Loon, 2007) informed item retention. KR-20 reliability analysis indicated a reliability coefficient of 0.74, qualifying the test as "good".

3. Learning Achievement Test

A 20-item test based on Bloom's Revised Taxonomy (Anderson & Krathwohl, 2001) assessed six cognitive domains and included multiple - choice and short - answer questions. Following expert evaluation using the IOC, item analyses were conducted, and retained items met difficulty (0.20 - 0.79) and discrimination (≥0.2) thresholds. KR - 20 reliability analysis yielded a coefficient of 0.80, indicating "good" reliability.

4. Satisfaction Questionnaire

A 10-item questionnaire adapted from Bucarey & Alvarez (2006) assessed student satisfaction with the 5E learning cycle and 3D interactive models in terms of model format, teaching functionality, and learning process, rated on a 5-point Likert scale. The IOC values ranged from 0.67 to 1.00, validating all items for inclusion. Cronbach's Alpha indicated a reliability score of 0.80, categorizing it as "good" (Streiner, 2003).

Data collection and analysis

Data were collected through lesson plans, the critical thinking test, the learning achievement test, and the satisfaction questionnaire, with the following steps:

1. Approval for Study Conduct

Approval to conduct the study was obtained from the English Program Head and Academic Coordinator of Benjamarachutit School, supported by a request letter from Nakhon Sri Thammarat Rajabhat University.

2. Participant Orientation

Participants (60 students from M3/7-8) were informed about the study's purpose, duration, and scope.

3. Implementation of Lesson Plans

Over six weeks, the researcher taught the unit on "Electrical Energy" to M.3/7 students using the 5E model with 3D interaction for exploration, explanation, and elaboration phases.

4. Post-test Administration

- Critical Thinking Test: A 20-item test was administered to assess critical thinking.
- Learning Achievement Test: Administered a day later to evaluate topic comprehension.
- Satisfaction Questionnaire: Distributed to assess student satisfaction with the intervention.

Data analysis included the following statistical approaches:

- The critical thinking test results, with a criterion of 75%, and learning achievement test results,

Table 1 5-point Likert Scale Description and Interpretation

Likert scale	Interpretation
5	Completely Satisfied
4	Very satisfied
3	Moderately satisfied
2	Slightly satisfied
1	Not at all satisfied

with an 80% criterion, were analyzed using one-sample t-tests, means, and standard deviations.

- Satisfaction levels were analyzed using mean and standard deviation on a 5 - point Likert scale.

Results

The data analysis in this study is organized into three components: (A) the quantitative analysis of students' critical thinking skills, (B) the analysis of learning achievement scores, and (C) the evaluation of students' satisfaction with the 5E learning cycle integrated with a 3D interactive model. These analyses aim to provide accurate insights and validate the research objectives.

A. Assessment of students' Critical Thinking

This section addresses the first research objective: to assess students' critical thinking scores after learning through the 5E learning model with a 3D interactive component, using a set criterion of 75%.

Table 2 One sample t-test of Critical Thinking Test

Critical Thinking Components	n	full score	M	percentage	SD	t	sig.
1. Inference	30	5	3.60	72.00	18.64	-0.88	.19
2. Recognition of Assumption	30	4	3.76	94.17	12.60	8.33*	.00
3. Deduction	30	3	2.40	80.00	22.49	1.22	.12
4. Interpretation	30	4	3.46	86.67	24.33	2.63*	.01
5. Evaluation of Arguments	30	4	3.07	76.67	17.29	0.53	.30
Over-all	**30**	**20**	**16.30**	**81.50**	**5.11**	**6.97***	**.00**

* $p \leq .05$

Table 2 presents the critical thinking test results, showing the percentage mean scores for each component. Students scored highest on Recognition of Assumption (M = 94.17%), demonstrating a strong ability to critically assess information, draw valid conclusions, and formulate supportive evidence. The Interpretation skill ranked second (M = 86.67%), followed by Deduction (80.00%), Evaluation of Arguments (76.67%), and Inference (72.00%).

Four components—Recognition of Assumption, Interpretation, Deduction, and Evaluation of Arguments—exceeded the 75% criterion, with Recognition of Assumption and Interpretation achieving statistical significance. However, Evaluation of Arguments and Deduction were not statistically significant, and Inference fell 3% below the criterion. Overall, the results indicate a mean critical thinking score of 16.30 out of 20, or 81.50%, with a standard deviation of 5.11. A t-value of 6.97, statistically significant at the .05 level, confirms that students' critical thinking performance surpassed the 75% benchmark.

B. Evaluation of students' Learning Achievement

This section addresses the second research objective: to evaluate students' science learning achievements scores after instruction via the 5E learning model with 3D interactive support, with a criterion of 80%.

Table 3 One-sample T-test of Learning Achievement Test

Learning Achievement Components	n	full score	$\bar{x}$	percentage	SD	t	sig.
1. Remembering	30	2	1.83	91.67	11.99	5.33*	.00
2. Understanding	30	2	1.90	95.00	15.26	5.39*	.00
3. Applying	30	5	4.53	90.67	13.63	4.29*	.00
4. Analyzing	30	4	3.90	97.50	7.63	12.57*	.00
5. Evaluating	30	4	3.87	96.67	8.64	10.56*	.00
6. Creating	30	3	2.80	93.33	25.37	2.88*	.01
Over-all	**30**	**20**	**18.83**	**94.17**	**6.99**	**11.30***	**.00**

* $p \leq .05$

Table 3 presents the learning achievement test results, highlighting that Analyzing scored highest (M = 3.90), indicating that 97.50% of students excelled in understanding circuit connections, energy and power calculations, and key topic concepts. Evaluating followed closely (M = 3.87, or 96.67%), then Understanding (M = 1.90, or 95.00%), Creating (M = 2.80, or 93.93%), Remembering (M = 1.83, or 91.67%), and Applying (M = 4.53, or 90.67%). The overall mean learning achievement score was 18.83 out of 20, equating to 94.17% and a standard deviation of 6.99. The calculated t-value of 11.30, significant at the .05 level, confirms that students exceeded the 80% criterion.

C. Level of students' satisfaction on Learning

This analysis supports the third research objective, which examines student satisfaction with the 5E learning cycle incorporating a 3D interactive model.

Table 4 Overall result of Student Satisfaction of 5E Learning Cycle with 3D Interactive Model

Satisfaction Components	n	M	SD	Interpretation
1. Format of the 3D interactive model activities	30	4.72	0.46	Completely satisfied
2. Functionality of teaching-learning	30	4.92	0.24	Completely satisfied
3. Learning process	30	4.93	0.29	Completely satisfied
Over-all	**30**	**4.85**	**0.33**	**Completely satisfied**

Table 4 shows an overall mean satisfaction score of 4.85 with a standard deviation of 0.33, indicating a high satisfaction level. Each questionnaire component received a rating of "completely satisfied". Learning Process received the highest satisfaction score (M =

4.93), followed by Functionality of Teaching-Learning Activities (M = 4.92), and Format of the 3D Interactive Model** (M = 4.72). These findings suggest that Grade 9 students at Benjamarachutit School were highly satisfied with the integration of the 5E learning cycle and 3D interactive model in the "Electrical Energy" unit, showing strong engagement and positive feedback.

Discussion

Based on the research objectives, the above research results are discussed as follows:

1. Evaluation of Students' Critical Thinking Scores After Using the 5E Learning Cycle with a 3D Interactive Model (Criterion: 75%)

The 5E learning cycle, augmented with a 3D interactive model, aimed to enhance critical thinking in Thai grade 9 students and meet a criterion of 75%. Four out of five critical thinking components exceeded this threshold: Recognition of Assumption, Interpretation, Evaluation of Arguments, and Deduction, while Inference fell 3% below and lacked statistical significance. This suggests the model's efficacy in fostering critical thinking, with teacher facilitation essential for optimal outcomes.

The 5E model's ability to support critical thinking aligns with findings that immersive technologies, such as VR and 3D models, can improve cognitive engagement and attentiveness (Schott & Marshall, 2018). The structured stages of the 5E learning cycle facilitate these skills by scaffolding student engagement and exploration, particularly in active environments where learners interact with technology.

According to the research of Amaliyah, Rusdianto, & Supeno (2023), the 5E learning cycle model is excellent for helping students hone their critical thinking skills. The 5E learning cycle model is used frequently to apply the critical thinking subskills that students must acquire. As a result, the model is useful for developing students' critical thinking abilities. In the study, students were able to define, organize, change the original notion, and elaborate after going through each phase of the 5E learning cycle model and interacting with the surroundings or peers. In the Engagement phase, the students fix their mental attention on a thing, issue, circumstance, or occurrence that the teacher presented. The exercises in this phrase relate to prior knowledge and dispel students' preconceptions and aid to reduce cognitive disequilibrium. Inquiring, outlining an issue, demonstrating a divergent event, and enacting a difficult scenario are all strategies for drawing students in and keeping them focused on the learning objective. In addition, the teacher establishes the guidelines and protocols for assigning the work.

In the Exploration phase, the students have time to investigate items, happenings, or scenarios during the activity with the use of 3D interactive model. The 3D model allows the students a preview of what are they going to learn. It serves as a bridge for students to discuss their ideas on the topic and what they will delve further. During this phase, the teacher's role is to act as a coach or facilitator. The activity is started by the teacher, who then gives the students the time and freedom to give interpretations of the phenomenon. If needed, the instructor can help students start reconstructing their explanations by providing coaching or guidance. It is imperative to use physical experiences and tangible materials.

In the Explanation phase, the teacher focuses the class's attention on particular facets of the engagement and exploration activities with the help of the 3D interactive model. The teacher starts by asking the class to explain their ideas. Second, the instructor presents technological or scientific explanations in an unambiguous, formal, and direct manner. The arranging of the exploratory experiences is done through explanations. The first portion of this phase should be based on the explanations provided by the students, with a clear connection made between the explanations and the experiences from the engagement and exploration phases of the instructional approach. Presenting ideas, procedures, or abilities in a condensed, straightforward, and understandable manner is crucial to this phase in order to go to the following one.

In the Elaboration phase, the 3D interactive model was used as a guide for students to relate or link their learnings to real situations. This stage makes it easier to apply principles to new but closely related circumstances. Sometimes, students misinterpret concepts, or only understand the concept in relation to the exploration experience. Additional time and experience gained from elaborate activities aid in learning. During this stage, there is also a chance to present students with novel scenarios and issues that call for the transmission of the same or comparable explanations. The main objective is the generalization of ideas, procedures, and abilities.

Lastly, the Evaluation phase. This is a crucial chance for students to assess their comprehension and apply the skills they have learned. Furthermore, the students must be provided with feedback regarding the sufficiency of their explanations. Informal evaluation should begin at the start of the 5E sequence and continue throughout. Following the elaboration stage, the teacher should finish with a formal evaluation. Teachers need to evaluate student learning outcomes as a matter of practical education. During this stage, teachers conduct tests to ascertain the comprehension level of every student.

Based on the result gathered, the second component, Recognition of Assumption received the highest percentage of 94.17. It shows that the students' scored higher than the above criterion. Recognition of Assumption is the ability of students to give comments with the correct information (Watson & Glaser, 2002). The students achieved a higher Recognition of Assumption score because they had practiced in the exploration phase. In this phase, students were asked to roam around the room and to discover how the lighting works, visualize the method of energy using the 3D interactive model as well as the components involved in the circuit connection, and how energy and power are generated. The exploration phase in the 5E learning cycle model leads students to comment with correct information, generating information and facts about the problem, and formulating substantial evidence that supports their assumptions. This phase can train students to prove their theories by conducting hands-on activities and analyzing gathered data (Amaliyah et al., 2023).

The results of the second component of Interpretation showed the score above 75%. The percentage score of the students was 86.67 which is higher than the set criterion. Interpretation refers to the understanding of the learners on a wide range of experiences, circumstances, data, events, judgments, norms, beliefs, rules processes, or criteria and the ability to communicate their learning (Watson & Glaser, 2002). The class had received training during the elaboration and evaluation phases, which is reflected in the high interpretation score. At this stage, the students are tasked to relate their learning to real life situations where it is highly evident. Students adapted their knowledge and abilities to the novel circumstances throughout the elaboration phase. Furthermore, through the analysis and application of information and abilities for self-assessment related to conceptual comprehension, the evaluation phase practiced self-regulation (Amaliyah et al., 2023).

The third component is Deduction and the result of the average score achieved by the students was 80.00, which is 5% above the set criterion. However, it is statistically not significant. Deduction refers to the conclusion that is formulated as argument and abstracted into logic (Watson & Glaser, 2002). The students were able to make rational decisions by taking into account relevant data and reducing the consequences that arise from data, statements, or other forms of representation. The class could achieve a high deduction score because in each meeting the investigation was designed to direct the students to build conclusions. In the explanation phase, students explained the results of their observations, related them to the concepts, and made conclusions based on the observations. The method used developed the skill but not at a high level due to factors such as (1) conceptual understanding of students was poor, (2) active participation of students in the learning process needed to be improved. Conceptual knowledge is a critical point for the generation and selection of appropriate procedures in solving problems. Conceptual understanding allows students to transfer an explanation of the phenomenon to different situations (Kola, 2017). Teachers should familiarize students to think critically by assigning them to experiment, to seek explanations and finding solutions to the problems, and to make inquiries about the matter to be discussed in the next section to understand the concept (Hartono, 2013). In the elaboration phase, students applied the concepts which they already understood in order to identify and obtain the elements needed for making a conclusion.

The fourth component is the Evaluation of Arguments. The results showed that the students received a score of 76.67, which is above the set criterion of 75%. However, it is statistically not significant. Evaluation of Arguments refers to the ability to analyze information objectively and accurately and to draw accurate conclusions (Watson & Glaser, 2002). There was not much improvement observed in Evaluation of Arguments. Certain factors were lacking such as minimal teacher's guidance and feedback. Several studies confirmed that teacher and peer feedback is a significant factor that affects critical thinking development and learning achievement. For example, a study conducted by Wambsganss et al. (2020) confirmed that individual feedback was helpful in developing students' reasoning and argumentative writing skills. Based on the analysis

of the data obtained, students have not been able to give a strong reason for an argument and draw a conclusion well. This finding is in line with the results of Seventika, Sukestiyarno, and Mariani (2018) and Basri, Purwanto, and Sisworo (2019), which found that the ability of student to analyze was not that high. The class could achieve still a passing score because the elaboration phase facilitated the students to apply each concept that they had learned toward new conditions. Furthermore, in the evaluation phase, students also evaluated their progress in achieving learning objectives.

The fifth component of Inference showed an average score achieved as 3% lower than the set criterion and deemed not significant. The Inference is the ability to draw a conclusion based on a set of seen or presumptive facts (Watson & Glaser, 2002). In the engagement phase, students were accustomed to analyzing the previous knowledge and experience with the information or facts that was presented by the teacher. However, the low score achieved was due to students not being familiar with some of the facts that was presented to them. Given that critical thinking is built on prior knowledge, a limited understanding of a subject matter prevents advancing new innovative ideas and improving critical thinking skills. This finding is in accord with the ideas of Geertsen (2003), who argues that implementing critical thinking skills across domains is more challenging, regardless of past experiences or received training. This can be explained by the fact that cognitive development necessitates and is based on the acquisition and construction of knowledge. Glaser's (1984) review of previous studies also confirms that the development of thinking and problem - solving skills is reliant on the way of teaching and using knowledge. Furthermore, in the exploration phase, students were not able to fully analyze situations such as l why the roads are designed in such a way that are confusing. Some students lack the ability to draw conclusion based on the facts, or a situation presented and from that, they have a difficulty in making decision based on the given situations or facts given by the teacher. The students were not able to objectively sort the information and to give accurate conclusions; as well as identify conclusions. This finding is align with the findings of Aiyub, Suryadi, Fatimah, and Kusnandi (2021) noting that the critical thinking skills of students in Pidie Jaya Regency Junior High School were in a low category.

The findings confirm that Benjamarachutit School's M3 students benefited from the 5E model's integration with a 3D interactive approach, facilitating independent and collaborative learning and increasing active participation. Astuti et al. (2020) similarly found that 3D visualization enhances critical thinking and scientific attitudes, supporting student engagement and promoting improved outcomes. The positive impact of 3D models on learning experience and imagination reinforces the approach's applicability in current classrooms (Barab et al., 2000; Higgins, Xiao, & Katsipataki, 2012; Jabbour, 2014; Omilani et al., 2016).

2. Assessment of Students' Learning Achievement Scores After Using the 5E Learning Cycle with a 3D Interactive Model (Criterion: 80%)

The analysis of students' learning achievement scores revealed that they surpassed the criterion of 80%, supporting the study's objective that the 5E learning cycle with a 3D interactive model enhances student achievement. Specifically, after three weeks focusing on the "Electrical Energy" unit, students demonstrated significant improvement, with a mean achievement score of 18.83 (94.17%), exceeding the set criterion. This outcome suggests that the 5E learning cycle, combined with the 3D interactive model, effectively promotes student learning achievements.

The 5E model—comprising Engagement, Exploration, Explanation, Elaboration, and Evaluation—encourages students to explore and connect new concepts with prior knowledge through multiple engagement opportunities (Ruiz-Martín & Bybee, 2022). This study's inquiry - based, learner - centered approach empowered students to work both independently and collaboratively, enhancing problem - solving and critical - thinking skills as they actively explored and investigated within their learning environment (Hussain, 2015). In this model, the researcher's role is primarily as a facilitator, guiding students to discover knowledge independently rather than directly imparting it. Students engaged in formulating, investigating, and refining their understanding, which enriched their comprehension.

This integration of the 5E learning cycle with a 3D interactive model aligns well with revised Bloom's taxonomy—encompassing levels from remembering to creating—to support knowledge development. The researcher accessed students' prior knowledge and engaged them with activities that promoted curiosity and connected past learning experiences to current ones. Activities encouraged them to generate ideas, conduct investigations, and develop deeper understanding with the help of the 3D model. Students subsequently

demonstrated their conceptual understanding and acquired skills through various tasks, such as calculations and group presentations, which enabled both self-assessment and evaluation of progress toward learning objectives.

These results align with the findings of similar studies. For example, Ming (2022) observed that students taught using the 5E model with Minecraft Education Edition outperformed those taught using traditional methods. Similarly, Malik, Dirgantara, and Agung (2017) reported improvements in student achievement when implementing a 5E inquiry-based model for teaching static fluid. Prahani et al. (2022) also observed that the 5E model fosters critical, analytical, and creative thinking, supporting overall learning outcomes.

Within the learning achievements, the "Analyzing" component achieved the highest percentage score (97.50%). This skill involves breaking down material into constituent parts and understanding their interrelationships (Krathwohl, 2002). The Exploration phase of the 5E model particularly supports this skill, as students learned to organize their ideas about current flow, circuit connections, and other key concepts. This indicates that the 5E model supports higher-order cognitive processes (Sotáková & Ganajová, 2023).

The second highest score was in "Evaluating" (96.67%), involving judgments based on criteria (Krathwohl, 2002). In this Evaluation phase, students assessed their understanding and critiqued presented information. They used tools like tests and presentations for self and peer assessment, demonstrating effective evaluation skills (Sotáková & Ganajová, 2023).

The "Understanding" component received a high mean score of 95.00%, indicating significant student development in interpreting, classifying, summarizing, and explaining information (Krathwohl, 2002). This result is consistent with Gorowara and Lynch (2019) findings, where inquiry-based learning significantly improved student comprehension.

For "Creating," students scored a notable 93.33%, demonstrating their ability to synthesize elements into new, coherent wholes (Krathwohl, 2002). This skill was primarily fostered during the Elaboration phase, as students applied new knowledge to real - life contexts, similar to Mubarok, Suprapto, and Adam's (2019) study on the impact of inquiry-based learning on students' higher - order thinking.

The "Remembering" component scored 91.67%, reflecting the students' ability to recall information from long-term memory, particularly in the Engagement phase, where students connected prior knowledge to new concepts (Krathwohl, 2002). This aligns with Ong et al.'s (2018) findings, which showed that the 5E model enhances memory retention among students.

The "Applying" component scored 90.67%, showing that students effectively used procedures in new situations, as observed in the Exploration and Explanation phases. This finding aligns with Freeman's (2014) research, which highlighted that active learning boosts science achievement.

Overall, the study observed that Grade 9 students of Benjamarachutit School, English Program, actively participated during class discussions, demonstrating that the 5E learning cycle with a 3D interactive model greatly benefits student learning. Educational tools like 3D visualization not only foster scientific understanding but also enhance imagination, critical thinking, and overall achievement (Barab et al., 2000; Higgins et al., 2012; Jabbour, 2014; Omilani et al., 2016).

3. Investigation on student satisfaction after using 5E learning cycle with 3D Interactive model

The results indicate a high level of student satisfaction with the 5E learning cycle integrated with a 3D interactive model, with all components achieving a "Completely Satisfied" rating. This high satisfaction level supports the model's effectiveness in enhancing students' critical thinking and learning outcomes. The student-centered approach of this method allowed students to build skills essential for science learning, with the teacher facilitating rather than directing learning. This approach was new for many students, who were accustomed to more teacher - directed instruction. Based on the findings, the 5E learning cycle with a 3D interactive model was highly effective in promoting critical thinking and learning achievements in science. Supporting these results, Hsu et al. (2014) recommend student-centered learning to foster self-regulation skills and emphasize the need for active learning environments where students can actively engage and self-assess, taking a central role in their own learning.

Among the satisfaction components, the Learning Process received the highest rating, reflecting students' engagement and their ability to think critically. Students indicated that the 5E learning cycle combined with the 3D model deepened their understanding of the lesson. The integration of a 3D model increased student interest in the subject, prompting greater effort to learn new skills and thereby enhancing learning outcomes (Teplá et al.

2022). Similarly, Ardila et al. (2023) found that students reported high satisfaction, enjoyment, and perceived skill improvement with 3D systems across randomized clinical trials.

Functionality of Teaching-Learning Activities ranked second in satisfaction. Students reported that these activities made the content more engaging and relevant to real-life situations. Aligned with 21st - century skills, students leveraged technology to connect prior knowledge with current topics, feeling more encouraged to learn due to the active, technology - integrated teaching - learning environment. Ceylan - Eliyeşil & Tuna (2023) reported similar findings, showing that the 5E learning cycle with 3D technology promoted active participation and enjoyment while enhancing learning outcomes.

Lastly, the Format of the 3D Interactive Model also received a high satisfaction rating. Students found the format engaging, noting the visual appeal and ease of use, with suitable colors for differentiation and quick loading times. Many students expressed interest in using similar technology-assisted environments in other classes, describing the 3D model as fun, educational, visually engaging, and user-friendly. According to Ceylan - Eliyeşil & Tuna (2023), students find information learned in a technology-rich environment more memorable and understandable.

Overall, the satisfaction ratings suggest that the 5E learning cycle with a 3D interactive model effectively promotes critical thinking and enhances learning achievements. This study underscores the importance of innovative, technology-aided learning, which encourages active student participation in educational activities. Technology-integrated learning aligns with the literature on student-centered education, which advocates for the use of digital platforms to engage students, promote self-directed learning, and provide responsive support from teachers (Chen & Tsai, 2021; Knorn et al., 2022). Although technology is beneficial, careful monitoring and guidance are essential to ensure alignment with educational goals. Teachers should consider designing instructional materials that foster student engagement and connection while maintaining a structured, supportive environment. These findings add to the understanding of the 5E learning cycle with a 3D interactive model's effectiveness in science education.

Conclusions

Based on the analysis, the following conclusions are formulated in relation to the research objectives:

1. The implementation of the 5E learning cycle with a 3D interactive model effectively developed critical thinking skills among Thai M3 students, with a performance target of 80%. Among the five components of the critical thinking assessment, four components—Recognition of Assumption, Interpretation, Evaluation of Arguments, and Deduction—exceeded this criterion. Only one component, Inference, scored slightly below the criterion by 3%, though this difference was statistically insignificant. The M3 students at Benjamarachutit School, English Programme, benefited from this method, which fostered independent and collaborative learning while maximizing technology use in class. Overall, the method proved effective in enhancing students' critical thinking. However, effective teacher facilitation is essential to optimize critical thinking development throughout this process.

2. Analysis of the learning achievement scores confirmed that students scored above the 80% criterion, supporting the second research objective: the 5E learning cycle with a 3D interactive model enhances students' learning achievements. The findings demonstrate the effectiveness of the three-week instructional period, particularly for the "Electrical Energy" unit. Overall, the results confirm that the method used is effective for improving student learning outcomes.

3. Student satisfaction with learning the "Electrical Energy" unit was high, indicating that the 5E learning cycle with a 3D interactive model is highly effective in fostering critical thinking and learning achievements.

Recommendations

Implementation recommendations focus on enhancing the strengths of the 5E learning cycle with a 3D interactive model, addressing areas for improvement. Suggestions include the incorporation of animations and augmented reality, more engaging discussions, and increased collaborative tasks to support critical thinking and learning achievements and assess student attitudes during learning. Additionally, it is recommended that teachers receive training on implementing technology-supported learning cycles to further develop students' critical thinking and achievement.

For future research, the following are recommended:

1. Further investigation is needed to develop specific skills, such as Inference, to fully enhance students' critical thinking.

2. Teachers in other science fields should consider using this method to evaluate its effectiveness on students' higher-order thinking skills and learning outcomes.

3. The use of the 7E learning cycle is recommended to assess its effectiveness in the technology-integrated teaching and learning process.

4. Conducting student interviews would offer valuable insights to optimize the design of this teaching method.

Research Limitations

1. The study was limited to assessing the critical thinking and learning achievements of grade 9 (M3) Thai students in the English Programme at Benjamarachutit School, aged 13 - 14 years. Therefore, the results may not fully represent other Thai students in different programs or schools.

2. The research employed a quasi-experimental design with a one - group posttest-only format, consisting of treatment (X) and posttest (O) stages. The sample consisted of 30 M3/7 students (11 males, 19 females) selected through cluster random sampling.

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