Diagram-based Scientific Explanation: A Pilot Study on Learning Model Development for the Biological Science Classroom

Piriya Wannathai[a] and Chaninan Pruekpramool[b]

Corresponding author: Chaninan Pruekpramool (chaninan@g.swu.ac.th)
[a] Doctoral Student in Science Education, Science Education Centre, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand
[b] Science Education Centre, Faculty of Science, Srinakharinwirot University, Bangkok 10110, Thailand

Keywords: Diagram-based scientific explanation, scientific explanation, progression of learning, learning achievement

Abstract

The ability in constructing scientific explanations is one of the educational benchmark tests for various countries. Many learning models have been proposed to serve as tools for students' learning development. Identifying certain gaps has led us to consider creating a new learning model that aligns with the learning goals and the needs of students. Therefore, this research presents a pilot implementation of a newly developed learning model. The aims of this research are: (1) to develop a learning model to enhance the ability of grade 10 students in constructing scientific explanations in the biological science classroom; (2) to compare the students' ability in constructing scientific explanations before, during, and after learning with the model; (3) to study the students' progression of learning in constructing scientific explanations; and (4) to compare the learning achievement of students before and after learning using a 60% criterion. The Diagram-based Scientific Explanation (DSE) learning model was created using a research and development process. The participants consisted of 36 Grade 10 students, who studied in a school in Phetchaburi, Thailand, and were selected by convenience sampling. The DSE model comprised of six steps designed to enhance students' ability in constructing scientific explanations, facilitate progression of learning, and improve learning achievement.

Introduction

Teaching students to explain natural phenomena scientifically is a vital learning goal in science curricula across many countries. Widely recognized international standards, such as the Next Generation Science Standards and the Australian Science Curriculum, emphasize the importance of students' ability in constructing scientific explanations at the secondary level (Australian Curriculum Assessment and Reporting Authority, 2020). Similarly, Thailand's Basic Education Core Curriculum B.E. 2008 and Revised edition B.E. 2017 science standards highlight the understanding of scientific principles and the ability to explain phenomena as crucial learning outcomes (Ministry of Education, 2017).

However, despite the clear emphasis on scientific explanation skills in the curricula, there is a pressing need to enhance students' competency in this area. The Programme for International Student Assessment (PISA), which assesses 15-year-old students' knowledge and skills in reading, mathematics, and science, has revealed that the average science competency scores of Thai students were lower than the average score of the Organization for Economic Co-operation and

Development (OECD) in 2015 (Chatmaneerungcharoen & Saetae, 2024; Institute for the Promotion of Teaching Science and Technology (IPST), 2018; Khotabin & Narjaikaew, 2024; Natap, 2023; OECD, 2015) and 2018 (IPST, 2018; Sriraudom, 2022). Notably, the score in explaining phenomena scientifically was at the lowest level compared to other competencies (IPST, 2018; Khotabin & Narjaikaew, 2024; Natap, 2023; OECD, 2015; Sriraudom, 2022). Furthermore, Thailand was ranked among the group of low-scoring countries (IPST, 2018; OECD, 2018). These findings underscore the urgent need to improve students' ability in constructing scientific explanations and suggest that previous teaching and learning experiences have fallen short in promoting this essential skill.

The ability in constructing scientific explanations is a crucial process that involves students gathering evidence, scientific data, and applying scientific reasoning to explain natural phenomena (McNeill & Krajcik, 2008). This ability comprises three essential components: (1) claim, (2) evidence, and (3) reasoning (McNeill & Krajcik, 2008). Previous research has highlighted that Thai students' proficiency in constructing scientific explanations has been low, with the reasoning component being particularly challenging (Aniwatanawongand & Jantrasri, 2019; Khotabin & Narjaikaew, 2024; Meela & Artdej, 2017; Natap, 2023; Sapasuntikul, 2016; Wannathai & Pruekpramool, 2021). Similarly, international studies have also reported that the reasoning component poses difficulties for students (McNeill & Krajcik, 2008; Oktavianti, Handayanto, Wartono, & Saniso, 2018). These findings suggest that special emphasis should be placed on developing students' reasoning skills in the context of scientific explanations.

In Thailand, local variations significantly shape teaching practices in Thai schools. In many Thai schools, science teaching emphasizes content memorization over scientific explanation. Large class sizes and limited teacher training in inquiry-based approaches contribute to diverse instructional approaches. Furthermore, cultural expectations often discourage students from openly questioning information or constructing argumentative explanations. These contextual variables have a direct impact on how students construct scientific explanations. Various learning models have been proposed to enhance students' ability in constructing scientific explanations.

These learning models typically involve students (1) stating their claims by drawing on their prior knowledge or understanding of provided situations and questions related to the learning content, (2) investigating and exploring evidence to support their claims, (3) explaining their findings or understanding and constructing scientific explanations using models, diagrams, or mind maps, and (4) summarizing the learning content and applying it to explain new situations. While previous models address claim and evidence construction, they often lack explicit scaffolding for developing scientific reasoning, a gap particularly critical in the Thai educational context where reasoning is a major area of weakness. Thai students have been found to struggle with the reasoning component, even when achieving high scores in other components of scientific explanation (Juthanarupakit, Jantarakantee, & Chiangga, 2018). In the context of Thai students' performance on international standardized tests, our review revealed that existing instructional models do not adequately support the development of scientific explanation skills. This disconnect motivated the design of the DSE model, aiming to bridge the theoretical and practical gaps identified.

Previous research suggests that students may construct better scientific explanations when they possess accurate scientific knowledge (Aldresti, Rahayu, & Fajaroh, 2018; Meela & Artdej, 2017; Oktavianti et al., 2018), which underscores the importance of both learning achievement and the ability in constructing scientific explanations. Additionally, examining students' progression of learning can provide insights into their knowledge and understanding after learning, as well as reflect on teachers' teaching and learning management, thereby enabling teachers to improve their teaching competency to better meet students' needs (Kaldaras, Akaeze, & Krajcik, 2021). The DSE learning model can serve as a guideline for researchers, educators, and policymakers interested in promoting science learning in the country.

Research objectives

(1) To develop the DSE learning model, (2) to compare students' ability in constructing scientific explanations before, during, and after learning with the model, (3) to study students' progression of learning in constructing scientific explanations, and (4) to compare students' learning achievement before and after learning with a 60% criterion.

Literature review

Ability in Constructing Scientific Explanation

The process of constructing scientific explanations involves students gathering evidence, scientific data, and scientific reasoning to explain scientific phenomena. This ability comprises three components: (1) claim, which is the statement of students' understanding of the scientific phenomenon; (2) evidence, which is the scientific data used to support the claim; and (3) reasoning, which is the scientific principle that explains the link between the claim and evidence (McNeill & Krajcik, 2008). Constructing scientific explanations might be challenging for students because this process requires coordinating multiple and complex skills (Moore & Wright, 2023). To make a claim, students need to understand the question or phenomenon because the claim is a statement that answers a question related to the phenomenon being examined (Moore & Wright, 2023). During the process of gathering evidence, students need to analyse, diagnose, and consider all available evidence before selecting evidence that supports their scientific explanation. This process also promotes critical thinking skills, which are essential in the 21st century (Holmes, Wieman, & Bonn, 2015; Ortega-Quevedo, Gil-Puente, & Rapp, 2023). On the other hand, the reasoning component of scientific explanations requires students to apply scientific principles and develop a deeper understanding of the scientific concept (McNeill & Krajcik, 2007; Oktavianti et al., 2018; Wannathai & Pruekpramool, 2024).

Previous research studies (Aniwatanawongand & Jantrasri, 2019; Meela & Artdej, 2017; Sapasuntikul, 2016; Wannathai & Pruekpramool, 2021, 2024) have shown that Thai students tend to have a low level of ability in constructing scientific explanations , with reasoning being the component where they face the most challenges and receive lower scores compared to the other components. Providing reason was found to be the most difficult process for students when constructing scientific explanations, as it requires them to understand relevant scientific principles and use them to justify why the evidence supports the claim (McNeill & Krajcik, 2008; Oktavianti et al., 2018). These findings suggest that special attention should be given to enhancing students' ability in the reasoning component of constructing scientific explanations.

Learning models and Techniques for Enhancing Ability in Constructing Scientific Explanation

Various learning models and techniques have been proposed to enhance students' ability in constructing scientific explanations. These include the 5E Inquiry Model (Juthanarupakit et al., 2018; Likhitjunyarak, Suwanjinda, & Thammaprateep, 2023), Engage-Investigate-Model-Apply (EIMA) Model (Dechsuwanrasami, Sitthiraksae, & Nuangkaew, 2024; Promsorn, 2019; Sriraudom, 2022), Model-Observe-Reflect-Explain (MORE) Thinking Frame (Boonrod & Chuchat, 2015), Predict-Observe-Explain (POE) Sequence (Onthong & Nasaree, 2023; Sapasuntikul, 2016), Explanation-Oriented Lesson Model (Nawani, Kotzebue, Spangler, & Neuhaus, 2019), Process-Oriented Guided Inquiry Learning Model (Aldresti et al., 2018), Argument-Driven Inquiry (Sirithon & Jantarakantee, 2019), and Common Knowledge Construction Model (Kaewbamrung, 2011)Each of these learning models has its unique learning process, all of which are based on constructivism and emphasize four key features that help students construct better scientific explanations: (1) introducing interesting scientific issues or situations into the lesson; (2) investigating, conducting experiments, or searching for information to generate evidence that is appropriate and sufficient to support the claim; (3) discussing the evidence and constructing the scientific explanation; and (4) applying the knowledge from the lesson to build the scientific explanation in a new situation. All of these features are related to the principles of inquiry learning, which promote a student-centred approach that allows students to investigate information through various methods until they gain understanding and construct their own knowledge (Soonjan & Kaewkhong, 2022).

However, although these learning models can guide the enhancement of students' ability in constructing scientific explanations, they may not fully address the reasoning component, which often scores lower than other components (Juthanarupakit et al., 2018; Sriraudom, 2022; Wannathai & Pruekpramool, 2024). Techniques such as the Claim-Evidence-Reasoning (CER) framework (McNeill, 2012), Premise-Reasoning-Outcome (PRO) framework (Tang, 2016), science writing heuristic (Ruengtham, 2016), and model-evidence link diagram (Aniwatanawongand & Jantrasri, 2019; Lombardi, Sibley, & Carroll, 2013) have been integrated to address this issue. Among these, the model-evidence link diagram stands out by requiring students to connect evidence and claims with reasoning, fostering deeper reasoning skills (Aniwatanawongand & Jantrasri, 2019).

The proposed learning model builds on four key features of existing models and incorporates the model-evidence link diagram to strengthen reasoning. The learning model aims to help students understand scientific principles and use them to reason and connect evidence to claims. It is expected to improve students' learning achievement and progression of learning in constructing scientific explanations (Figure 1).

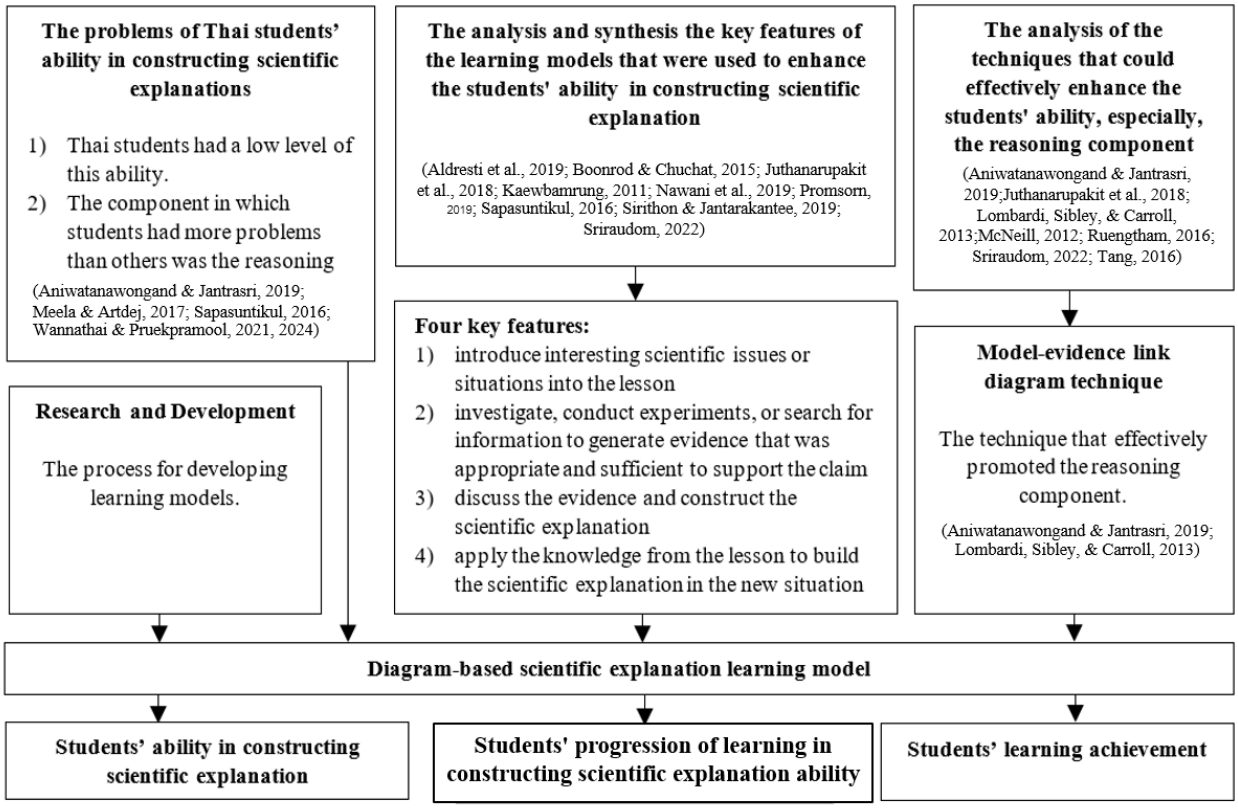

Figure 1. The theoretical framework for developing the DSE learning model

Methodology

The DSE learning model was developed using a research and development (R&D) process, organized into three loops with four phases each, as follows:

Phase 1: Analysing the Fundamental Concept for Developing the Model (R_1)

The researchers reviewed literature on the ability in constructing scientific explanations, exploring theories, problems, learning models and techniques. Prior to the implementation of the DSE model, classroom observations at the R&D school revealed that students struggled to construct coherent scientific explanations, particularly in structuring reasoning sentences. Teachers primarily used inquiry-based methods, however, these were not sufficient due to limited opportunities for students to engage in evidence-based reasoning activities. This analysis shaped the foundational concepts for developing the DSE learning model.

Phase 2: Designing and Developing the Model (D_1)

The researchers designed the DSE model based on their foundational analysis. Subsequently, seven lesson plans were developed, covering topics in biological science. The research instruments consisted of the following: (1) the ability in constructing scientific explanations pre-post tests, (2) the learning achievement test, and (3) the semi-structured interview form. To ensure the quality and validity of the instructional materials and assessment tools, expert reviews, and statistical analyses were conducted. Detailed descriptions of the development and validation of the research instruments are provided in Appendix 1.

Phase 3: Initial pilot study (R_2) and Improving the Model (D_2)
The DSE learning model, lesson plans, and tests were piloted with 42 grade 10 students who were not part of the study and were enrolled in a biological science course. After the pilot study, revisions were made, including to multimedia resources, adjusted time allocation, keyword prompts, and enhanced worksheets with examples.

Phase 4: Second pilot study (R_3) and Evaluating the Model (D_3)
The participants in the second pilot study included 36 Grade 10 students from a school in Phetchaburi province, Thailand, who were selected using convenience sampling in the second semester of 2021. The DSE learning model was implemented in a biological science class to study its effects. The embedded mixed-method research design was used, combining quantitative and qualitative data collection and analysis, following Cohen, Manion, and Morrison (2018). Before and after implementing the DSE learning model, students' ability and learning achievement were collected by the quantitative data collection (QUAN). The qualitative data collection (qual) was used to collect the students' progression of learning in constructing scientific explanations during implementation and students' opinions after the implementation. All data were interpreted the results using quantitative data, supported by qualitative data (QUAN (qual)) (Figure 2).

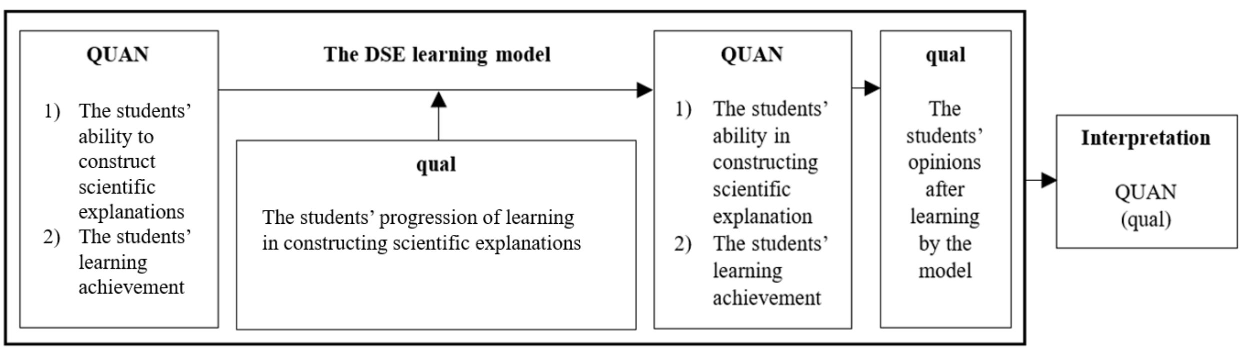

Figure 2. The embedded mixed-methods research design of this study

The quantitative and qualitative data were analysed as follows:

(1) Students' ability in constructing scientific explanations pre and post-test scores were analysed using mean ($\bar{x}$) and standard deviation (S.D.). Each test included five questions scored with a rubric adapted from McNeill and Krajcik (2008) which included three scoring levels (0, 1, and 2). Each question had a maximum score of six points. Both pre-test and post-test consisted of five questions, with a total of 30 scores.

(2) The students' progression of learning in constructing scientific explanations was analysed using Krippendorff's (2018) content analysis. Responses written on worksheets during each learning session were grouped into three components: claim, evidence, and reasoning. Each component was assessed at three levels: good, moderate, and unsatisfactory. Additionally, the overall progression for each session was analysed using specific criteria with a total score of six. Students were classified into three levels: good (score 5-6), moderate (score 3-4), and

unsatisfactory (score 0-2). Changes in students' levels were compared using the percentage of student numbers to demonstrate their progression. Students' learning behaviours in constructing scientific explanations and their opinions about the DSE learning model were analysed using analytic induction (LeCompte & Preissle, 1993). Students were coded and divided into three groups based on their levels of ability: good (A1 – A5), moderate (B1 – B5), and unsatisfactory (C1 – C5).

(3) The students' learning achievement pre- and post-test scores were compared using mean and standard deviation. The post-test mean score was compared with a 60% criterion using the mean percentage to evaluate improvement.

Results

Part 1: The Development of the DSE Learning Model

The final DSE learning model consisted of six steps: (1) introducing the question, (2) brainstorming to identify a claim, (3) finding evidence, (4) drawing a diagram, (5) constructing a scientific explanation, and (6) constructing explanations for new situations (Figure 3).

Figure 3. The DSE learning model

(1) *Introducing the question*: Teacher introduced situations related to the learning topic and provided a question for constructing scientific explanations. Meanwhile, students explained and shared their prior knowledge related to the learning situations.

(2) *Brainstorming to identify claims*: Students brainstormed in groups to identify temporary claims or possible assumptions about the question using mind mapping

(3) *Finding evidence*: Students explored and investigated evidence based on the information related to the question.

(4) *Drawing a diagram*: Students draw a model-evidence link diagram in groups. Arrows (→) were used to indicate when evidence supports a claim, and arrows with a stroke (↛) were used to indicate when evidence contradicts a claim. If the evidence does not support any claims, no arrow was drawn. For example, there are two claims and two evidence. The evidence 1 supports the claim 1 and contradicts the claim 2. Whereas, the evidence 2 supports only the claim 1 and does not support or relate to the claim 2. Therefore, students could mention that the claim 1 is an appropriate claim (Figure 4).

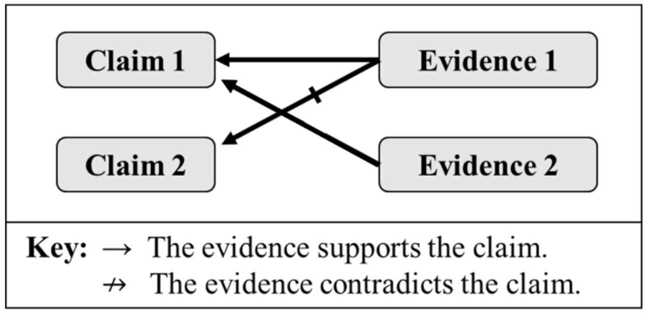

Figure 4. An illustration of how to use arrows while making a diagram

Students use the reasoning template to explain why the evidence supports the claim by providing related scientific principles (Figure 5).

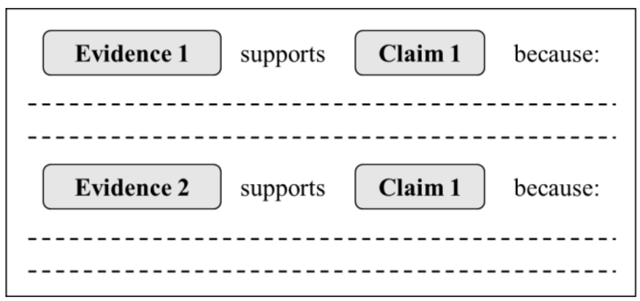

Figure 5. A template for writing the reasoning based on how evidence supports claims

(5) *Constructing a scientific explanation*: Students construct a scientific explanation by combining the claim, evidence, and reasoning, and share it with their group. The researchers developed a guideline template to help students express the complete scientific explanation using appropriate phrases (Figure 6), as some students struggled to write the explanation despite having the correct components.

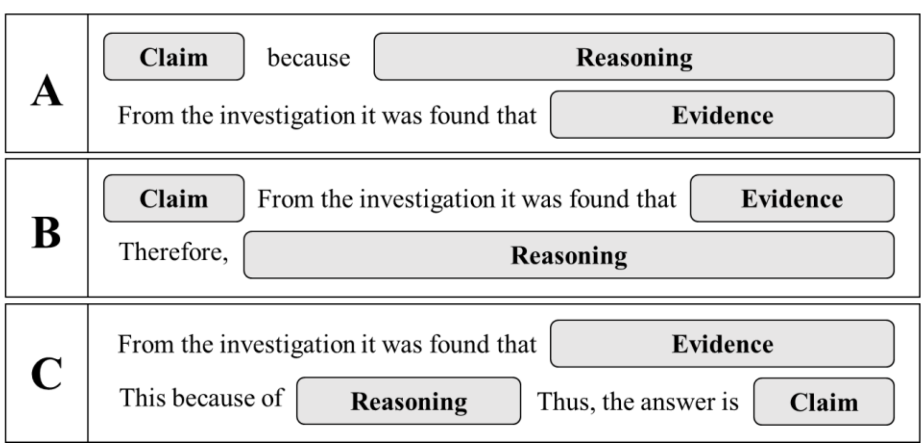

Figure 6. Guideline templates for writing scientific explanations using appropriate phrases

(6) *Constructing explanations for new situations*: Students used their knowledge gained to construct explanations for new situations related to the learning topic. Students can use the guideline templates from step 5 for writing scientific explanations. Teachers reflect on students' learning and their ability in constructing scientific explanations.

Part 2: The Comparison of the Students' Ability in Constructing Scientific Explanation

After learning with the model, students' mean scores in constructing scientific explanations improved (Table 1).

Table 1. The students' ability in constructing scientific explanations before and after learning

	n	Total score	Max. score	Min. score	$\overline{x}$	S.D.	95%CI
Pre-test	36	30.00	19.00	5.00	12.56	4.42	11.12 - 14.00
Post-test	36	30.00	26.00	8.00	15.03	5.51	13.23 – 16.83

Students demonstrated improved performance in the post-test compared to the pre-test. The claim component showed the most notable improvement, followed by evidence and reasoning. These results suggest that the DSE learning model had a positive effect on students' ability to construct scientific explanations (Figure 7).

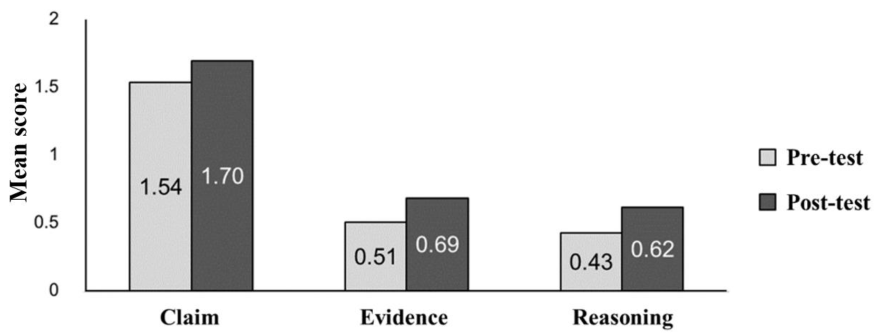

Figure 7. The comparison between the mean scores of each component before and after learning

Part 3: The Students' Progression of Learning of Constructing Scientific Explanations

During implementation, 86.11% of students initially performed at an unsatisfactory level, with none reaching a good level. Over time, performance improved, though a dip occurred in week five due to misconceptions during a wastewater treatment activity. By week seven, only 5.56% remained at the unsatisfactory level, while 44.44% reached a moderate level and 50.00% achieved a good level. (Figure 8).

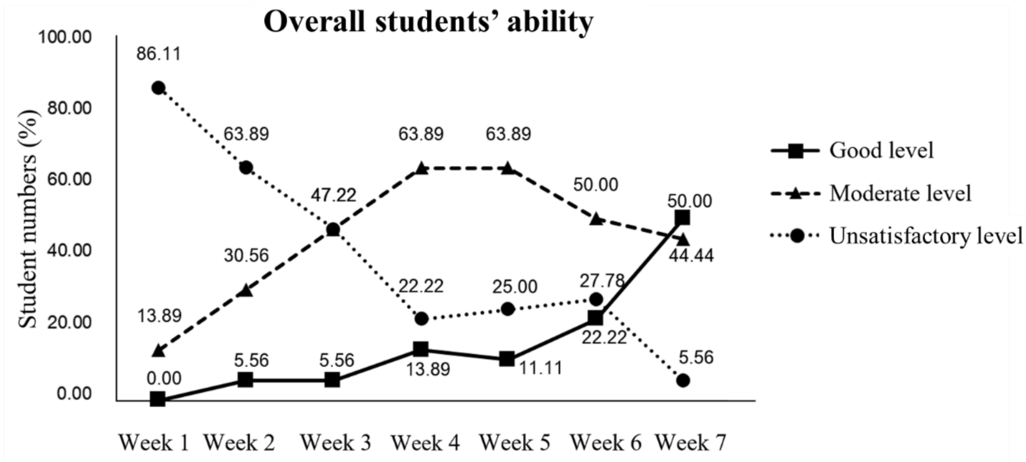

Figure 8. The students' progression of constructing scientific explanations during the seven weeks

Figure 9 shows that in week one, 52.78% of students made unsatisfactory claims, while 47.22% made accurate ones. From weeks two to six, accurate claims steadily increased, reaching 97.22% by week seven, with only 2.78% at an unsatisfactory level. This indicates a clear improvement in claim-making through the model. No students were classified at a moderate level, as each activity required only one claim. Errors stemmed from incorrect claims, with no instances of multiple claims provided.

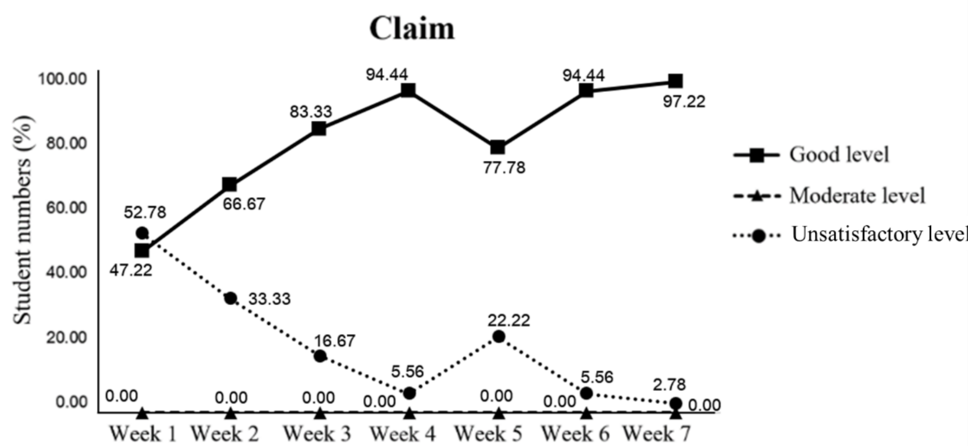

Figure 9. The students' progression in the claim component during the seven weeks

Figure 10 shows that in week one, 86.11% of students were at an unsatisfactory level in providing evidence, with the remainder at a moderate level and none at a good level. By week seven, the percentage of unsatisfactory students dropped to 30.56%, while 44.44% reached a moderate level and 25.00% achieved a good level, indicating overall progress. A notable improvement occurred in week six, when activities on air pollution and acid rain prompted students to include more supporting evidence.

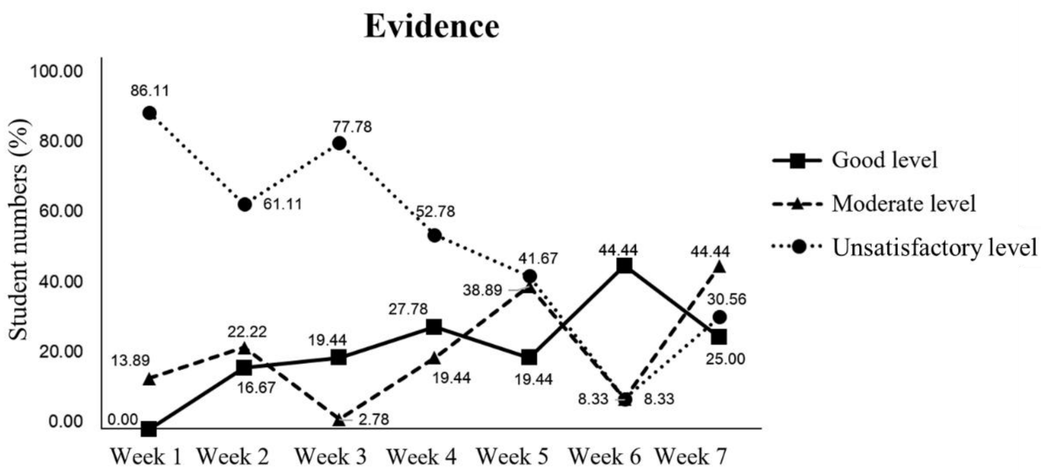

Figure 10. The students' progression in the evidence component during the seven weeks

Figure 11 shows that all students began at an unsatisfactory level in reasoning during week one. By week seven, this dropped to 5.56%, with 33.33% at a moderate level and 61.11% at a good level. The final activity on methane production from livestock prompted students to apply consistent data on cattle fermentation, strengthening their reasoning skills.

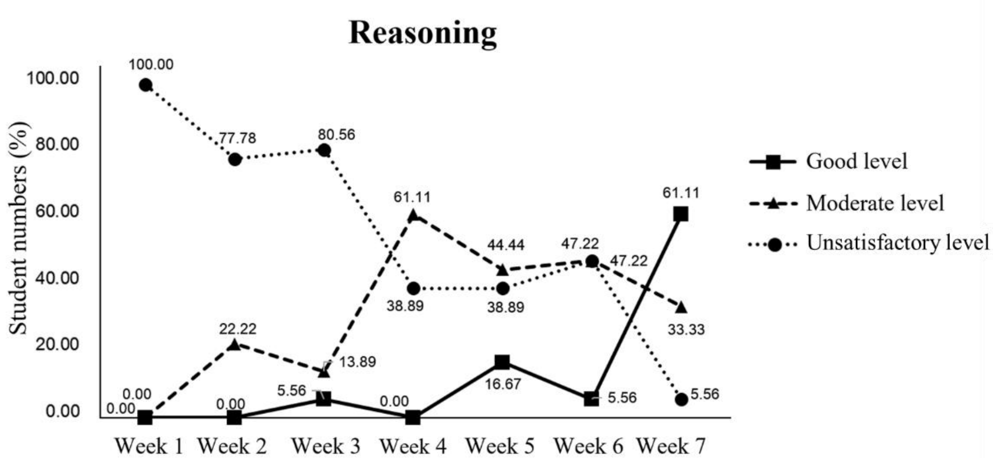

Figure 11. The students' progression in the reasoning component during the seven weeks

The observational and interview data revealed that students' behaviours and opinions during the DSE learning process varied by their ability levels. Appendix 2 summarizes these behaviours by learning step and ability level, with representative quotes illustrating their experiences.

Part 4: The Students' Learning Achievement

Students achieved higher mean scores in learning after using the learning model (Table 2).

Table 2. The students' learning achievement scores before and after learning

	n	Total score	Max. score	Min. score	$\overline{x}$	S.D.	95%CI
Pre-test	36	31.00	23.00	5.00	9.61	3.94	8.32 – 10.90
Post-test	36	31.00	27.00	14.00	18.27	3.05	17.27 – 19.27

The data distribution of students' post-test scores was analysed using mean, standard deviation, and the mean percentage. The results revealed that the students' post-test scores were below 60% criterion (Table 3).

Table 3. The comparison between the students' learning achievement score and the 60% criterion

	N_{total}	Max. score	% of criterion	Mean	Mean percentage	S.D.
Post-test	36	31.00	60	18.27	58.9	3.05

Discussion

1. The six-step process of DSE learning model improves students' ability in constructing scientific explanations by integrating a model-evidence link diagram to address the limitations of earlier models. Grounded in inquiry-based learning and constructivist theory (Steffe & Gale, 1995), it emphasizes investigation, problem-solving, and critical thinking. The first two steps of the DSE learning model utilize brainstorming, an approach found by prior studies (Boonrod & Chuchat, 2015; Natap, 2023) to support self-discovery of misconceptions. Likewise, students in our test school demonstrated a shift toward more accurate understandings of the scientific concepts explored while completing DSE model steps one and two. In the third step, students collect and assess evidence, enhancing their ability to evaluate its validity and relevance (Holmes et al., 2015; Sapasuntikul, 2016). The model-evidence link diagram, introduced in step four, guides students in evaluating evidence and claims, supporting the transition from temporary to accurate explanations (Aniwatanawongand & Jantrasri, 2019; Lombardi et al., 2013). Step five focuses on constructing and discussing explanations collaboratively, fostering communication and independent problem-solving, while step six involves applying knowledge to new contexts, reinforcing competency (Nawani et al., 2019).

2. The DSE learning model improved students' ability in constructing scientific explanations and progression of learning. Students achieved the highest scores in the claim component after learning with the model, followed by the evidence and reasoning components, respectively. The claim component, which involved answering questions, was relatively easier for students as they could draw on their prior knowledge or knowledge from their conclusion (McNeill & Krajcik, 2007; Meela & Artdej, 2017; Wannathai & Pruekpramool, 2021), resulting in higher scores compared to the other components (Janhom & Phornphisutthimas, 2020; Oktavianti et al., 2018; Sapasuntikul, 2016; Sriraudom, 2022; Wannathai & Pruekpramool, 2024). In the evidence component, students needed to analyse the provided information in the tests to support the claim. However, if they struggled with analysing or misunderstood how the information was used as evidence, they may not provide adequate evidence to support their scientific explanations (Farida, Setiawan, & Muntholib, 2021; Janhom & Phornphisutthimas, 2020; Wannathai & Pruekpramool, 2024). The

reasoning component received the lowest scores compared to the other components. Providing reasoning required applying scientific principles, and students who lacked understanding or had misconceptions about scientific concepts struggled to generate appropriate reasoning (Janhom & Phornphisutthimas, 2020; Oktavianti et al., 2018; Sapasuntikul, 2016; Sriraudom, 2022; Wannathai & Pruekpramool, 2024). However, after learning with the model, students showed improvement in their reasoning skills.

3. The DSE learning model resulted in higher learning achievement for students because the model provided students understanding scientific principles related to the contents by investigating the evidence and reasoning to support their claim. According to the study of Wannathai and Pruekpramool (2024), students with a stronger understanding of scientific principles, theories, and laws related to the content could have a high learning achievement. The statistical analysis revealed that students' mean learning achievement score increased from 9.61 (pre-test) to 18.27 (post-test), indicating an improvement in content understanding following the DSE model intervention. Despite the increase, the mean post-test percentage was 58.9%, falling short of the 60% proficiency criterion. This may be attributed to certain activities in the learning model that did not fully support students in achieving all learning objectives. For example, during the evidence-searching step, many students focused narrowly on the given question, overlooking broader content. As a result, they lacked sufficient knowledge to answer the achievement test comprehensively. Similarly, in the knowledge-summarizing step, most students could respond only to directly presented information, with few demonstrating a full grasp of all objectives.

The development of the DSE model was informed by existing literature; however, its true value is demonstrated by its application in classroom settings. Our pilot implementation in the R&D school shows that the model not only addresses deficits in constructing scientific explanations but also provides a framework for integrating scientific reasoning into daily teaching practices. This praxis-focused discussion highlights how the model supports teacher practices and enhances student learning by fostering reflective and evidence-based approaches to scientific problem-solving. The findings suggest that while the DSE learning model supports students' scientific reasoning, its impact may also be influenced by teachers' capacity to provide appropriate instructional support. In many Thai schools, teachers receive limited training in guiding students' evidence-based inquiry, particularly in emerging STEM areas. Teacher preparation often emphasizes content delivery rather than inquiry facilitation or research-based learning. As a result, students' challenges in sourcing information and applying knowledge may partly reflect instructional gaps.

Conclusion

The DSE learning model reflected key features of inquiry-based learning to enhance students' ability in constructing scientific explanations . It consisted of six steps, including introducing the question, brainstorming for claims, finding evidence, drawing a diagram, constructing a scientific explanation, and constructing explanations for new situations. Students showed improvement in their ability in constructing scientific explanations after learning with the model, with highest scores in providing claims, followed by evidence and reasoning. They used more accurate scientific principles in their reasoning. Students demonstrated better levels of progression, engaging in learning behaviours such as answering questions, brainstorming, investigating, and drawing diagrams. These behaviours promoted accurate claim and evidence consideration, linking evidence to claims, and constructing complete scientific explanations. Students also achieved higher learning achievement, gaining conceptual understanding. However, their learning achievement was still below the criteria of 60%, indicating the need for more focus on acquiring knowledge and classroom discussions on relevant topics.

Limitations and Recommendations

To prevent inconsistency in students' evidence due to unreliable sources, teachers or educators implementing the learning model should specify reliable sources for information search in each learning issue, reducing the time spent on student activities. Additionally, teachers should train students on how to begin reasoning sentences by providing guiding questions or sentence patterns. Emphasis should be placed on students to double-check their writing to ensure that all components of scientific explanation are included. Different processes and supporting factors are needed for students at different levels of ability. In-depth examination of these processes and factors can provide insights on how to promote students' abilities further. For achieving higher levels of learning achievement, teachers should also employ strategies to summarize topics for greater clarity. This study represents a pilot implementation of the Diagram-Based Scientific Explanation (DSE) learning model, the pre- and post-intervention data indicate a significant improvement in scientific reasoning skills, it is important to consider that some of this progress may be due to increased familiarity with the subject matter over the term. Future research should incorporate a normative comparison group to determine the extent to which the DSE model contributes additional value beyond natural developmental trends. Importantly, our findings also suggest that students’ struggles with constructing scientific explanations may stem not only from gaps in scientific knowledge but also from broader challenges in written literacy. Thus, integrating explicit instruction in argumentative writing across science and language arts curricula could further strengthen students’ abilities, enhancing both scientific reasoning and literacy outcomes. Besides, this study conducted with a small numbers of participants. While the findings offer preliminary insights, they are not intended to be broadly generalized at this stage. The model has potential for adaptation in other science subjects beyond biology. However, such applications should be made with caution. Successful use in different disciplines would require careful adjustments to fit the subject matter and sufficient teacher professional development to apply the model effectively. Future research should involve larger and more diverse samples to confirm and expand upon these initial findings.

Acknowledgements

The researchers would like to express their gratitude to the Graduate School of Srinakharinwirot University, Thailand, for the financial support provided for this research.

Ethics statement

The human research ethics for this study have been approved by the Human Research Ethics Committee of Srinakharinwirot University, Thailand (Certificate number: SWUEC/E/G-343/2564).

References

Aldresti, F., Rahayu, S., & Fajaroh, F. (2018). The influence of inquiry-based chemistry learning with the context of socio-scientific issues on high school students' scientific explanation skills. *Jurnal Pengajaran MIPA, 23*(2). https://dx.doi.org/10.18269/jpmipa.v23i2.12413

Aniwatanawongand, P., & Jantrasri, R. (2019). Evaluating the impact of model-based inquiry with model-evidence link on grade 11 students' scientific explanation of electrolyte and non-electrolyte solution. *Walailak Journal of Learning Innovation, 5*(1), 65-83.

Australian curriculum assessment and reporting authority. (2020). *The shape of the Australian curriculum version 5.0.* Sydney: Australian Government Printer Canberra.

Boonrod, J., & Chuchat, A. (2015). Effects of science instruction using more model on science learning achievement and scientific explanation ability of lower secondary school. *An Online Journal of Education, 10*(2), 238–248. Retrieved from https://so01.tci-thaijo.org/index.php/OJED/article/view/35277

Chatmaneerungcharoen, S., & Saetae, R. (2024). The development of grade 7 students' scientific competency through inquiry - based leaning with using the context, personal, local/ national, and global levels. *Journal of Educational Studies Review, 39*(3), 1-13.

Cohen, L., Manion, L., & Morrison, K. (2018*). Research methods in education* (8th ed.). NY: Routledge.

Dechsuwanrasami, S., Sitthiraksae, H., & Nuangkaew, J. (2024). Learning management by using EIMA instruction model on concept and ability in making scientific explanation in daily life topics for sixth-grade students. *Journal of Education Studies, 12*(2), 45–57.

Farida, I.I., Setiawan, A.M., & Muntholib, M. (2021). Assessing eighth graders' scientific explanation on human excretory system. In: *AIP Conference Proceedings.* Malang, Indonesia; AIP Publishing LLC.

Holmes, N. G., Wieman, C. E., & Bonn, D. A. (2015). Teaching critical thinking. *Proceedings of the National Academy of Sciences, 112*(36), 11199-11204. https://doi.org/10.1073/pnas.150532911

Institute for the Promotion of Teaching Science and Technology. (2018). *Results of PISA 2015: Assessment Science, Reading and Mathematics (Complete edition).* Bangkok: IPST.

Janhom, C. & Phornphisutthimas, S. (2020). The survey of senior secondary students' scientific explanation about digestion. In *The 21st National Graduate Research Conference, March 27th, 2020 at Khon Kaen University* (pp. 644-654). Khon Kaen: Khon Kaen university.

Juthanarupakit, K., Jantarakantee, E., & Chiangga, S. (2018). Implementing scientific inquiry approaches to develop grade 10th students' scientific explanation in the topic of circular motion. *The 13th RSU National Graduate Research Conference, 13*, 1741-1753.

Kaewbamrung, A. (2011). *The effects of common knowledge construction model on ability in constructing explanations and concepts in topic of work and energy of high school students in physics.* (Master thesis). Chulalongkorn University, Bangkok.

Kaldaras, L., Akaeze, H., & Krajcik, J. (2021). Developing and validating Next Generation Science Standards aligned learning progression to track three-dimensional learning of electrical interactions in high school physical science. *Journal of Research in Science Teaching, 58*(4), 589-618.

Khotabin, S., & Narjaikaew, P. (2024). Grade 12 students' scientific explanation competency on celestial sphere and astronomical phenomena through model–based learning. *Journal of Research Unit on Science, Technology and Environment for Learning, 15*(1), 114-132.

Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. California: Sage publications.

LeCompte, M., & Preissle, J. (1993). Ethnography and qualitative design in educational research (2nd ed.). London: Academic Press Ltd.

Likhitjunyarak, A., Suwanjinda, D, & Thammaprateep, J. (2023). The effects of 5es inquiry instruction on learning achievement and scientific explanation ability in the topic of cell of grade 10 students at chanachanupatham school in songkhla province. *Journal of Education Thaksin University, 23*(1), 89–101.

Lombardi, D., Sibley, B., & Carroll, K. (2013). What's the alternative? Using model-evidence link diagrams to weigh alternative models in argumentation. *The Science Teacher, 080*, 36-41.

McNeill, K. L. (2012). *Supporting grade 5-8 students in constructing explanations in science: the claim, evidence, and reasoning framework for talk and writing*. Boston: Pearson.

McNeill, K. L., & Krajcik, J. (2007). *Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations Thinking with data*. Mahwah: Lawrence Erlbaum Associates Publishers.

McNeill, K. L., & Krajcik, J. (2008). Assessing middle school students' content knowledge and reasoning through written scientific explanations. *Assessing science learning: Perspectives from research and practice,* 101-116.

Meela, P., & Artdej, R. (2017). Model based inquiry and scientific explanation: Promoting meaning-making in classroom. *Journal of Education Naresuan University, 19*(3), 1-15.

Ministry of Education. (2017). Basic education core curriculum 2008 (Revised edition 2017). Bangkok: The agricultural co-operative Federation of Thailand, Ltd.

Moore, B. A., & Wright, J. (2023) Constructing written scientific explanations: a conceptual analysis supporting diverse and exceptional middle- and high-school students in developing science disciplinary literacy. *Frontiers in. Education.* 8:1305464. doi: 10.3389/feduc.2023.1305464

Natap, S. (2023). *Phenomenon based learning for developing competency in explaining scientific phenomena of the 8th grade students about earth and it's change*. (Independent study). Naresuan University, Phitsanulok.

Nawani, J., Kotzebue, L. v., Spangler, M., & Neuhaus, B. J. (2019). Engaging students in constructing scientific explanations in biology classrooms: a lesson-design model. *Journal of Biological Education, 53*(4), 378-389.

OECD. (2015). *Thailand student performance (PISA 2015).* Retrieved on December 10, 2019, from http://gpseducation.oecd.org/CountryProfile?plotter=h5&primaryCountry=THA&treshold=10&topic=PI

OECD. (2018). *Thailand student performance (PISA 2018).* Retrieved on December 10, 2019, from https://gpseducation.oecd.org/CountryProfile?primaryCountry=THA&treshold=10&topic=PI

Oktavianti, E., Handayanto, S., Wartono, W., & Saniso, E. (2018). Students' scientific explanation in blended physics learning with e-scaffolding. *Jurnal Pendidikan IPA Indonesia, 7*(2), 181-186. https://doi.org/10.15294/jpii.v7i2.14232

Onthong, U., & Nasaree, N. (2023). Predictive, Observational, Explanatory learning management (POE) that promotes competencies in scientific explanation of phenomena on physical properties of materials for grade 4 students. *NEU Academic and Research Journal, 13*(2), 144-157.

Ortega-Quevedo, V., Gil-Puente, C. & Rapp, C.V. (2023). Social construction of technology: an experience for development of critical-thinking and nature of science and technology. *International Journal of Innovation in Science and Mathematics Education*, 31(1), 15-29.

Promsorn, K. (2019). Effects of the EIMA learning management on scientific explanation ability, reasoning and thinking ability and science learning achievement of grade 9 students. *Journal of Multidisciplinary in Social Sciences, 15*(1), 70-78.

Ruengtham, T. (2016). SWH: Science Writing Heuristic. *IPST Magazine, 45*(203), 7-13.

Sapasuntikul, K. (2016). *Effects of chemistry teaching strategy using the predict-observe-explain sequence on the ability in scientific explanation making and rationality of tenth grade students*. (Master thesis). Chulalongkorn University, Bangkok. Retrieved from https://www.car.chula.ac.th/display7.php?bib=b2127591.

Sirithon, N. & Jantarakantee, E. (2019). Implementing argument-driven inquiry approach for developing grade 10th students' ability in making scientific explanation in the topic of force, mass, and law of motion. *Silpakorn University Journal, 39*(1), 130-141. DOI: https://doi.org/10.14456/sujthai.2019.8

Soonjan, J. & Kaewkhong, K. (2022). Elementary science teachers' understanding of inquiry-based teaching and self-evaluation of their practices: A case study from Thailand. *International Journal of Innovation in Science and Mathematics Education*, 30(1), 30-44.

Sriraudom, J. (2022). *Learning activity based EIMA instructional model to enhance the scientific explanation ability and analytical thinking of mathayomsuksa 5 students.* (Master thesis). Mahasarakham University.

Steffe, L. P., & Gale, J. E. (1995). *Constructivism in education*. New York: Psychology Press.

Tang, K. S. (2016). Constructing scientific explanations through premise–reasoning–outcome (PRO): An exploratory study to scaffold students in structuring written explanations. *International Journal of Science Education, 38*(9), 1415-1440.

Wannathai, P. & Pruekpramool, C. (2021). Comparing the efficiency between ability in constructing scientific explanation restricted- and extended-response subjective tests for mathayom suksa 4 students. *Journal of Graduate Research, 12*(2), 103-118. Retrieved from https://so02.tci-thaijo.org/index.php/banditvijai/article/view/250697

Wannathai P., & Pruekpramool C. (2024). Investigating Thai grade 10 students' ability in constructing scientific explanations: Insights from learning achievement and school size factors. *Science Education International, 35*(2), 143-153. https://doi.org/10.33828/sei.v35.i2.8

Whitney, D. R., & Sabers, D.L. (1970). *Improving essay examination III. Use of item analysis, Technical Bulletin 11, (Mimeographed).* Iowa City: University Evaluation and Examination Service.