Journal of Green Learning, e-ISSN 2807-890X
Vol. 5, No. 1, June 2025, pp. 18-29.
DOI: 10.53889/jgl.v5i1.557

Developing systems thinking of Thai grade 11 students through model-based learning with concept mapping

Tanakon Kongped[1], Kanyarat Cojorn[1]

[1]Faculty of Education, Mahasarakham University, Thailand

Article Info

Article history:
Received December 25, 2024
Revised February 12, 2025
Accepted March 12, 2025

Keywords:
Concept mapping
Electrostatics
Model-based learning
System thinking

ABSTRACT

This action research aimed to develop systems thinking skills of Thai grade 11 students through model-based learning with concept mapping. The research was designed using an action research approach, focusing on students who faced challenges with the subject matter. Participants included 32 grade 11 students from a public high school in northeastern Thailand. The study utilized a learning management plan that incorporated nine sub-lessons, structured into three learning cycles. The instruments included the model-based learning with concept map learning management plan, a systems thinking assessment, a systems thinking rubric, and a classroom behavior observation form. Results indicated a continuous improvement in students' systems thinking skills from learning cycle 1 to 3, with an increasing number of students meeting the performance threshold. When examining each aspect, it was found that in cycles 1 and 3, the highest average scores were in root cause analysis, while the lowest were in the feedback. In cycle 2, the highest average scores were also in root cause analysis, while the lowest were in causal loop. The model-based approach provided students with a mechanism to develop a better understanding, while the concept maps helped them connect the content and reinforce what they had learned. This study contributes to the field of science education by providing evidence that supports the use of model-based learning and concept mapping to enhance systems thinking among high school students.

Corresponding Author:
Kanyarat Cojorn
Department of Curriculum and Instruction
Faculty of Education
Mahasarakham University
Thailand
Email: kanyarat.c@msu.ac.th

1. INTRODUCTION

Systems thinking is a cognitive approach that prompts learners to view problems as interconnected systems, enabling them to comprehend the functioning of a system and attempt to resolve it (Shaked, 2019). This skill is advantageous in science education as it not only aids learners in problem-solving, but also facilitates their understanding of the entire process. Developing learners' systems thinking also helps them to build up their higher-order thinking abilities, such as analytical thinking and critical thinking, which are crucial for addressing both mathematical and real-world problems (Arnold & Wade, 2015). Thus, there is a correlation between systems thinking and success in education.

In science education, especially in physics, electrostatics could be considered a concept that can help learners to apply science with their understanding of real-world phenomena (Mazibe et al., 2023). Considering the nature of the concept, we could note that learners must apply physics concepts such as vectors, forces, electric fields, and potentials to understand the interactions between charged particles. Systems thinking could be beneficial in this case as it lets students recognize that these physical principles are interconnected, enabling them to comprehend the overall behavior of electrostatic systems. The holistic approach of systems thinking allows them to not only deepen their understanding of physics but also to connect these principles to natural phenomena such as lightning or the operation of electronic devices (Rakbamrung et al., 2015)

However, enhancing students' systems thinking can be a challenging task for educators, as it requires careful consideration of various components such as cognitive development, instructional design, and the integration of multiple disciplines (Basile & Caputo, 2017; Trochim et al., 2006). In the context of electrostatics, learners must navigate through complex stages, starting with foundational mathematical skills like algebra and vectors, before they can fully comprehend the concept and develop systems thinking. In Thailand, the educational system has been criticized for providing a passive and rigid science learning environment. This has negatively impacted the overall educational landscape, as reflected in the country's PISA scores, where Thailand ranks at an unexpectedly low level compared to global benchmarks (OECD, 2022). This problem affects Thai students from their early exposure to fundamental subjects like mathematics and science all the way through to grade 11, where they often lack the necessary skills to understand complex subjects like electrostatics. Therefore, an instructional method that addresses these gaps is crucial to improve both mathematical understanding and systems thinking in students.

Taking the problems in the contextual area and elements of systems thinking into account, it can be assumed that students in the Thai educational context need an instructional method that helps them process the components of subject matters, analyze their working procedures, and answer essential questions. In this study, model-based learning is introduced as a teaching and learning method that uses models—such as diagrams, physical objects, or simulations—to help students understand complex concepts. Instead of merely reading or listening to explanations, students interact with models that visually represent how systems function (Constantinou et al., 2019; Schwartz, 2019). This approach encourages students to understand how the components of a system interact to produce dynamic phenomena (Canlas & Guevarra, 2020). Concept mapping can further enhance this process by allowing learners to study and connect different components together, fostering a deeper understanding of how they are interrelated (Napier-Raman et al., 2023). Recognizing the potential of integrating concept mapping into model-based learning, the current study employed these principles to develop a learning management plan aimed at enhancing Grade 11 students' systems thinking in the electrostatics concept. The results of the study could contribute to improving instructional methods for science education, providing a more active and engaging approach to learning complex scientific phenomena.

2. LITERATURE REVIEW

2.1 Systems thinking

Systems thinking can be defined as a broad concept that involves understanding how different parts of a system interact and influence one another to form a unified whole. According to Shaked (2019), systems thinking can be defined as the art and science of making reliable inferences about behavior by gaining a deep understanding of the underlying structure of a system. He emphasized that systems thinkers must be able to "see both the forest and the trees," meaning they should focus on both the big picture and the individual components. Senge (2006) defines systems thinking as a discipline for seeing wholes, focusing on interrelationships rather than isolated elements, and recognizing patterns of change rather than static snapshots. In Senge's, systems thinking operates in an intuitive domain, often neglected in traditional education. Sweeney and Sterman (2000) expanded on these ideas by emphasizing that systems thinking involves representing and assessing dynamic complexity, understanding how the behavior of a system emerges from the interaction of its components over time. The authors highlight essential systems thinking skills such as recognizing feedback loops, identifying stock and flow relationships, and understanding the role of delays and nonlinearities in a system.

Considering the definitions of systems thinking, Arnold and Wade (2015) synthesized the skills required for effective systems thinking into several key elements. First, Recognizing Interconnections is foundational, as it involves identifying the essential connections between parts of a system. Without training, individuals often overlook these crucial relationships. Next, Identifying and Understanding Feedback focuses on recognizing cause-effect feedback loops, which are vital for understanding how system behavior unfolds over time. Following this, Understanding System Structure requires grasping how the elements and interconnections within a system work together, building on the previous skills of recognizing feedback and interconnections.

Another essential skill is Differentiating Types of Stocks, Flows, and Variables. Stocks represent pools of resources, flows signify changes in these resources, and variables are factors that influence both. Understanding these interactions is key to analyzing system dynamics. Identifying and Understanding Non-Linear Relationships goes a step further, focusing on relationships that deviate from straightforward paths, which are crucial for interpreting more complex systems.

Understanding Dynamic Behavior stems from the interaction of feedback loops, interconnections, and stocks and flows, often resulting in unexpected outcomes, known as emergent behaviors. Reducing Complexity by Modeling Systems Conceptually is also critical, involving the ability to simplify and model systems in ways that make complex interactions more understandable. Finally, Understanding Systems at Different Scales enables individuals to interpret systems from small subsystems to larger interconnected systems of systems. Together, these elements provide a comprehensive framework for developing systems thinking skills.

2.2 Model-based learning

Model-based learning refers to a teaching approach where learners engage in the construction, revision, and validation of models to understand complex phenomena. Unlike learning with pre-constructed models, where students explore models to gain insights into a phenomenon, model-based learning focuses on creating interpretive representations that have predictive power (Crawford & Cullin, 2004; Nicolaou et al., 2009; Schwarz et al., 2009). The learning process in model-based learning is iterative, as learners continuously compare their models to the real-world phenomena they represent, receiving feedback and making necessary adjustments (Nicolaou et al., 2009). This cyclical approach, involving the generation and refinement of successive models, allows learners to deepen their understanding as they move from simplistic versions to scientifically accurate representations (Schwarz et al., 2009).

Model-based learning is consistent with a variety of skills, often referred to as modeling competence. This includes practices such as constructing, revising, using, comparing, and validating models (Constantinou et al., 2019) Additionally, model-based learning promotes meta-modeling knowledge, which includes understanding the nature and purpose of models and the cognitive process involved in creating them (Alessi, 2009). This type of learning goes beyond knowledge or skills and involves competence, as learners must master the modeling process and apply it to solve problems and meet complex demands in scientific inquiry.

Scholars have recognized the positive impact of model-based learning in various areas of science education (Baumfalk et al., 2019; Bolger et al., 2021; Canlas & Guevarra, 2020; Chu et al., 2018; Demirçali & Selvi, 2022; Sari et al., 2020; Tolba & Al-Osaimi, 2023). For instance, Baumfalk et al. (2019) found that model-based science curriculum and instruction significantly improved elementary students' explanations of hydrosphere-related phenomena, enhancing their scientific reasoning. Similarly, Canlas & Guevarra (2020) demonstrated that the model-based learning approach positively influenced students' academic performance and attitudes in Earth science, leading to better engagement and understanding. In the context of laboratory experiences, Bolger et al. (2021) reported that model-based inquiry supported students in grappling with data and uncertainty, helping them develop a deeper understanding of scientific practices.

Additionally, Chu et al. (2018) showed that integrating model-based learning with curriculum-based making activities in elementary science classes facilitated scientific modeling, enabling students to represent and explore scientific concepts more effectively. In addition, Demirçali & Selvi (2022) found that model-based science education enhanced students' academic achievement and scientific process skills, indicating its broad applicability across science disciplines. Sari et al. (2020) highlighted the effectiveness of model-based learning in improving students' understanding of heat and heat transfer concepts in introductory physics courses. Lastly, Tolba & Al-Osaimi (2023) demonstrated that using a model-based thinking strategy significantly developed high school students' physical concepts and inquiry thinking skills, further showcasing the value of model-based learning in enhancing scientific understanding.

Therefore, it could be assumed that learners could benefit from model-based learning in their development of systems thinking. To be specific, when applied to systems thinking, model-based learning can significantly enhance students' ability to understand complex systems as it encourages them to break down and visualize collaborative parts and dynamic behaviors. As learners build and refine their models, they could develop an understanding of feedback loops, interconnections, and the dynamic nature of systems. Consequently, they could not only improve their ability to analyze the system but also develop their systems thinking skills. This is because they can engage in the interpretation and prediction of how system components interact to produce emergent behaviors.

2.3 Concept mapping

In a general point of view, concept mapping could be defined as a tool used to visually demonstrate relationships between different concepts or components within a concept. It allows learners to organize information to highlight the connections between ideas. According to Napier-Raman et al. (2023), concept maps are diagrams that arrange ideas in a hierarchical structure, beginning with broader concepts and branching out into more specific details. Similarly, Buzan (2006) describes concept mapping as a "radiant" approach to thinking that encourages learners to explore and understand connections between topics by visualizing them in interconnected clusters. Concep mapping can be presented in flowcharts, Venn diagrams, and timelines.

Research has shown that concept mapping can have significant benefits in the science classroom, improving learning outcomes across different subjects. For example, Hariyadi et al. (2023) found that using a STEM-based mind mapping learning model effectively improved students' science literacy, especially in the context of Revolution 4.0, where new skills are essential. Similarly, Kaymaz & Doğru (2024) demonstrated that teaching the Cell and Division Unit in secondary school using concept maps significantly enhanced students' academic success. Khine et al. (2019) found that concept mapping improved metacognitive teaching and learning in undergraduate medical education, helping students grasp complex concepts more effectively.

Therefore, it could be noted that concept mapping can be integrated into model-based learning to enhance learners' systems thinking skills in science education. Specifically, by encouraging students to visualize the interconnections between concepts, they can see how different components of a system are related and work together to produce complex behaviors. In model-based learning, students are tasked with creating models to represent scientific phenomena, and concept maps can serve as an effective tool for organizing the relationships between different elements within these models. Concept mapping thus helps students break down complex systems into smaller, understandable components, and it is important in the development of a more comprehensive understanding of both the scientific models they are constructing and the system as a whole. This process also promotes the development of critical analytical thinking and problem-solving skills, both of which are essential for systems thinking.

Moreover, previous studies on model-based learning have emphasized the need to explore additional areas of science and integrate model-based learning with other methods to improve student understanding. Recognizing the potential of these approaches in the development of students' systems thinking, we combined model-based learning and concept mapping to develop students' systems thinking skills in the context of learning electrostatics. In addition to addressing gaps in earlier research, this study also offers an alternative instructional solution for the context of science education in Thailand. The purpose of this study is to examine the effects of integrating model-based learning with concept mapping on improving the systems thinking skills of Thai grade 11 students as they learn about electrostatics.

3. METHOD

3.1 Research design

The study was designed using an action research approach (Kemmis et al., 2014). To demonstrate, it focuses on fixing only students who face challenges with the subject matters. The classroom instruction was managed through the PAOR (Plan, Action, Observation, and Reflection) learning cycle, which guided the structure of the learning management plan. This study included nine sub-lessons organized into a learning management plan, and the intervention was divided into three PAOR learning cycles, with each cycle covering three sub-lessons. After each cycle, the students' systems thinking skills were assessed. At the conclusion of the three learning cycles, the percentage of students who met the performance threshold was evaluated, and the results were discussed.

3.2 Participant

The participants were 32 grade 11 students from a public high school in a suburban area of northeastern Thailand. They were selected through cluster random sampling, using a grade 11 class as the criteria. The province where the students reside ranked mid-level in the national mathematics test (National Institute of Educational Testing Service, 2020), suggesting that the participants reasonably represent the general student population in Thailand. All participants were treated in accordance with ethical standards for human research, and their identities were kept confidential to ensure their privacy.

3.3 Instruments

3.3.1 Model-based learning-concept map learning management

A learning management plan was developed with the principles of model-based learning. Therefore, students are instructed with the focus to let them understand how phenomena in electrostatic are modeled. Learners are expected to identify components and tell how each connect to one another. Concept mapping is used as a tool to let them show their understanding on the electrostatic. There were 9 sub-lesson plans which are 1) electric charge, 2) types of electric force, 3)electrostatic induction, 4) Coulomb's law, 5) Definition of electric field and electric field of a point charge, 6) electric field of a system of charge, 7) Electric field lines and forces acting on charged particles in an electric field, 8) Potential difference due to a uniform electric field, and 9) Electric potential due to a point charge. The learning activity is structured into 4 key stages (Table 1).

Table 1 Learning activities

Stage	Activity
Generating a model	Teacher prompts students to create their own models through questions or activities. Students collectively respond using a "Point Grouping" concept map at the front of the class. This encourages students to observe and generate models that explain or predict various natural phenomena.
Evaluating the model	Students design and conduct experiments or gather research data, summarizing their findings into a "Linked Grouping" concept map. This allows them to assess the effectiveness of their models.
Modifying the model	Students modify and adjust their models based on their observations until they can accurately explain the data. They then summarize their modifications into a new concept map, linking it to the original "Linked Grouping" map.
Elaborating the model	Students use the revised model to explain different scenarios or solve additional problems, demonstrating the model's broader applicability.

The learning management plan was evaluated prior to the implementation by peer experts in learning management and science education. The learning management plan was evaluated at an expected level of appropriateness ($\bar{x}$ = 4.43-4.55).

3.3.2 Systems thinking evaluation

The systems thinking assessment consists of three sets of open-ended questions based on given scenarios, where students are required to explain causes and effects. Each set includes two scenarios, with each scenario containing three sub-questions that cover three different aspects of systems thinking: root cause analysis, causal loop, and feedback. The researcher submitted the newly developed systems thinking assessment to experts for evaluation to ensure that the questions aligned with the scenarios. The assessment achieved a consistency index (IOC) of 1.00, indicating a perfect level of alignment.

3.3.3 Observation form

The classroom behavior observation form focuses on four key areas for observation: 1) cooperation, 2) participation in improving group work, 3) critical and logical thinking, and 4) attention to detail. This is to examine students' behaviors in each learning cycle. The classroom behavior observation checklist was presented to experts for evaluation, and its appropriateness was assessed with ratings ranging from 4.60 to 4.80.

3.4 Data collection and analysis

The learning management plan was implemented through cycles of planning, action, observation, and reflection, with each cycle covering three sub-lessons. After each learning cycle, the activities were adjusted based on the assessment of students' systems thinking skills. The data were analyzed using descriptive statistics, with the passing criterion set at 70% (8.4/12) of the total score for each student. This iterative process allowed for continuous improvement of the learning activities and assessment of student progress.

System thinking was analyzed using the following procedures. The systems thinking rubric is designed with three key dimensions and is structured with a ranking scale from 0 to 2 for each dimension. A score of 0 is given when the student provides a blank or irrelevant answer, 1 is assigned when the student writes something partially correct or incomplete, and 2 is awarded for a fully correct response. The first dimension, Systemic Root Cause Analysis, evaluates the student's ability to explain the significance of the problem, provide specific details, understand the complexity, and articulate key aspects. The second dimension, Causal Loop, assesses the student's ability to explain how the different stages of the problem are connected, including the problem-solving process, solutions, and their effects on related factors. Lastly, the Feedback dimension measures the student's ability to analyze the problem from multiple perspectives, incorporating feedback loops and cycles in problem-solving. Since each learning cycle involves two items, the full score for each cycle is 12 points, with a maximum of 6 points for each item.

4. RESULT

The result of the three-cycle action research implementation to develop systems thinking skills among the 32 target students—using a model-based learning approach combined with concept mapping, and aiming for at least 70% of the total score—can be summarized in terms of the number of students who met and did not meet the 70% threshold, as shown in Figure 1.

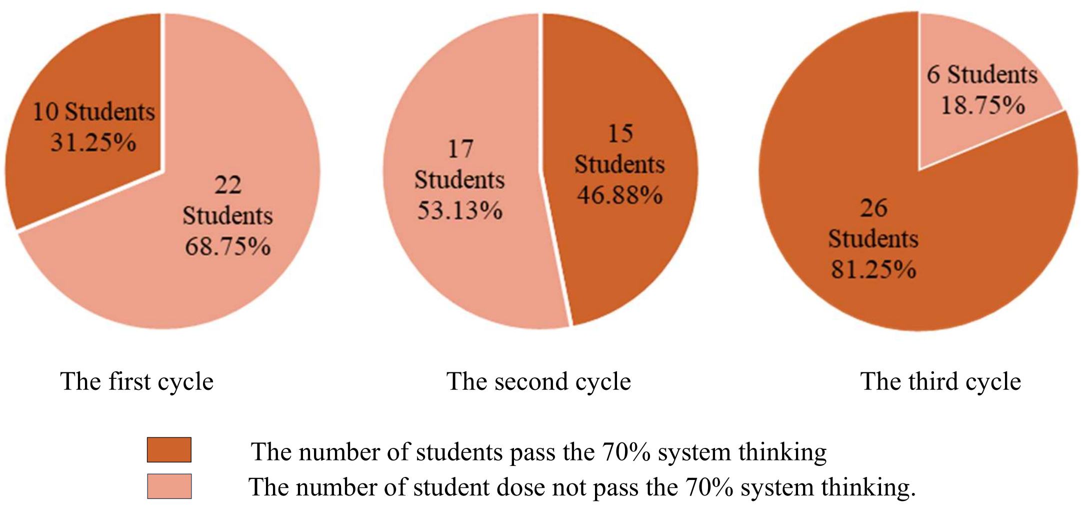

Figure 1 Summary of the learning cycles

From Figure 1, it can be seen that among the 32 target students who underwent model-based learning combined with concept mapping, during learning cycle 1, 10 students (32.25%) achieved the 70% score criterion, while 22 students (68.75%) did not. In learning cycle 2, 17 students (53.13%) met the 70% criterion, whereas 15 students (46.88%) did not. By learning cycle 3, 26 students (81.25%) reached the 70% threshold, while 6 students (18.75%) did not. When comparing the students' thinking assessment systems against the 70% benchmark, the data analysis produced the following results.

4.1 Learning cycle 1

The first 3 lesson plans namely electric charge, types of electric force, electrostatic were employed. After completing the learning activities, the researcher administered an individual systems thinking assessment to each student. The assessment encompassed three aspects of systems thinking, with each aspect worth a maximum of 4 points, for a total of 12 points. The average systems thinking scores of the target students who participated in the learning activities during learning cycle 1 for each aspect are shown in Table 2.

Table 2 System thinking after learning cycle 1

Aspects of system thinking	Fullmark	Average	%	Interpret
Systemic Root Cause Analysis	4	2.66	66.50	Not passing
Causal Loop	4	2.34	58.50	Not passing
Feedback	4	2.22	55.50	Not passing
Overall	12	7.22	60.17	Not passing

According to Table 2, during learning Cycle 1, when considering the overall average score across all components of systems thinking, the average was 7.22 out of 12 points, or 60.17%, which is below the established benchmark. Thus, the students' average scores did not meet the criterion. When examining the average scores by individual component (each with a total of 4 points), it was found that the component with the highest percentage of the average score was Systemic Root Cause Analysis, with an average of 2.66 points (66.50%). The next highest was Causal Loop, with an average of 2.34 points (58.50%). The component with the lowest average percentage was Feedback, with an average of 2.22 points (55.50%), respectively. It was observed that the group of students who did not pass the criteria still lacked the process of thinking in terms of connecting cause and effect and feedback. As a result, they were unable to summarize and link the content from the learning activities. This may be because the students were not familiar with this new form of learning activities, which they had not encountered before, making it difficult for them to create and revise their concept maps. During the model construction phase, students struggled to make decisions when forming mental models. In the model evaluation and modification phases, they did not observe and compare the differences between their group and other groups to improve their own models. The learning activity was adjusted on the focus of stimulating students' interest by using questions and connecting events to their daily lives.

4.2 Learning cycle 2

After activity adjustment, the learning management plan was employed again. Learning cycle 2 covers 3 sub-lesson plans including Coulomb's law, definition of electric field and electric field of a point charge, and electric field of a system of charge. The target students who received the learning activities during Action Cycle 2 had average systems thinking scores in each aspect as shown in Table 3.

Table 3 System thinking after learning cycle 2

Aspects of system thinking	Fullmark	Average	%	Interpret
Systemic Root Cause Analysis	4	3.19	79.75	Passing
Causal Loop	4	2.41	60.25	Not passing
Feedback	4	2.66	66.50	Not passing
Overall	12	8.26	68.83	Not passing

Table 3 indicates that, during learning cycle 2, the overall average score for all components of systems thinking was 8.26 out of 12 points, or 68.83%, which is still below the established benchmark. Thus, the students' average performance did not meet the criterion.

When examining the averages by individual component (each out of 4 points), the component with the highest average percentage was Systemic Root Cause Analysis, scoring an average of 3.19 points (79.75%). Following this was Feedback, with an average of 2.66 points (66.50%). The component with the lowest average percentage was Causal Loop, with an average of 2.41 points (60.25%), respectively. This shows that the learning activities resulted in improved systems thinking among students. The researcher refined and developed the learning activities by emphasizing group presentations in class, where each group explained the principles, theories, or phenomena based on the models they had created. This allowed students to assess which models better explained the phenomena or predicted problems. The teacher also clarified the scoring criteria and informed the students that behavior would also be assessed, encouraging them to work cooperatively. The teacher played an active role in stimulating each group to engage in the activities.

In the stage of connecting cause and effect, students demonstrated an improved ability to summarize and link the content into concept maps. However, in the model modification stage, students were unable to further revise and expand their concept maps. Behavior observations during the learning activities revealed that some students began to cooperate more in dividing tasks and became more careful, which led to better outcomes. This indicates that students showed improvements in both behavior and systems thinking, possibly due to the activities being closely related to their daily lives, and the use of concept maps helped them systematically connect knowledge and summarize it in steps. It cannot be overlooked that nearly half of the class still did not meet the threshold. To address this, we adjusted the activities to provide additional support, specifically focusing on helping students improve in the model modification stage.

4.3 Learning cycle 3

Learning cycle 3 was to instruct the last three sub-lesson plans of electric field lines and forces acting on charged particles in an electric field, potential difference due to a uniform electric field, and electric potential due to a point charge. With the adjustment of learning activities after the previous phase, The target students who received the learning activities during learning Cycle 3 had average systems thinking scores for each aspect as shown in Table 4.

Table 4 System thinking after learning cycle 3

Aspects of system thinking	Fullmark	Average	%	Interpret
Systemic Root Cause Analysis	4	3.66	91.50	Passing
Causal Loop	4	3.03	75.75	Passing
Feedback	4	3.00	75.00	Passing
Overall	12	9.62	80.17	Passing

Table 4 indicates that, during learning cycle 3, the overall average score for all components of systems thinking was 9.62 out of 12 points, or 80.17%, which exceeds the established benchmark. Thus, the students' average performance met the criterion.

When considering the averages by individual component (each out of 4 points), the component with the highest average percentage was Systemic Root Cause Analysis, at 3.66 points (91.50%). Next was Causal Loop, with an average of 3.03 points (75.75%), and the component with the lowest average percentage was Feedback, at 3.00 points (75.00%), respectively. The results from the class observation indicate that all students were able to identify the problems. However, in the cause-and-effect linking and feedback phases, some students still struggled to connect ideas using concept maps. Observations of overall classroom behavior showed that students who did not meet the 70% threshold lacked cooperation in task delegation, were not careful in their work, which led to incorrect outcomes, and failed to plan and reflect before taking action. Additionally, they did not follow the steps in the activity as outlined.

5. DISCUSSION

This study was an action research project aimed at developing students' systems thinking skills through a model-based learning approach combined with concept mapping, with a target criterion set at an average of 70%. The findings showed that students' systems thinking scores improved in each action cycle. In Learning cycle 1, 10 students met the benchmark, in Learning cycle 2, 17 students met the benchmark, and in Learning cycle 3, 26 students met the benchmark. This improvement can be attributed to the learning activities involving model-based learning and concept mapping, which encouraged students to construct models and summarize information using concept maps through the processes of creation, application, revision, and expansion of these models. In other words, model-based learning involves students in understanding and explaining phenomena by building and refining models, thereby helping them visualize and understand abstract concepts more effectively (Barak & Hussein-Farraj, 2013). During the modeling process, students learn about each component that makes up the model and link various sub-models into an integrated whole (Coll, France & Taylor, 2005). This approach prompts learners to connect knowledge and relationships more thoroughly, giving them opportunities to explain their thinking and link concepts within the system.

Moreover, concept maps enable the organization of knowledge in a sequential manner. They use lines and linking words to connect different concepts and integrate content (Ault, 1985). This helps students organize information and view problems systematically, leading to higher scores. These findings align with research by Khajeloo and Siegel (2022), who found that concept maps are effective tools to help students understand relationships between concepts, clearly reflecting their knowledge, understanding, and the interactions between ideas. Constructing concept maps also helps enhance students' systems thinking skills. Similarly, Dounas-Frazer (2016) studied students' abilities to construct experimental system models and to solve problems with malfunctioning electrical circuits in a physics lab course. The results showed that models facilitate the cognitive tasks required for problem-solving. Additionally, the problem-solving process can engage students in practicing the scientific principles of model construction, enabling them to tackle systematic problems more effectively.

In learning cycle 1, 31.25% of the students achieved the 70% standard. Model-based learning involves creating diagrams, symbols, or artifacts to explain concepts, principles, theories, laws, and natural phenomena (Aubusson et al., 2006; Manee & Nuangchalerm, 2023). Incorporating diagrams or concept maps that emphasize content connections helps students see an overall, systematic picture and build a structured understanding of the core content and related concepts. Considering each component of systems thinking, the highest average score was in Systemic root cause analysis (66.50%), followed by Causal loop (58.50%), and the Feedback (55.50%). Systemic root cause analysis scored the highest because students were given opportunities to express their own models extensively, supported by questions or activities that captured their interest. Engaging students with thought-provoking questions can stimulate curiosity and foster deeper learning (Hootstein, 1994), leading them to be more involved in model construction. This finding aligns with Hung (2008), who found that constructing instructional models enhances students' systems thinking skills and clarifies theories and systematic thinking skills. In contrast, the Feedback component had the lowest average score because students were unable to decide how to modify their models or to observe and compare differences between their group's model and those of their peers in order to make improvements. Continuous creation and refinement of models are necessary for understanding and explaining phenomena (Buckley et al., 2004). Evidently, students faced challenges in revising and utilizing models, consistent with Hestenes (1997), who noted that scientific understanding emerges from model construction and application. This difficulty prevented them from summarizing their understanding into a concept map that could provide feedback on the narrative or story aspect.

In learning cycle 2, 53.13% of students met the 70% standard. The researcher improved the activities by emphasizing in-class presentations, encouraging students to confidently display their conceptual models, set topics for comparison and evaluation of models, and engage in hands-on practice. Through this process, students constructed knowledge by creating models (Krause et al., 2003), increasing their interest in the activities. Looking at each system's thinking component, Systemic root cause analysis once again had the highest average percentage (79.75%), followed by Feedback (66.50%), and the lowest was Causal loop (60.25%). Systemic root cause analysis remained the highest because of the improved activities that encouraged presentation and explanation of principles and theories, as well as proposing conceptual models, fostering interaction between teacher and students, and among students themselves, thus promoting critical thinking (Jong et al., 2015). Adjusting concept-mapping activities to have a hierarchical structure allowed students to better connect their knowledge. This is consistent with Ault (1985), who stated that concept maps help students sequentially structure their knowledge and use linking words to integrate various concepts, leading to a more systematic understanding.

When comparing the Causal loop component to cycle 1, students showed a noticeable improvement in average scores. However, it remained the lowest in Cycle 2. This is because the physics content on electric fields became more difficult, and since electric fields are highly complex and abstract concepts, they are not easily accessible for novice learners (Hart, 2008). Consequently, students struggled to summarize the content into a concept map, leading to the lowest average score in Causal loop during this cycle. This finding aligns with Torre and Dario (2023), who noted that concept mapping may not be suitable for some students, especially those unfamiliar with the technique, as it may cause confusion rather than clarity.

In learning cycle 3, 81.25% of students met the 70% standard. Considering each component of systems thinking, Systemic root cause analysis again had the highest average (91.50%), followed by Causal loop (75.75%), and the Feedback (75.00%). Systemic root cause analysis remained highest because students were increasingly able to identify problems and summarize them in concept maps. Classroom behavior observations showed that students developed better behaviors overall. The learning activities, which required cooperation, division of responsibilities, careful work procedures, and following a systematic sequence, coupled with the creation and refinement of models, helped students better visualize abstract phenomena (Barak & Hussein-Farraj, 2013). Additionally, using concept maps increased their Systemic root cause analysis scores, consistent with de Sousa et al. (2019), who found that developing system-thinking concept maps helps visualize and understand complex relationships, ultimately benefiting students' learning experiences.

Although Feedback improved markedly from Cycles 1 and 2 and met the criterion, it still had the lowest average score in Cycle 3. Some students still struggled to grasp the overall picture of the concept map due to difficulties in clear communication. Insufficient communication between teachers and students can leave the feedback process thin or ambiguous, preventing optimal learning (Faizi et al., 2013). Thus, additional media or tools are needed to facilitate understanding of the overall concept map structure. This aligns with Van Leeuwen (1997), who stated that media serve as teaching aids that make complex subjects more accessible and more understandable to students. In conclusion, model-based learning combined with concept mapping can enhance students' systems thinking. By the end of the three action cycles, 26 out of 32 students scored above the 70% benchmark. Although 18.75% of students did not reach the standard, this was primarily due to frequent absences, leading to a lack of understanding in systems thinking.

6. CONCLUSION

The study utilized the principles of model-based learning integrated with concept mapping to design a learning management plan aimed at improving grade 11 students' systems thinking in learning electrostatics within the Thai educational context. After three learning cycles on topics related to the concept, the results indicated that the learning management plan was effective in continuously improving the participants' skills, as a greater number of students passed the 70% threshold as the study progressed. Therefore, it can be concluded that model-based learning, when integrated with concept mapping, is a beneficial instructional method that can lead to significant improvements in systems thinking. This study contributes to the field of science education by providing evidence that supports the use of model-based learning and concept mapping, particularly in developing higher-order thinking skills such as systems thinking.

In terms of implication of the results, pedagogically, the integration of model-based learning and concept mapping can be seen as an effective strategy for systems thinking, particularly in complex subjects like electrostatics. This approach encourages active learning, critical thinking, and collaboration among students, which are essential skills in the 21st century. Therefore, science teachers could also employ the principles for the sake of their classes. Academically, the study adds to the body of literature supporting innovative instructional methods in science education. It suggests that educators should consider adopting similar strategies in their studies in underexplored concepts of science and other science related skills.

However, some limitations could not be overlooked. The sample size was relatively small, which may limit the generalizability of the findings to a broader population. Additionally, the study was conducted using an action research approach, which involved iterative learning cycles that allowed for the adjustment of activities based on ongoing observations and assessments. While this flexibility is beneficial in refining instructional methods, it also means that the study's design may not provide the same level of control and rigor as a traditional experimental study. Future research could address these limitations by employing a pre- and post-test design with a comparative group, allowing for a more robust evaluation of the effectiveness of model-based learning and concept mapping in developing systems thinking.

REFERENCES

Alessi, S. (2009). Modeling a system and teaching a system: Enhancing what students learn from modeling. In *Model-Based Approaches to Learning* (pp. 199-214). Brill.

Arnold, R. D., & Wade, J. P. (2015). A definition of systems thinking: A systems approach. *Procedia Computer Science*, *44*, 669-678.

Aubusson, P. J., Harrison, A. G., & Ritchie, S. M. (2006). Metaphor and analogy: Serious thought in science education. In *Metaphor and analogy in science education* (pp. 1-9). Dordrecht: Springer Netherlands.

Ault Jr, C. R. (1985). Concept mapping as a study strategy in earth science. *Journal of College Science Teaching*, 15(1), 38-44.

Barak, M., & Hussein-Farraj, R. (2013). Integrating model-based learning and animations for enhancing students' understanding of proteins structure and function. *Research in Science Education*, 43, 619-636.

Basile, G., & Caputo, F. (2017). Theories and challenges for systems thinking in practice. *Journal of Organisational Transformation & Social Change*, *14*(1), 1-3.

Baumfalk, B., Bhattacharya, D., Vo, T., Forbes, C., Zangori, L., & Schwarz, C. (2019). Impact of model-based science curriculum and instruction on elementary students' explanations for the hydrosphere. *Journal of Research in Science Teaching*, *56*(5), 570-597.

Bolger, M. S., Osness, J. B., Gouvea, J. S., & Cooper, A. C. (2021). Supporting scientific practice through model-based inquiry: A students'-eye view of grappling with data, uncertainty, and community in a laboratory experience. *CBE—Life Sciences Education*, *20*(4), ar59.

Buckley, B. C., Gobert, J. D., Kindfield, A. C., Horwitz, P., Tinker, R. F., Gerlits, B., ... & Willett, J. (2004). Model-based teaching and learning with BioLogica™: What do they learn? How do they learn? How do we know?. *Journal of Science Education and Technology*, 13, 23-41.

Buzan, T. (2006). *The Ultimate Book of Mind Maps* (UK ed. edition). Thorsons.

Canlas, A. C., & Guevarra, M. D. (2020). Model based learning approach effects on students academic performance and attitudes in earth science. *Jurnal Pendidikan MIPA*, *21*(1), Article 1.

Chu, S. L., Deuermeyer, E., & Quek, F. (2018). Supporting scientific modeling through curriculum-based making in elementary school science classes. *International Journal of Child-Computer Interaction*, *16*, 1-8.

Coll, R. K., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: implications from research. *International Journal of Science Education*, *27*(2), 183-198.

Constantinou, C. P., Nicolaou, C. Th., & Papaevripidou, M. (2019). A framework for modeling-based learning, teaching, and assessment. In A. Upmeier zu Belzen, D. Krüger, & J. van Driel (Eds.), *Towards a Competence-Based View on Models and Modeling in Science Education* (pp. 39–58). Springer International Publishing.

Crawford, B. A., & Cullin, M. J. (2004). Supporting prospective teachers' conceptions of modelling in science. *International Journal of Science Education*, *26*(11), 1379-1401.

Demirçali, S., & Selvi, M. (2022). Effects of Model-Based Science Education on Students' Academic Achievement and Scientific Process Skills. *Journal of Turkish Science Education*, *19*(2), 545-558.

de Sousa, L. O., Hay, E. A., & Liebenberg, D. (2019). Teachers' understanding of the interconnectedness of soil and climate change when developing a systems thinking concept map for teaching and learning. *International Research in Geographical and Environmental Education*, 28(4), 324-342.

Dounas-Frazer, D. R., Van De Bogart, K. L., Stetzer, M. R., & Lewandowski, H. J. (2016). Investigating the role of model-based reasoning while troubleshooting an electric circuit. *Physical Review Physics Education Research*, *12*(1), 010137.

Faizi, R., El Afia, A., & Chiheb, R. (2013). Exploring the potential benefits of using social media in education. *International Journal of Engineering Pedagogy (iJEP)*, *3*(4), 50-53.

Hariyadi, S., Rofiâ, A., Santosa, T. A., & Sakti, B. P. (2023). Effectiveness of STEM-based mind mapping learning model to improve students' science literacy in the era of Revolution 4.0. *Jurnal Penelitian Pendidikan IPA*, *9*(10), 791-799.

Hart, C. (2008). Models in physics, models for physics learning, and why the distinction may matter in the case of electric circuits. *Research in Science Education*, *38*, 529-544.

Hestenes, D. (1997, March). Modeling methodology for physics teachers. In *AIP conference proceedings* (Vol. 399, No. 1, pp. 935-958). American Institute of Physics.

Hung, W. (2008). Enhancing systems-thinking skills with modelling. *British Journal of Educational Technology*, *39*(6), 1099-1120.

Hootstein, E. W. (1994). enhancing student motivation: make learning interesting and relevant. *Education*, *114*(3), 475-479.

Jong, J. P., Chiu, M. H., & Chung, S. L. (2015). The use of modeling-based text to improve students' modeling competencies. *Science Education*, 99(5), 986-1018.

Kaymaz, N. N., & Doğru, A. (2024). The effect of teaching the secondary school 7th grade cell and division unit with concept map on the academic success of students. *Science Insights Education Frontiers*, 21(2), 3383-3407.

Kemmis, S., McTaggart, R., & Nixon, R. (2014). *The action research planner*. Springer.

Khajeloo, M., & Siegel, M. A. (2022). Concept map as a tool to assess and enhance students' system thinking skills. *Instructional Science*, *50*(4), 571-597.

Khine, A. A., Adefuye, A. O., & Busari, J. (2019). Utility of concept mapping as a tool to enhance metacognitive teaching and learning of complex concepts in undergraduate medical education. *Archives of Medicine and Health Sciences*, *7*(2), 267.

Manee, K., & Nuangchalerm, P. (2023). Development of grade 10 students' modelling skills on circulatory system through model-based learning. *Journal of Advanced Science and Mathematics Education*, *3*(2), 113-120.

Mazibe, E. N., Gaigher, E., & Coetzee, C. (2023). Exploring dynamic pedagogical content knowledge across fundamental concepts of electrostatics. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(3), 1-14.

Napier-Raman, S., Rosas, S., Hossain, S. Z., Mpofu, E., Lee, M.-J., Liamputtong, P., Dune, T., & Mapedzahama, V. (2023). Concept mapping method. In P. Liamputtong (Ed.), *Handbook of social sciences and global public health* (pp. 1–25). Springer International Publishing.

National Institute of Educational Testing Service. (2020). *The summary of the ONET results on mathematics for grade 6 students*. National Institute of Educational Testing Service.

Nicolaou, C., Nicolaidou, I., & Constantinou, C. (2009). Scientific model construction by pre-service teachers using Stagecast CreatorTM. In P. Blumschein, W. Hung, & J. Strobel J. (Eds.), *Model-based approaches to learning: using systems models and simulations to improve understanding and problem solving in complex domains* (pp. 215-236). Sense Publishers.

OECD. (2022). *Thailand student performance (PISA 2022)*. https://gpseducation.oecd.org/CountryProfile?primaryCountry=THA&treshold=10&topic=PI

Rakbamrung, P., Thepnuan, P., & Nujenjit, N. (2015). Use of a system thinking learning force and motion concept in physics for nurse course. *Procedia - Social and Behavioral Sciences*, *197*, 126–134.

Sari, I. M., Karim, S., Saepuzaman, D., Ramalis, T., & Rusdiana, D. (2020). *The development of model-based learning in introductory physics: the effectiveness of improving students understanding in heat and heat transfer*. Proceedings of the 7th Mathematics, Science, and Computer Science Education International Seminar, MSCEIS 2019, 12 October 2019, Bandung, West Java, Indonesia.

Schwartz, R. S. (2019). Modeling Competence in the Light of Nature of Science. In A. Upmeier zu Belzen, D. Krüger, & J. van Driel (Eds.), *Towards a competence-based view on models and modeling in science education* (pp. 59-77). Springer International Publishing.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632-654.

Senge, P. (2006). *The fifth discipline: The art and practice of the learning organization.* (2nd ed.). Doubleday/Currency.

Shaked, H. (2019). Systems thinking for principals of learning focused schools. *Journal of School Administration Research and Development, 4*(1), 18-23.

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249-286.

Tolba, E. G. A., & Al-Osaimi, A. M. (2023). The effectiveness of using the model-based thinking strategy in developing first-grade high school students' physical concepts and inquiry thinking skills. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(4), em2254.

Torre, D., German, D., Daley, B., & Taylor, D. (2023). Concept mapping: An aid to teaching and learning: AMEE Guide No. 157. *Medical Teacher*, *45*(5), 455-463.

Trochim, W. M., Cabrera, D. A., Milstein, B., Gallagher, R. S., & Leischow, S. J. (2006). Practical challenges of systems thinking and modeling in public health. *American Journal of Public Health*, *96*(3), 538-546.

Van Leeuwen, T. (1997). Media in education. In *Encyclopedia of language and education: Language policy and political issues in education* (pp. 211-218). Dordrecht: Springer Netherlands.