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Developing Systems Thinking of Grade 10 Science Students through Problem-based Learning with Causal Maps

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Abstract

This research aims to enhance students' systems thinking through problem-based learning (PBL) with causal maps in the context of biology, specifically on the immune system. The study involved 19 science students. The research instruments included lesson plans incorporating PBL with causal maps and a systems thinking test. Data were analyzed using descriptive analysis. Results showed that students' systems thinking improved across three cycles. In the first cycle, the average score was 7.26 out of 16 (45.39%), with 8 students achieving a good level. In the second cycle, the average score increased to 10.42 (65.13%), with 16 students reaching a good level. By the third cycle, the average score reached 13.84 (86.51%), and all 19 students achieved a good level. These findings suggest that incorporating problem-based learning with causal maps in science classrooms may enhance students' systems thinking and could be a valuable approach in science education.

Keywords: Causal Maps, Problem-Based Learning, Science Learning, Systems Thinking

1. Introduction

Effective problem-solving and decision-making require understanding and navigating systemic interconnections in a complex context. The system thinking is a necessary learning skill for modern classroom. Many fields and specialties necessitate system thinking which emphasizes understanding system dynamics and interrelationships. Recent educational research demonstrates that problem-based learning might improve students' systems thinking by presenting them with significant, real-world challenges (Nagarajan & Overton, 2019; Hurst, 2020; Szozda et al., 2022; Darwis & Patimbangi, 2024). PBL enables students to investigate challenges, cooperate, and apply theory to practice.

Systems thinking is a holistic view of thinking and higher-ordered thinking to school. The components of a system that are connected and interrelated (Senge, 2014; Orgill et al, 2019) as well as the cause-and-effect relationships that affect each other within a system. That is thinking in the form of the overall picture can go back and forth. It helps students understand problems and their structure in depth (Buzan, 2024). In addition, systems thinking also plays an important role in helping develop advanced thinking process skills as well as helping students deal with complex real-world problems. This prepares students to deal with and solve problems that arise more directly and efficiently (Hurst, 2020; Huda et al., 2022; Cabrera & Cabrera, 2023).

In organizing the teaching and learning activities on the topic of cells of living things, it was found that students were able to identify and tell the functions of various organelles that are components within the cells of living things. However, students were still unable to explain how each organelle works and is connected to each other (Adnan, 2022). They were also unable to explain whether if one organelle malfunctioned, it would affect other organelles. The connection of each element to show the cause-and-effect relationship is an important characteristic of the components of systems thinking (Mambrey et al., 2020).

Learning management methods, including tools that help promote systems thinking among students are problem-based learning management. It is a learning arrangement that uses problems related to students as the starting point for learning. This can provide students having the opportunity to be primarily self-learners (Sjaifuddin et al., 2019; Tan, 2021; Di et al., 2022; Thaochalee & Nuangchalerm, 2023; Khonkla et al., 2024). Problem-based learning management gives students the freedom to learn and create knowledge on their own through direct experience. This helps students increase motivation for sustainable learning (Nagarajan & Overton, 2019; Amaral et al, 2021; Deniş-Çeliker & Dere, 2022). However, the problems used should be complex and ambiguous. or make students curious and want to learn (Office of the Secretary of the Education Council, 2007).

Therefore, students should develop systems thinking and learning process to deal with higher-ordered thinking. Causal maps, sometimes called causal loop diagrams, show system feedback loops and interdependencies. Students may learn how system components interact and impact each other using causal maps. Causal maps are diagrams that illustrate relationships between multiple variables in a system, using plus and minus signs to indicate interactions (Franconeri et al., 2021). Causal maps have been used as a tool to promote systems thinking (Cox et al, 2018; Cox et al, 2019). That helps students work through the complexity of problem systems by making causal connections between elements of the system in which the problem is embedded, helping students understand the structure of the problem and see possible solutions (Ke et al, 2020). Based on the problem and principles mentioned, the researcher was interested in developing students' systems thinking by using problem-based learning with causal maps to pass the criteria at a good level or higher.

2. Methodology

2.1. Target Group

The target group of students were grade 10 science students in the second semester of the academic year 2023 at a school in Mahasarakham province, Thailand. The target group was selected based on the score of system thinking who does not pass the good level. Therefore, the target group of this research were 19 students. They were volunteering to join the program of study based on an onsite learning organization.

2.2. Research Instruments

Lesson plan: Six lesson plans for problem-based learning with causal maps received 12 hours of immune system instruction. In one cycle, use two lesson plans which can be shown in Table 1. The lesson plans passed quality inspections from 5 experts, specialists in curriculum and teaching, measurement and evaluation, and content. Lesson plans are revised according to expert advice. After that lesson plans were used for research.

Table 1. Problem-Based Learning with Causal Maps Lesson Plans

Cycle	lesson plan		Time (hours)
1	1	Nonspecific defense mechanism	2
	2	Specific defense mechanism	2
2	3	Immunization	2
	4	Allergy	2
3	5	Autoimmune disease	2
	6	Immunodeficiency due to HIV infection	2
Total			12

From Table 1, lesson plans passed quality inspections from 5 experts, specialists in curriculum and teaching, measurement and evaluation, and content. Lesson plans are revised according to expert advice. After that lesson plans were used for research.

Systems thinking test: Subjective test used to collect data from target students at the end of each cycle. It is divided into 3 cycles, 2 items per cycle, the tests consisted of 4 components: identify the problem, identify variables related to the problem, specify the relationship between variables and create a causal cycle diagram. The constructed test was checked using the index of item objective congruence by 5 experts. The systems thinking tests were revised according to expert advice. After that systems thinking tests were used for research. The observation of student behavior is structured, to observe behaviors that indicate students' systems thinking during learning activities in each cycle.

2.3. Data Collection

This research uses an action research model. The researchers conducted research according to the concept of Kemmis & McTaggart (1988). Each cycle has 4 steps: plan, act, observe, and reflect. The researchers divided the data collection into 3 cycles as shown in Figure 1 and explained the following in more detail below.

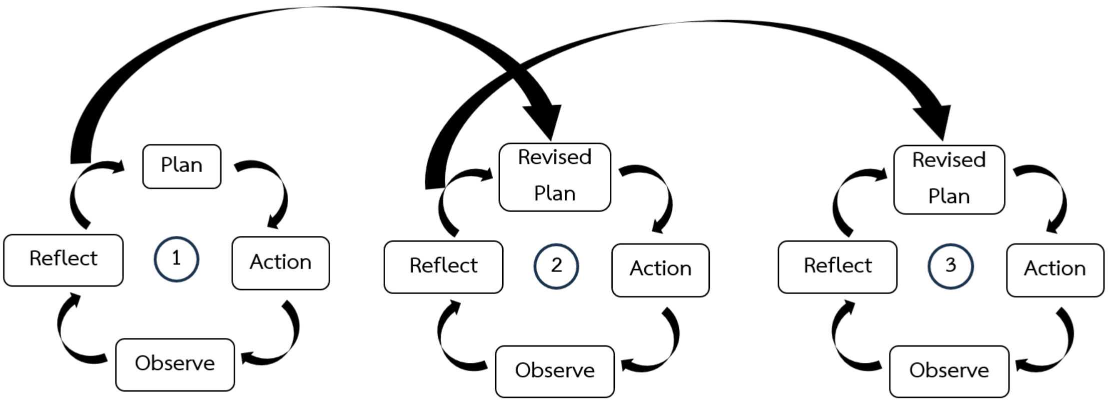

Figure 1. Cycles of Action Research

2.3.1. Plan

The plan is started by exploring the problem, student context, class observation, and confirm the problem by having students a systems thinking test. Then find a solution by studying papers and research related to the systems thinking test, problem-based learning, causal maps lesson and other research instruments related to solving such problems. Followed by the creation and development of research instruments.

2.3.2. Act

After building and improving research instruments, implementing lesson plans using problem-based learning with causal maps for targeted students. Cycle 1 uses lesson plans 1 and 2. Cycle 2 uses lesson plans 3 and 4. Cycle 3 uses lesson plans 5 and 6.

2.3.3. Observe

During the learning management, the researcher observed the student behavior of systems thinking of the target students. using a structured behavioral observation form. At the end of each lesson plans cycle. The researcher collected data on the systems thinking scores of the target students. Using a systems thinking test with 2 items per cycle. Then collect systems thinking data of students who did not pass the specified criteria by looking at the students' journal. It also collects information from post-learning records that occur during learning activities.

2.3.4. Reflect

Analyze the data and summarize the results from the student behavior of systems thinking form, systems thinking test and student's journals, how the research result was, what's the problem. Then bring this information to plan for solving problems in the next cycle. Until the purpose of the research is achieved, the cycle is stopped.

2.4. Data Analysis

Data were analyzed from the systems thinking test. Data were analyzed by comparing students' responses with adjusted scoring criteria as in Table 2 and classified into 4 levels of individual systems thinking namely, excellent, good, fair and improve as in Table 3, to analyze and evaluate whether students pass the set criteria or not. In addition, data were analyzed from student behavior of systems thinking form and student's journals. which analyzes the data by interpreting it to explain the meaning of the data, summarizing the data, and then reporting the results by describing it.

Table 2. Systems Thinking Scoring Criteria

Components	Level		
	0	1	2

1. Identify the problem	Not write about problems or writing issues that do not correspond to the given problem situation.	Write problem points that are consistent with the given problem situation, but it covers only part of the given problem situation.	Write problem points that are consistent and cover all given problem situations.
2. Identify variables related to the problem	Not write variables or write variables that are not related to the problem from the problem situation.	Write the variables related to the problem correctly from the problem situation but not complete with all variables.	Write the variables related to the problem correctly from the problem situation and complete all variables.
3. Specify the relationship between variables	Not Write the relationship or write the relationship with a plus or minus sign between not every pair of cause-and-effect variables.	Write the relationship with a plus or minus sign between every pair of cause-and-effect variables but some relationships are not right.	Write the relationship with a plus or minus sign between every pair of cause-and-effect variables and all the relationships are correct.
.4Create a causal cycle diagram	not draw or take some pairs of variables with no specified relationship and draw them together to form a causal circuit diagram or added unreasonably.	Take every pair of variables that indicate a relationship and draw them together to form a causal circuit diagram or reasonably added but some relationships are not right.	Take every pair of variables that indicate a relationship and draw them together to form a causal circuit diagram or reasonably added and correct in every relationship.

Table 3. Criteria for Interpreting Scores for Systems Thinking

Score ranges	Systems thinking level
13-16	Excellent
9-12	Good
5-8	Fair
0-4	Improve

3. Result

The results of the analysis of the systems thinking of the target group students both before learning activities, and after learning activities in each cycle. The finding reveals a clear upward trend in performance across each cycle. It improves in identifying problems, understanding variables, specifying relationships, and creating causal diagrams. The intervention or repeated cycles seem to have had a significant positive impact on participants' abilities. By Cycle 3, all students met the level standard, indicating a successful progression and mastery of the systems thinking. The data analysis results are shown in Table 4.

Table 4. The Systems Thinking Score Between Before and After Learning Activities in Each Cycle

Cycle	Score component					Pass the good level
	Identify the problem (4)	Identify variables related to the problem (4)	Specify the relationship between variables (4)	Create a causal cycle diagram (4)	Total)16(	
Before	1.84 46.05)%(	0.74 18.42)%(	1.26 31.58)%(	1.16 28.95)%(	5.00 31.25)%(	0)0.00%(
Cycle 1	2.37 5)9.21%(	.142 3)5.53%(	.195 4)8.68%(	.153 3)8.16%(	.726 4)5.39%(	8)42.11%(
Cycle 2	3.53)88.16%(	2.16)53.95%(	2.47)61.84%(	2.26)56.58%(	10.42)65.13%(	16)84.21%(
Cycle 3	4.00)100.00%(	2.95)73.68%(	3.58)89.47%(	3.32)82.89%(	13.84)86.51%(	19)100.00%(

From Table 4, it shows that before organizing a learning activity using problem-based learning with causal maps, the researchers surveyed 19 students whose scores on the systems thinking did not pass the good level up criterion. Subsequently, the researchers organized learning activities using problem-based learning with causal maps for a total of 3 cycles, resulting in all 19 students developing in problem-based learning with causal maps passing the good level up criterion as the following details.

Cycle 1: It was found that 8 students in the target group passed the good level up criterion, representing 42.11%, but there are 11 students who have not yet passed the good level up criterion, representing 57.89%. When considering the total score for all components of the systems, students had the mean total score of systems thinking equal to 7.26 points out of 16 full scores, representing 45.39%. While considering the scores for each aspect, a total of 4 full points, it was found that the identify the problem score, identify variables related to the problem, specify the relationship between variables and create a causal cycle diagram had the mean score of 2.37, 1.42, 1.95 and 1.53 points respectively, representing 59.21%, 35.53%, 48.68% and 38.16% respectively, which shows that in cycle 1, students have developed systems thinking in all 4 components. When compared to before organizing the learning activities as shown in Figure 2.

Cycle 2: It was found that 16 students in the target group passed the good level up criterion, representing 84.21%, but there are 3 students who have not yet passed the good level up criterion, representing 15.79%. When considering the total score for all components of the systems thinking students had the mean total score of systems thinking equal to 10.42 points out of 16 full scores, representing 65.13%. While considering the scores for each aspect, a total of 4 full points, it was found that the identify the problem score, identify variables related to the problem, specify the relationship between variables and create a causal cycle diagram had the mean score of 3.53, 2.16, 2.47 and 2.26 points respectively, representing 88.16%, 53.95%, 61.84% and 56.58% respectively, which shows that in cycle 2, students have developed systems thinking in all 4 components. When compared to operating cycle 1 as shown in Figure 2

Cycle 3: It was found that 19 students in the target group passed the good level up criterion, representing 100.00%, which is considered to have achieved the objectives of the research set. The researchers therefore stopped organizing learning activities using problem-based learning with causal maps at the end of the 3 cycles. When considering the total score for all components of the system thinking the students had the mean score of systems thinking equal to 13.84 points out of 16 full scores, representing 86.51%. While considering the scores for each aspect, a total of 4 full points, it was found that the identify the problem score, identify variables related to the problem, specify the relationship between variables and create a causal cycle diagram had the mean score of 4.00, 2.95, 3.58 and 3.32 points, respectively, representing 100.00%, 73.68%, 89.47% and 82.89%, this shows that in cycle 3, the students' mean scores in all components of the systems thinking increased significantly from cycle 2. As shown in Figure 2.

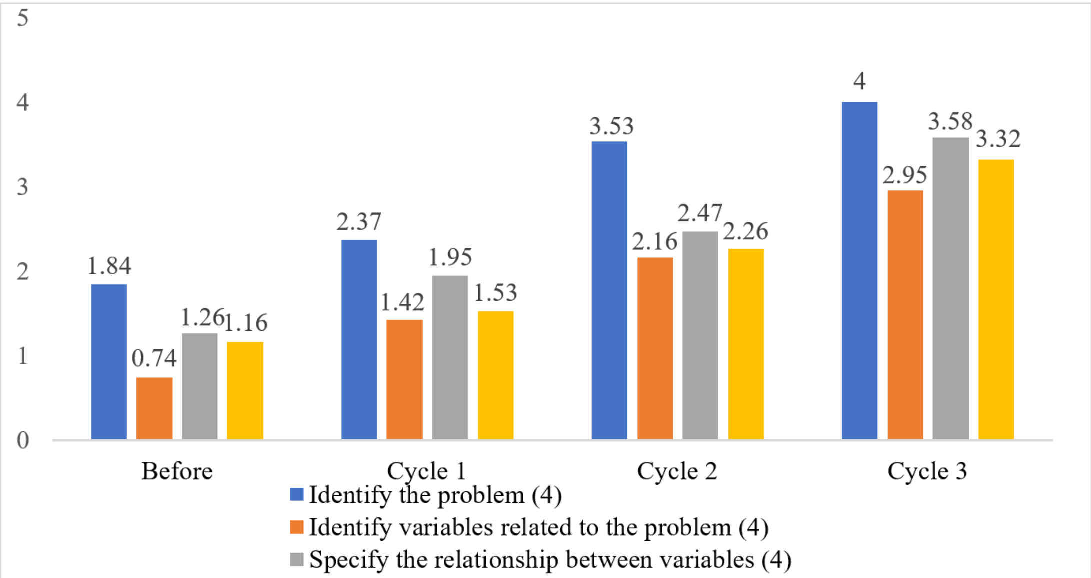

Figure 2. Mean Score of System Thinking

4. Discussion

Cycle 1: It was found that students had a mean score for the systems thinking equal to 7.26 points. When considering individual scores, there were 8 students whose scores pass the good level up criterion, this is because problem-based learning with causal maps. It is a learning arrangement that encourages students to learn through problem situations related to students. Give students the opportunity to search and collect information. To analyze and understand the causes or mechanisms of problems. By writing a causal diagram on an activity sheet with steps in writing according to the elements of systems thinking divided into sections, so that students can practice systems thinking through situations related to problems with the immune system in conjunction with writing causal diagrams. Amaral et al. (2021) said that if the learning arrangement includes activities for students to create causal maps from real-life problem situations of students. It can help develop students' thinking skills. Deniş-Çeliker & Dere (2022), problem-based learning management is learning management with the main objective. To help students create knowledge on their own by developing advanced thinking skills needed today. Problem situations to stimulate students to systematically analyze, classify, and separate the elements of problems. and provide opportunities for students to face problems as well as learning on their own through researching for additional information. to be used for decision making and this is consistent with the research of Nagarajan & Overton (2019), students participate in problem-based learning, it will result in students being able to think critically as well as specifying problems. It makes alignment with many elements of a systems thinking approach.

Causal maps are also used as a tool to promote system thinking. It has the potential to help students organize information. To understand the complexity of a problem system through causal connections between the system components in which the problem is embedded. As well as helping students see possible solutions. and helps students build an understanding of the dynamics of systems. Cox et al. (2018, 2019) found that integrating causal maps into learning activities helps students structure information effectively. To allow students to write connections between various variables to explain reasons and relationships between various variables within the system, which can promote students' systems thinking. And it is consistent with the research of Ke et al. (2020) that said students will be able to understand systems thinking When students use a tool for systems thinking namely causal maps, and this is consistent with the research of Sabel et al. (2023) which said that modeling through causal maps can promote students to have higher systems thinking. Because students will gain an understanding of the dynamics of the system, each element in the system is causally connected to each other (Dalila et al., 2022; Suradika et al., 2023).

However, there were still 11 students whose scores for systems thinking did not pass the good level up criterion. In this regard, the student's score does not pass the criteria. This is because there are some problems in identifying the problem. There were also some students who identified variables that were not relevant to the problem. Or there are still students who can identify a few variables related to the problem. Including the incorrect identification of the relationship between some pairs of variables. And they create a causal cycle diagram that added some relationships that didn't make sense. The researcher took the problems that occurred in operation cycle 1 and brought them to improve and develop in Operation cycle 2.

Cycle 2: When improving the development of learning activities using problem-based learning with causal maps from cycle 1, it was found that the students' mean scores for the systems thinking were 10.42 points. When considering individual scores, there were 16 students whose scores pass the good level up criterion, this shows that students are improving in creating better system thinking. This may be a result of the researchers developing learning activities in the problem analysis stage. By adjusting problem situations to be relevant or likely to occur in students' lives. The insertion of video clips or illustrations related to the issues to stimulate students' interest and ask questions to guide students in searching for information and thinking analytically to connect to the issues this will lead to the determination of issues that are more consistent and comprehensive in the problem situation.

Teachers should pose targeted questions to stimulate student interest and guide their research toward relevant learning objectives. It is consistent with the research of Amaral et al. (2021), real-life problems increase motivation and encourage students to learn from that problem. In addition, the researcher developed learning activities in the self-learning stage by asking questions about what happened in the problem situation. Allowing students to think analytically and see various important words as a guideline for searching for additional information and then analyzing them (Jumini et al., 2022; Abdurahman et al., 2023; Anggraeni, et al., 2023).

In addition, there are examples of problem situations close to the students. To create a clear understanding for students about the relationships between variables that must be represented by plus or minus signs (+ or -) and to encourage students to search for more information. The correctness of the relationships that students identified, and this is consistent with the research of Cox et al. (2019) said that if there are still some students who associate the relationship with the incorrect sign, it is a result that points to the need for teachers to find ways to create clear understanding for students. Teachers must encourage students to gather additional information. As well as asking questions to allow students to think analytically. and is a guideline for students to search for information to analyze reasonableness and check the correctness of various relationships before adding them to the causal circuit diagram.

However, there were still 3 students whose scores for systems thinking did not pass the good level up criterion. In this regard, the student's score does not pass the criteria. This is because there are some problems in identifying variables related to the problem and specify the relationship between variables. Moreover, most of them had problems in drawing the creation of a causal cycle diagram. The researcher took the problems that occurred in operation cycle 2 and brought them to improve and develop in operation cycle 3.

Cycle 3: When improving the development of learning activities using problem-based learning with causal maps from cycle 2, it was found that the students' mean scores for the systems thinking were 13.84 points. When considering individual scores, it was found that There are 19 target group students, all of whom have passed the good level up criterion. This may be a result of the researcher developing learning activities in the self-learning stage. Students were encouraged to help their friends in the group find information. Including encouraging students to bring their searched information to share with members within the group (El Islami & Nuangchalerm, 2020). In order for students to check the accuracy and completeness of the variables that are factors related to the problems they have identified. This will allow students to exchange information with each other. In addition, the researchers encouraged students to share their opinions on the reasons for the relationship between the variables that the students specified and members within the group. In order to check the accuracy of the relationship between the variables that the students specified.

Amaral et al. (2021) stated that exchanging ideas with friends is very beneficial. This is because it helps students discover additional relationships that they may not have noticed before. Sabel et al. (2023) focused on the students participating in reasoning about relationships. It allows students to consider complex relationships. Students are encouraged to discuss reasons for relationships in the causal cycle diagrams that students write together with their group members. To check the correctness of the causal circuit diagram that the students wrote. This is in line with research by Hanisch & Eirdosh (2021), students should share and compare their own diagrams with their peers. to jointly critique each other's work and may suggest additional arrows or ideas to correct the part of their own diagram that is still incorrect, and this is consistent with the research of Cox et al. (2018) stated that it is very important to provide students with valuable discussion and analysis of each student's diagram. While students create diagrams. Teachers must encourage students to jointly explain the reasons for the relationship between various variables in the diagrams (Cox et al., 2019). It may also be a result of students practicing systems thinking from problem situations that are a continuation of the original problem situation. Therefore, students have higher scores in systems thinking. A new situation that is different from the original or is a continuation of the situation. Students will be able to identify the problem, identify variables related to the problem, specify the relationship between variables and can create a causal cycle diagram of the cause cycle according to that situation continuously.

5. Conclusion

This study helps students improve their capacity to systems thinking concepts in a way that meets the good level-up criteria. In the first cycle, 8 students achieved a good level of performance, while 11 students did not; in the second cycle, 16 students achieved a good level of performance, while 3 students did not in the third cycle, 19 students achieved a level of performance. It can be suggested that problem-based learning with causal maps should be introduced into science classrooms. Students can learn science through solving problems, systems thinking and authentic learning in the era of necessary learning skills required. The results highlight the importance of iterative learning and continuous improvement in educational interventions. Educational settings could apply this structured, cyclical approach to gradually improving students' systems thinking as well as necessary learning required.

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