*A Model-Based Inquiry Activity Using LEGO to Promote System Thinking of Grade 11 Students on Buffer Solution Topic*

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**Abstract**
System thinking in chemistry education aims to prepare future students who can apply the chemistry knowledge to addressing real-world complex phenomenon and have more holistic perspectives. The system thinking skills are divided into three levels: (1) analysis of system components, (2) synthesis of system components, and (3) implementation. In this study, a model-based inquiry learning activity using LEGO was developed in order to promote students' system thinking on the topic of buffer solutions. In the activity, LEGO was used as a tool for students to simulate systems for representing the pH controlling process in related natural phenomena such as maintaining the pH of seawater, the circulatory system, and the food industry, etc. The activity was implemented for 30 Thai high school students in the science and mathematics program using a one-group pretest-posttest design. A test on system thinking specific to the buffer solution topic and a student's self-evaluation questionnaire on system thinking skills were used as tools for collecting data. An analysis of the three levels of system thinking skills showed that the average posttest score of each level was significantly higher than the pretest score in all levels especially in the synthesis of system components level and students could apply the knowledge to the real-world issues. After the activity, students' reports from the questionnaire indicated that they could relate each component in the systems and could expand their knowledge to other systems.

Keywords: Model-Based Inquiry; System Thinking; LEGO; Buffer Solution; High School

## Introduction

According to the 20-year National Development Plan in Thailand, there is a desire to increase the level of satisfaction of establishments with graduates (Office of Education Council: ONEC, 2017). However, the graduates' competencies do not match the requirements of establishments (Office of Education Council: ONEC, 2017). Students lack skills and knowledge that connect what they have studied to daily life, which affects their future jobs (Orgill, York, & MacKellar, 2019). Especially, based on the 21st-century skills, thinking skill is one of the learners' key competencies that are needed to be developed (The ministry of education Thailand, 2010).

System thinking in chemistry education aims to prepare a new generation of students who can apply their chemistry knowledge to addressing real-world complex phenomena and be able to use their system thinking skills in their future jobs (Orgill et al., 2019). System thinking in chemical education consists of eight skills which are divided into three levels: (1) analysis of system components, (2) synthesis of system components, and (3) implementation which are shown in table 1 (Assaraf & Orion, 2005).

Table 1: Three levels of system thinking

| Level of system thinking | Skills |
|---|---|
| Analysis of system components | The ability to identify the components of a system and processes within the system. |
| Synthesis of system components | The ability to identify relationships among the system's components. |
| | The ability to identify dynamic relationships within the system−understanding how the components of a system are related and affect one other as a function of time. |
| | The ability to organize the systems' components and processes within a framework of relationships-understanding that all of the relationships within a system are interconnected. |
| | The ability to understand the cyclic nature of systems−understanding the repetition in the system's behavior and the cause of the repeating behaviors. |
| Implementation | The ability to make generalizations−understanding general patterns in the system that can be applied to other systems or situations. |
| | Understanding the hidden dimensions of the system−understanding invisible components and processes that contribute to the system's behavior. |
| | Thinking temporally: retrospection and prediction−understanding the cause that impacts the current behavior of the system or the effect of interventions on the system, and how current actions affect the future behavior of the system, then students will be able to predict what will happen when the system interferes, and apply that knowledge to other circumstances |

Many topics in chemical education can be implemented by embedding a perspective of system thinking into lesson plans, including earth systems with a focus on the hydro cycle

(Assaraf & Orion, 2005; BenZviAssaraf & Orion, 2010), carbon dioxide and climate change (Aubrecht et al., 2019), and catalysis (Ravi, Puente-Urbina, & Bokhoven, 2021). The buffer solution topic can be embedded with a system thinking perspective because it is related to other concepts such as the particulate nature of matter, chemical reactions, stoichiometry, chemical equilibrium, acid-base chemistry, and to everyday life as well. (Kusumaningrum et al., 2017). However, like many other topics in chemistry, buffer is an abstract topic by nature (Şendur, Toprak, & Pekmez, 2011). Students are required to understand the concept at submicroscopic and symbolic levels, which might be difficult for them to understand the content (Setiadi & Irhasyuarna, 2017). Therefore, teachers should play a key role in helping students overcome this difficulty by designing learning activities to help them understand the macroscopic aspect, sub-microscopic aspect, and symbolic aspect of the concept (Johnstone, 1993; Chittleborough, 2014). Models such as LEGO can be used to represent the sub-micro particles in the substances being observed (Chittleborough, 2014). LEGO was used as a model for teaching chemistry for many topics, including stoichiometry (Witzel, 2002), ionic bonding (Ruddick & Parrill, 2012), nanotechnology (Campbell, Miller, Bannon, & Obermaier, 2011), chemical equilibrium, reaction kinetics (Cloonan, Nichol, & Hutchinson, 2011), and catalysis (Horikoshi, Kobayashi, & Kageyama, 2013), because LEGO bricks can easily be connected and disconnected, allowing for rapid model construction and modification, and they can be used to represent a fraction of atoms, and molecular compound models (D. Campbell et al., 2011; D. J. Campbell, 2004).

Regarding the importance of system thinking skills that can help students examine and address complex behaviors and phenomena from a more holistic perspective (Orgill et al., 2019), the skills could be articulated via inquiry-based instruction. Inquiry-based instruction is widely used in science teaching because the method can promote students' understanding of the nature of scientific discovery or scientific method as well as how scientists explain knowledge of the natural world (National Research Council, 2000). Therefore, in this study, a model-based inquiry learning using LEGO bricks as a model was developed to promote students' understanding and system thinking skills on the buffer solution topic. When students think systematically, they can recognize the significance of learning science that affects the environment and their daily lives, which corresponds to the establishment's required skills.

**The Development of Model-based Inquiry Using LEGO Activity**

In this study, there are three model-based inquiry activity plans which are designed to teach students about the change in pH of the water and a solution of acetic acid and sodium acetate in the laboratory; daily buffer solution activities from a food or hair care manufacturing industry situation; and daily buffer solution activities from an acidosis disease situation. Overall, the lesson plans took up a total of ten periods: 4 for the first plan, and 3 each for the other two.

A model-based inquiry learning activity using LEGO was then developed to promote system thinking of students on the buffer solution topic. The relationships between model-based inquiry and system thinking are shown in table 2.

Table 2: Relationships between model-based inquiry that according to system thinking

| The level of system thinking | System thinking skill | Alignment with model-based inquiry learning process |
|---|---|---|
| **Analysis of system components** | Ability to identify the components of a system and processes within the system. | **1. Engaging with questions or problems**<br>Sample question:<br>1) What are the components of the system and what are their characteristics? |
| | | **2. Developing assumptions or hypotheses** |
| | | **3. Making systematic observations to test hypotheses–** inquire the information or experiment and make observation to test hypothesis. |
| **Synthesis of system components** | -Ability to identify relationships among the system's components.<br>-Ability to identify dynamic relationships within the system | **4. Creating models–** build a model to represent the components in the system using LEGO. |
| | -Ability to organize the systems' components and process within a framework of relationships<br>- Ability to understand the cyclic nature of systems | **5. Evaluating the model–** create a description of the model's principles and assess it from the relationships of components that affect one another. |
| **Implementation** | - Ability to make generalizations<br>-Understanding the hidden dimensions of the system<br>- Thinking temporally: retrospection and prediction | **6. Revising the model and applying it in new situations–** modify the model and apply the model to other situations or contexts such as daily life, environment, etc. |

The model-based inquiry activity plans were implemented during the COVID-19 outbreak situation. Hence, the activities had to be conducted online. Learning activities consist of 6 phases of model-based inquiry (Windschitl, Thompson, & Braaten, 2008). The details of the eight sub-skills which are divided into three levels of system thinking, their meaning which is related to the buffer solution topic, and their implementation in model-based inquiry are shown in table 3.

Table 3: The system thinking components, their meaning that relate buffer solution, and their implementation in model-based inquiry

| System thinking components | Meaning in relation to buffer system | Implementation in model-based inquiry |
|---|---|---|
| Ability to identify the components of a system and processes within the system. | Ability to identify the buffer components in an acid-base conjugate pattern that maintains the pH process in a defined situation | Teacher defines the scenario of the buffer system in everyday life and engages with the question or problem, such as which components in this context play a part in buffer system pH regulation, then invites the students to hypothesize and inquire about the facts and observations to test the hypothesis. |
| Ability to identify relationships among the system's components | Ability to identify relationships among the acid-base conjugate components in a buffer solution when the amount of each is affected by the addition of acid or base | Students creates a model of the buffer components in the system, at least one pair of acid-base conjugates in that buffer system, using LEGO. |
| Ability to identify dynamic relationships within the system | Ability to identify dynamic relationships within the buffer system such as the amount change in an acid-base conjugate which is a buffer system's component involving the Le Chatelier's principle | Students creates a model of the buffer components in the system using LEGO with a lot of acid-base conjugates to show how the components in the buffer system interact dynamically. |
| Ability to organize the systems' components and processes within a framework of relationships | Understanding that all of the relationships within a buffer system are interconnected and expressed in a pattern by a chemical equation, which is a common framework understanding in chemistry | Teacher has students write the symbol as a chemical equation to represent the interactions and relationships of the components in the buffer system. |
| Ability to understand the cyclic nature of systems | Ability to understand the repeatition in the behavior of the buffer system and the cause of the repeated behaviors, such as understanding the dynamic change of acid-base conjugate and explaining how the buffer works to balance the system | Students makes a description of the model's principles, explain the reason for the change in the amount of acid-base conjugate, and assess the model from the relationships of components that affect one another. |
| Ability to understanding the hidden dimensions of the system | Understanding the invisible components and processes that contribute to the buffer system's behavior, such as the components of the buffer system in the microscopic aspect consisting of particulate levels, which can be used to explain the movement of electrons, molecules, particles, or atoms | Students notice the microscopic aspect of the buffer component while constructing the model. |
| Ability to make generalizations | Understand and apply general patterns of how the buffer works in the buffer system to other situations | Students illustrate the general pattern of interactions between LEGO models that can be applied to other situations. |
| Thinking temporally: retrospection and prediction | Understand the cause of the buffer system's current behavior or the effect of interventions on the system, as well as how current actions affect the system's future behavior, be able to predict what will happen when the buffer system interferes, and be able to apply that knowledge to other situations. | Students modify the model to fit different scenarios or contexts, such as daily life and the environment. |

**Research Method**

This study aims to answer a research question "Can the model-based inquiry promote systems thinking in grade 11 students on the buffer solutions topic?"

This study is a one-group pretest-posttest design. The sample was 30 students from 5/8 class who are studying in science program in the second semester of academic year 2020 at Bodindecha (Sing Singhaseni) school. The purposive sampling was implemented to select the sample.

Samples' required background:
(1) The particulate nature of matter
(2) Chemical reactions
(3) Stoichiometry
(4) Solution chemistry
(5) Chemical equilibrium
(6) Acid/base chemistry

The instruments used in the study components:
1. The scenario-based test of system thinking in buffer solution
2. Student's self-evaluation questionnaire

**The scenario-based test of system thinking in buffer solution**

The tools developed using the scenarios-based test that aligned with each component of system thinking consist of writing an explanation, drawing a simple model after learning, and creating a model by using LEGO and graphic tools, which were infographics. The test has a total score of 27 and consists of 7 items. This could examine the level of system thinking skills of the students as shown in table 4.

Table 4: Sample question on buffer solution to test system thinking.

| Level of system thinking | System thinking skill | Question | Item | Total score |
|---|---|---|---|---|
| **Analysis of system components** | Ability to identify the components of a system and processes within the system. | What elements in the sea play a role in regulating the pH of the sea and making the sea pH almost constant? (specified in the form of an acid-base conjugate) | 1 | 6 |
| **Synthesis of system components** | Ability to identify relationships among the system's components | When sea acidity increases, how does it affect the amount of acid-base conjugate in item 2? | 3 | 2 |
| | -Ability to identify dynamic relationships within the system<br>-Ability to understand the cyclic nature of systems | Explain the reasons for the change in the amount of acid-base conjugate in item 3. | 4 | 2 |
| | Ability to organize the systems' components and processes within a framework of relationships | Write a chemical equation explaining the reason for the answer to question 3. | 6 | 1 |

| Level of system thinking | System thinking skill | Question | Item | Total score |
|---|---|---|---|---|
| Implementation | Ability to understanding the hidden dimensions of the system | Choose only one pair of acid-base conjugates from item 1 and show the particle model of that substance. | 2 | 3 |
| | Ability to make generalizations | Show a model to explain the reasons behind the answer of question 4. | 5 | 2 |
| | Thinking temporally: retrospection and prediction | If the rain that falls on this planet has the properties of a base, do students think that this rain flow into the sea will result in a sudden increase in seawater pH? Write a 1-page A4 infographic explaining the rationale behind the answer, using the questions 2–6 as a guide for the infographic design. | 7 | 11 |

## Student's self-evaluation questionnaire

The student's self-evaluation questionnaire on system thinking skills was developed using the five-point Likert-scale type (McCoach, Gable, & Madura, 2013). There are nine questions asking students to assess themselves after the implementation as evident by the test. The mean and standard deviation were used to analyze the data.

## Result and Discussion

The total score of the test was 27, which can be divided into 6, 5, and 16 scores corresponding to each level of system thinking in the test and 8 system thinking skills (see table 5).

Table 5: Results of the pretest score and posttest score of system thinking test on buffer solution

| Level of system thinking | Components of system thinking skill (Scores) | Pre-test | | Post-test | | t | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|
| | | Mean±SD | Percentage (%) | Mean±SD | Percentage (%) | | |
| **Analysis of system components** | 1. Ability to identify the components of a system and processes within the system (6) | 3.93±0.37 | 65.56 | 4.47±0.86 | 74.44 | 3.25 | 0.003 |
| **Overall (6)** | | 3.93±0.37 | 65.56 | 4.47±0.86 | 74.44 | 3.25 | 0.003 |
| **Synthesis of system components** | 2. Ability to identify relationships among the system's components (2) | 1.20±1.00 | 60.00 | 1.93±0.25 | 96.67 | 4.25 | 0.000 |
| | 3.Ability to identify dynamic relationships within the system (2) | 0.23±0.43 | 11.67 | 1.87±0.43 | 93.33 | 16.08 | 0.000 |

| Level of system thinking | Components of system thinking skill (Scores) | Pre-test | | Post-test | | t | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|
| | | Mean±SD | Percentage (%) | Mean±SD | Percentage (%) | | |
| Synthesis of system components | 4. Ability to understand the cyclic nature of systems (2) | 0.23±0.43 | 11.67 | 1.87±0.43 | 93.33 | 16.08 | 0.000 |
| | 5. Ability to organize the systems' components and processes within a framework of relationships (1) | 0.37±0.49 | 36.67 | 0.87±0.35 | 86.67 | 5.38 | 0.000 |
| **Overall (5)** | | 1.80±1.09 | 36.00 | 4.67±0.75 | 93.40 | 12.26 | 0.000 |
| Implementation | 6. Ability to Understanding the hidden dimensions of the system (3) | 2.87±0.57 | 95.56 | 2.97±0.18 | 98.89 | 0.90 | 0.375 |
| | 7. Ability to make generalizations (2) | 0.07±0.37 | 33.33 | 1.17±0.99 | 58.33 | 6.05 | 0.000 |
| | 8. Thinking temporally: retrospection and prediction (11) | 1.83±1.98 | 16.67 | 7.30±3.53 | 66.36 | 9.28 | 0.000 |
| **Overall (16)** | | 4.77±2.13 | 29.81 | 11.43±4.38 | 71.43 | 8.99 | 0.000 |
| | **Total (27)** | 10.50±2.34 | 38.89 | 20.57±5.12 | 76.19 | 10.88 | 0.000 |

From table 4, the total mean score of the posttest (20.56±10.07) was significantly higher than that of the pretest (10.50±4.84) at a .05 level of confidence. Overall, the results indicate that the model-based inquiry learning activity can promote system thinking skills in the students.

However, the results were further analyzed using normalized gain to gain in-depth information about the level of improvement in particular aspects of system thinking. Table 6 shows normalized gain scores of the system thinking test on the buffer solution topic in 3 levels of system thinking in each student.

Table 6: Results of normalized gain of system thinking test on the buffer solution topic

| Student No. | Normalized gain of level of system thinking | | | Interpretation | | |
|---|---|---|---|---|---|---|
| | Analysis of system components | Synthesis of system components | Implementation | Analysis of system components | Synthesis of system components | Implementation |
| 1. | 0.00 | 0.60 | 0.15 | - | Medium gain | Low gain |
| 2. | 1.00 | 1.00 | 0.38 | High gain | High gain | Medium gain |
| 3. | 1.00 | 1.00 | 0.67 | High gain | High gain | Medium gain |
| 4. | 0.00 | 0.00 | 0.15 | - | - | Low gain |
| 5. | 0.00 | 1.00 | 0.31 | - | High gain | Medium gain |
| 6. | 0.00 | 1.00 | 0.18 | - | High gain | Low gain |
| 7. | 0.00 | 1.00 | 0.17 | - | High gain | Low gain |
| 8. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 9. | 0.50 | 1.00 | 1.00 | Medium gain | High gain | High gain |
| 10. | 0.00 | 1.00 | 0.54 | - | High gain | Medium gain |

| Student No. | Normalized gain of level of system thinking | | | Interpretation | | |
|---|---|---|---|---|---|---|
| | Analysis of system components | Synthesis of system components | Implementation | Analysis of system components | Synthesis of system components | Implementation |
| 11. | 1.00 | 1.00 | 1.00 | High gain | High gain | High gain |
| 12. | 1.00 | 1.00 | 1.00 | High gain | High gain | High gain |
| 13. | 1.00 | 0.50 | 0.30 | High gain | Medium gain | Low gain |
| 14. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 15. | 1.00 | 1.00 | 1.00 | High gain | High gain | High gain |
| 16. | 0.00 | 1.00 | 0.57 | - | High gain | Medium gain |
| 17. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 18. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 19. | 1.00 | 1.00 | 1.00 | High gain | High gain | High gain |
| 20. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 21. | 0.00 | 0.50 | 0.15 | - | Medium gain | Low gain |
| 22. | 0.00 | 1.00 | 0.25 | - | High gain | Low gain |
| 23. | 0.00 | 1.00 | 0.46 | - | High gain | Medium gain |
| 24. | 0.00 | 0.67 | 0.15 | - | Medium gain | Low gain |
| 25. | 0.00 | 1.00 | 0.55 | - | High gain | Medium gain |
| 26. | 0.00 | 1.00 | 0.73 | - | High gain | High gain |
| 27. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 28. | 0.00 | 1.00 | 1.00 | - | High gain | High gain |
| 29. | 0.00 | 0.50 | 0.18 | - | Medium gain | Low gain |
| 30. | 0.00 | 1.00 | 0.50 | - | High gain | Medium gain |
| **Total** | **0.25** | **0.89** | **0.61** | **Low gain** | **High gain** | **Medium gain** |

Overall, students had gained in their level of analysis of system components, synthesis of system components, and implementation as indicated by low gain, high gain, and medium gain, respectively, and Figure 1 shows the percentage of the normalized gain scores of the system thinking test on buffer solution in 3 levels of system thinking in each student.

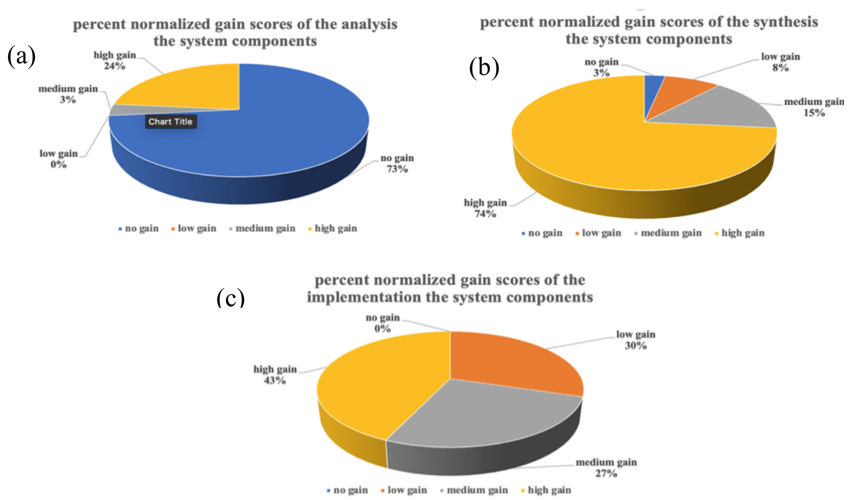


Figure 1: shows percent normalized gain scores of the system thinking test on buffer solution (a) in levels of analysis system components. (b) in level of synthesis the system components. (c) in level of implementation.

### Result of System Thinking at The Level of Analysis of system components

For the analysis of system components, the overall result was that the mean score of the posttest (4.47±0.86) was significantly higher than that of the pretest (3.93±0.86) at a .05 level of confidence (see table 5). When considering the overall normalized gain scores from table 6, the normalized gain of the analysis of the component level was 0.25, which showed that students' performance slightly improved at this level of system thinking.

The reasons arose from the students' having prior knowledge of conjugate acid and conjugate base since they learned about the theory of the acid-base topic. The content could be applied to identify the component of the buffer system in the learning activity that made most students get high scores on the pretest, have a bit more on the posttest, and slightly improve at this level of system thinking. However, when considering normalized gain scores for each student from table 6, some students had a high gain at these levels. The result was also consistent with the student's self-evaluation questionnaire, in which students agreed to a high level that teaching with LEGO allowed them to specify the buffer solution's components (see table 7).

### Result of system thinking at the level of Synthesis of system components

For the synthesis of system components, the result of the mean score of the posttest (4.67±0.75) was significantly higher than the mean score of the pretest (1.80±1.09) at a .05 level of confidence (see table 5). When considering overall normalized gain scores from table 6 the normalized gain of the synthesis of system component level was 0.89 which showed students' performance improved most at this level of system thinking. The reason behind this could be due to the fourth phase of model-based inquiry learning activity, which was creating models. Students used LEGO as a model tool to simulate systems for simulating the pH controlling process in an experiment as well as associated natural phenomena. In the fifth phase of the model-based inquiry learning activity, which was evaluating the model, students created a description of the model's principles and assessed it from the relationships of components that affect each other.

The results emphasized that the LEGO model was a learning tool that allowed students to see the interaction between each component in systems and virtualization that was more than macroscopic, which is submicroscopic (Taber & Akpan, 2016; González-Sánchez, Ortiz-Nieves, & Medina, 2014). Students were also able to organize the elements of a buffer system within a framework of relationships, and the results also corresponded to Hmelo-Silver, Jordan, Eberbach, & Sinha (2017) using the combination of conceptual representation with inquiry and model-base as a tool to allow students to have system thinking. However, considering normalized gain scores for each student from table 6, some students had a medium gain and one student had no gain at these levels.

The results were also consistent with the students' self-evaluation questionnaire, in which students agreed to a high level that teaching with LEGO allowed them to see the relationship of buffer components changing when acid or base was added, understand the buffer solution's operating principle, and could help students create a framework that depicted the link between the elements that changed in a system, such as a chemical equation (see table 7).

## Result of system thinking at the level of implementation

In the implementation aspect, the overall mean score of the posttest (11.43±4.38) was significantly higher than the mean score of the pretest (4.77±2.13) at a .05 level of confidence (see table 5) with the exception of the ability to understand the hidden dimensions of the system, because students could show a substance that was a component in a buffer system by drawing the structure of the substance at the molecular level in item 2. That made them have a fairly high score in the pretest, but they could not use that molecule to represent a substance in a chemical reaction in item 5. However, students could do better on both items 2 and 5 after learning through model-based inquiry using LEGO. There was also evidence from the analysis of students' self-evaluation questionnaire, observations in class, and conversations with students, they agreed at a high level that LEGO lessons were able to assist them in comprehending the mechanism of action of buffer solutions at the molecular or atomic level. Considering the normalized gain scores from table 6, the normalized gain of the analysis of the component level was 0.61 which showed that students' performances were moderately improved at this level of system thinking.

The reason behind this finding could be due to the sixth phase of the model-based inquiry learning activity, which was revising the model and applying it in new situations. Students could illustrate the LEGO model to explain the particle model of components that relate to contouring pH, which gave students virtualization at the molecule level (Campbell et al., 2011). Then they were able to make generalizations, modify the model, and apply the model to other situations or contexts such as daily life, the environment, etc. However, this is the highest level of system thinking. Some students were unable to apply the model to explain the principal work of buffer solutions in other situations. Considering normalized gain scores for each student from table 6, some students had a low gain and some had a medium gain at these levels.

According to students who had learned through the model-based inquiry activity, used LEGO as a tool to represent pH contorting in a buffer system, and had taken the system thinking test on buffer solution, which was a scenario-based test using a graphical tool that relates to the implementation level of system thinking, the results of the pretest score and posttest score of students who had developed system thinking corresponded to (Assaraf & Orion, 2005) which used drawing as one of many tools to assess system thinking and also related to Ravi, et al. (2021) who were developing graphical tools for system thinking specifically in catalysis. The results were also consistent with the student self-evaluation questionnaire, which revealed that students strongly agreed that LEGO activities could help them understand the mechanism of action of buffer solutions at the molecular or atomic level, and that they could apply their buffering knowledge to real-world problems (see table 7).

## Results of student's self-evaluation questionnaire

The student's self-evaluation questionnaire was used to give students an assessment of themselves after the implementation, and the data was then used to analyze the consistency with the experimental results of the pre-test and post-test. The results of the questionnaire analysis of the positive and negative questions by converting the calculations of the negative questions into positive ones are shown in table 7.

Table 7: Results of student's self-evaluation questionnaire

| Items | Mean ± SD | Interpretation |
|---|---|---|
| **1) Analysis of system components (Items 1-2)** | | |
| 1. Teaching with LEGO allows me to specify the buffer solution's components. | 4.17±1.24 | High level |
| 2. This LEGO instruction was unable to assist me in identifying the components of the buffer solution | 4.17±1.19 | High level |
| **Overall** | **4.17±1.21** | **High level** |
| **2) Synthesis of system components (Items 3-6)** | | |
| 3. LEGO taught me that if I add acids or bases to the buffer solution, the amount of substance in the solution will rise, as well as the compounds that are lowered. | 4.17±1.21 | High level |
| 4. The LEGO tutorial allows me to illustrate the buffer solution's operating principle. | 4.27±1.03 | High level |
| 5. The LEGO tutorial still didn't assist me to comprehend how buffer solutions affect pH. | 4.30±1.04 | High level |
| 6. Using LEGOs as a teaching tool allows me to create a framework that depicts the link between the elements that change in a system, such as chemical equations. | 4.00±1.06 | High level |
| **Overall** | **4.18±1.09** | **High level** |
| **3) Implementation (Items 7-9)** | | |
| 7. Using LEGOs to teach lets me apply my buffering knowledge to real-life issues. | 4.53±0.56 | Very high level |
| 8. I can visualize the notion of adjusting the pH of a buffer solution thanks to this LEGO instruction. | 4.17±1.07 | High level |
| 9. At the molecular or atomic level, LEGO lessons are unable to assist me in comprehending the mechanism of action of buffer solutions. | 4.33±1.01 | High level |
| **Overall** | **4.34±0.88** | **High level** |

## Conclusions

From the results of a model-based inquiry activity that requires students to learn through 6 phases, which are: engaging with a question or problem, developing a tentative or hypotheses, making systematic observations to test hypotheses, creating models, evaluating the model, revising the model, and applying it in new situations, the average posttest score of system thinking in all levels on the buffer solution topic was significantly higher than the average pretest score, which was statistically different at the .05 level. Including the normalized gain scores of 3 levels of system thinking, which include analysis of components, synthesis of components, and implementation, are indicated at a low level, high level, and medium level, respectively, that can answer the research question, which is which model-based inquiry activity can promote system thinking of grade 11 students on the buffer solution topic. System thinking made the most progress in the level of synthesis due to students' using LEGO as a model tool to virtualize the components and relations between components in the system as submicroscopic (Taber & Akpan, 2016; (González-Sánchez, Ortiz-Nieves, & Medina, 2014) and students' ability to implement knowledge into the real-world issue. The result from the student's self-evaluation questionnaire found that all three levels of system thinking were high-level.

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