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Enhancing Junior High School Students' System Thinking Competency through Water Treatment with Plant Modification: A Focus on Environmental Pollution

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ABSTRACT The research on the ability to think in systems in education is also minimal, which is why the ability to think in systems in Indonesia has not been optimally trained. Dealing with a system's complexity can be challenging at any age, particularly for students who must apply the system's cognitive capabilities during the learning process. Systems thinking is a key to Education for Sustainable Development (ESD) competency since it can help learners understand the complexity and dynamics of the world. This research investigates the impact of system thinking on Junior High School students through simple science projects addressing environmental pollution. The study involved 7th-grade students in a private school in Bandung, utilizing a quantitative approach with a one-group pre-test and post-test design; the research aimed to measure the improvement in students' system thinking competency using test items and analyzed the data with SPSS software and Rasch Stacking and Racking. Results from the Wilcoxon test indicated a significant difference after completing learning activities, with a 50% improvement based on Rasch analysis. This underscored the critical role of project-based learning in enhancing system thinking competency. Applying appropriate learning models is expected to enhance students' system thinking competency. The recommendation for future reference to other studies, such as directing the scientific investigation in detail. Design more precisely from the initial stage to the final stage so that the expected learning can be achieved, and students can go through all stages of STEM learning correctly to create a better prototype.

Keywords: Education for Sustainable Development (ESD), System thinking competency, Environmental pollution

1. INTRODUCTION

In 2015, a consensus was reached on the Agenda for Sustainable Development, which outlines the Sustainable Development Goals (SDGs). The implementation raises the question about education's role in achieving those objectives (Hoffmann & Siege, 2018). Education for Sustainable Development (ESD) is a tool for attaining SDGs and involves acquiring various competencies (De Haan, 2006). Learners should be empowered to act in complex situations, necessitating a shift towards sustainable development (Cebrián et al., 2020). One critical ESD competency is system thinking, enabling learners to understand the complexity and dynamics of environmental, social, and economic systems. This involves understanding relationships, analyzing complex systems, considering embedded systems, and dealing with uncertainty (UNESCO, 2017).

System thinking is recognizing, describing, and explaining complex components of reality as a system (Riess & Mischo, 2010). The measured characteristics include declarative or conceptual knowledge, modeling systems, solving problems using system models, and evaluating system models. This will be tested using test items and evaluated using the heuristic competence model of system thinking (Riess & Mischo, 2010). Understanding complex systems is challenging for students transitioning from simple cause-and-effect to complex reasoning (Mambrey et al., 2020). System thinking is considered a

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higher-order thinking capacity, involves the fundamental recall of data, and encompasses abilities like evaluation and creativity (Schuler et al., 2018). When faced with a complicated issue, system thinking is necessary to analyze the problem, grasp the relationships between its components, and the connections between the issue and other issues. Understanding systems is crucial for a successful ESD, which requires the ability to think in systems. Additionally, it deals with complex issues including the interactions between ecological, economic, and sociocultural issues (Fanta et al., 2020).

The global issues described in the Sustainable Development Goals by UNESCO (2017) present contextual problems differing from many simulated or written problems used in traditional teaching and learning in the classroom. One innovative learning model that can be oriented toward ESD goals is applying STEM knowledge and skills, starting with formulating the problem, thinking, designing, making, testing, and revising the design (Kartini et al., 2021). One of the concerns of sustainable development is the environmental aspect. Environmental education is the process of helping others acquire the knowledge, abilities, and values for people to take an active role as formal citizens in the development of an ecologically sustainable society (Osunji, 2021).

Nowadays, the most dominant environmental problem is wastewater. Wastewater can come from household and industrial activities. One alternative to treating wastewater is water treatment using plant media. Many researchers have researched treating water using environmental plant media, such as aquatic plants (*water bamboo* and *water jasmine*), *moringa seed, hyacinths, lettuce, watermelon papaya seed,* and others. Moringa seeds are used as a natural coagulant to reduce metals in water. The fine collision of Moringa seeds can cause coagulants in the impurities contained in the water (Ariyatun et al., 2018).

Systems thinking, as explained, relates to our role in the world: how do we handle societal challenges, how do we organize in a sustainable way, and how is the relationship between system and environment, and to build the sustainable consciousness among people around the world. Therefore, this competency needs to be built early in the school environment through simple projects that can be implemented in STEM teaching and learning. There is much research on increasing system thinking among students. However, no research is related to Enhancing the System Thinking Competency for Junior High School Students Through Water Treatment using Plant Modified on The Environmental Pollution Topic. Thus, this research aims to investigate the impact of system thinking through simple projects on science topics in Junior High School students.

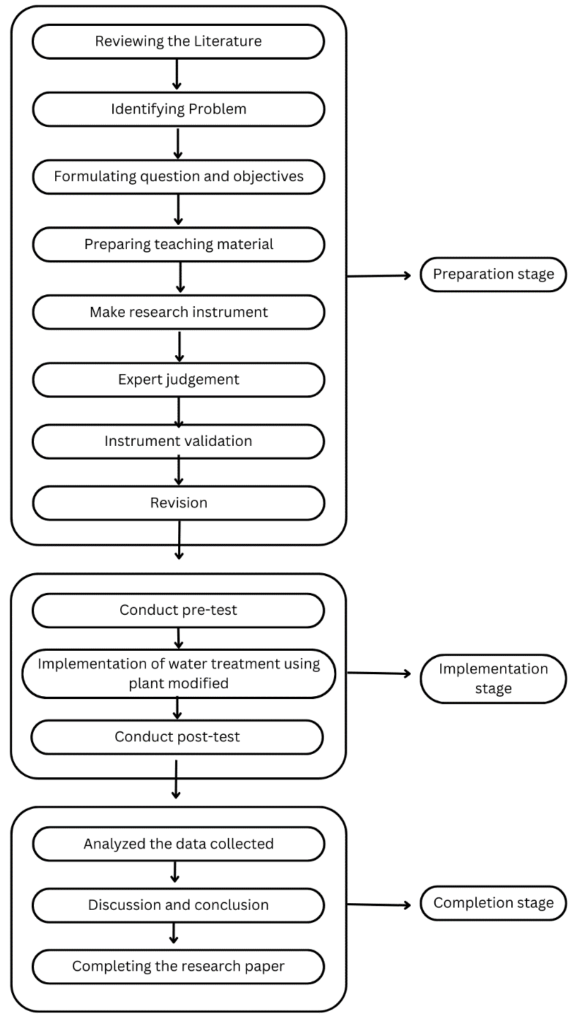

Figure 1 Research procedure

2. METHOD

2.1 Research Method

This research employed a quantitative approach using pre-experimental methods with a pre-post one-group design. This method was chosen to collect data on the system thinking competency of Junior High School students before and after the treatment (Creswell, 2014). The research utilized a pre-experimental design involving only the experimental group without considering a control group (Fraenkel et al., 2012). In the pre-experiment, all students received the same learning activity. The research specifically employed a one-group pre-test and post-test design. The research procedure stages are illustrated in Figure 1.

2.2 Participant

The population of this research was 7th-grade students in Junior High School who learned using the 2013 Curriculum. The sample included students from the 7th grade in a Junior High School located in Bandung, West Java. The sample consisted of 10 male and ten female students, selected using convenience sampling.

Table 1 Recapitulation analysis of system thinking competency test item (after validation)

Item Number	Outfit Mnsq	Outfit Ztsd	Ptmeasure corr.	Conclusion
1	0.72	-0.38	0.43	Accepted
2	0.10	-0.70	0.48	Accepted
3	0.68	-0.81	0.50	Accepted
4	0.84	-0.31	0.34	Accepted
5	1.00	0.05	0.38	Accepted
6	0.38	-1.04	0.57	Accepted
7	1.61	0.84	0.26	Accepted
8	1.30	1.59	0.18	Accepted
9	0.93	0.41	0.09	Accepted
10	0.78	-0.24	0.41	Accepted
11	0.84	-0.59	0.44	Accepted
12	1.42	1.80	0.06	Accepted
13	0.65	-1.40	0.58	Accepted
14	0.69	-0.77	0.49	Accepted
15	0.83	-0.64	0.49	Accepted
16	1.11	0.53	0.28	Accepted
17	0.50	-0.52	0.48	Accepted
18	1.23	0.73	0.17	Accepted
19	1.12	0.56	0.24	Accepted
20	1.17	0.64	0.26	Accepted
21	1.11	0.49	0.28	Accepted
22	0.58	-1.60	0.64	Accepted

Convenience sampling is a type of nonprobability or nonrandom sampling in which members of the target participant meet specific practical criteria, such as ease of accessibility, availability at a particular time, or willingness to participate for research purposes (Etikan, 2016) – choosing participants who are easily accessible.

2.3 Research instrument

This research instrument utilized in this study was a test item consisting of 22 multiple-choice questions, covering four dimensions within sub-capability 1: declarative/conceptual systems knowledge, modeling system, solving problems using system models, and evaluation of system models. Before being distributed, the instrument was validated by expert judgment in four lectures. Then, the student revised and tested the instrument. After getting the results, the test item was asses using the scoring rubric. The data was analyzed using Rasch stacking and racking to obtain the answers to outfit MNSQ, ZTSD, and Pt. Measure Correlation to see the item fit. Cronbach's Alpha value on this test item is 0.63, which is included in the "enough" category. While the item reliability was 0.89, the quality of the items in the reliability aspect of the instrument was good. The recapitulation analysis of the System thinking test item after validation is given in Table 1.

Then, the results were analyzed using the Rasch Stacking and Racking. The data analysis involved the Wright Map, Logit Score, and Scalogram. The Wright Map represented the difficulty of questions relative to students' abilities, facilitating a comparison between candidate's performance and question difficulties. Changes in students' conceptual mastery abilities were determined by comparing pre-posttest logit item sizes using the Rasch Model Stacking technique (Wright, 2003). A higher personal measure corresponded to better test performance, while a lower personal measure corresponded to poorer performance (Boone, 2016). The Scalogram presented data in a unique pattern representing an ideal scale, aiding in determining the seriousness level exhibited by students' responses in answering the test.

3. RESULT AND DISCUSSION

This section presents An investigation into junior high school students' thinking competency. To validate the results, Rasch Stacking and Racking were utilized for data analysis.

3.1 Learning Plant Modifies Water Treatment Project to Enhance System Thinking Competency

The explanation begins with interpreting statistically processed data, followed by discussing the outcomes of implementing STEM learning activities in building the prototype. It concludes with a detailed analysis of students' systems thinking skills using Rasch Stacking and Racking. The pre-test and post-test system thinking competency data were subjected to the Wilcoxon hypothesis test, with the results summarized in Table 2.

Table 2 Statistical test results on system thinking competency

System Thinking Competency (Test Item)		Pretest	Posttest
N		20	20
Mean		58.95	75.70
Standard deviation		20.79	21.35
Normality test (Saphiro wilk)	Sig	0.049	0.001
	Interpretation	Rejected	Rejected
Hyphotesis test (Wilcoxon test)	Sig	0.001	
	Interpreation	There's significance difference	

The table reveals that the average score of students in the initial data from the pre-test indicates a value of 58.95, suggesting that the student's ability to answer questions related to the system thinking competency indicator on environmental pollution is relatively low. After undergoing the treatment of creating water treatment using plant modification through STEM learning, a significant average difference in students' system thinking competency scores was observed between the pre-test and post-test. The Wilcoxon test results with a significance level of 0.001 further confirm this significant difference.

Researchers must carry out several stages of the STEM learning model when implementing it. These are formulating problems, thinking, designing, making, testing, and revising the design (Kartini et al., 2021). In this activity, students work in a group that has been divided by the teacher. System thinkers must enhance their individual and group efficacy to address issues and make decisions within their community. Collaborative group work fosters a sense of capability in individuals as they recognize their capacity to work collectively toward effecting change (Clark et al., 2017). To facilitate the learning activities, the teacher has developed a student worksheet. The worksheet plays a crucial role in guiding students through the process. For instance, when students identify a problem, the worksheet is structured to align with this objective. An example format is provided below, where students identify a problem by watching a video about the water conditions surrounding the school. This worksheet is a practical tool to guide students through the STEM learning activities, ensuring a systematic and practical approach to problem-solving within the context of the water treatment project.

Formulating Problem and Thinking

The learning activities in the first meeting were focused on identifying the problems around the school and thinking about alternative solutions, as shown in Figure 2. The identification of the problem began with the teacher showing a video about water pollution around the school. Then, students identified the physical and chemical conditions of the wastewater they had watched earlier. In this stage, students distinguished between polluted and unpolluted water conditions. For the physical condition, students analyzed the color and smell of the water. Meanwhile, for the chemical condition, students were asked to analyze the turbidity and pH of the water. After that, they concluded the problems they had found.

Following the scientific investigation, each group was asked to analyze the water condition problem and think about how to solve the water pollution problem. Students were indirectly encouraged to express the solutions to the wastewater problem using plant modifications. Students with good system thinking skills can make comprehensive decisions and avoid mistakes. System thinking skills were utilized by examining the impact of decisions or problems in other fields (Nuraeni et al., 2020).

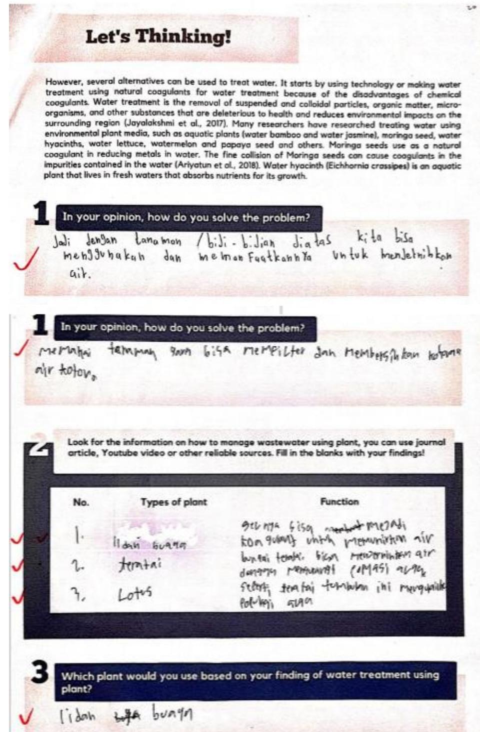

Figure 3 Answers on student's worksheet about thinking the solutions

Figure 3 displays the students' group worksheets. After the analysis, they identified several plants that could treat polluted water, including Biji Kelor, Apu-Apu, and Teratai. Each plant was assigned a different function in purifying the wastewater. Another group proposed different plants, such as Lidah Buaya, Teratai, Lotus, and Sirih Gading. Students were free to choose the type of plant they wanted to use and the required materials. In this stage, the indicator that was trained was conceptual system knowledge. The

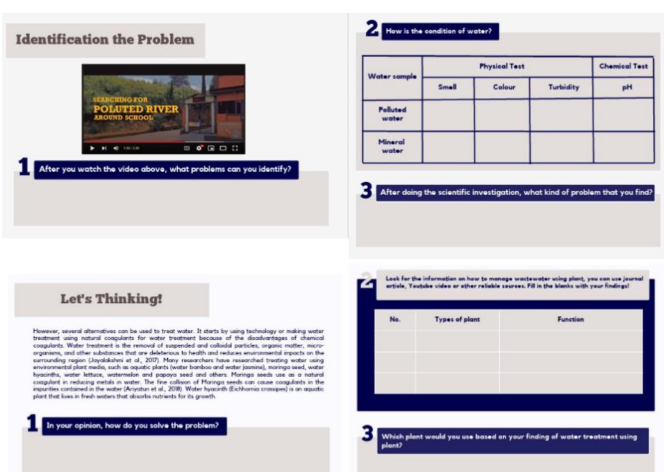

Figure 2 Questions on student's worksheet about Identification the problem thinking the solutions

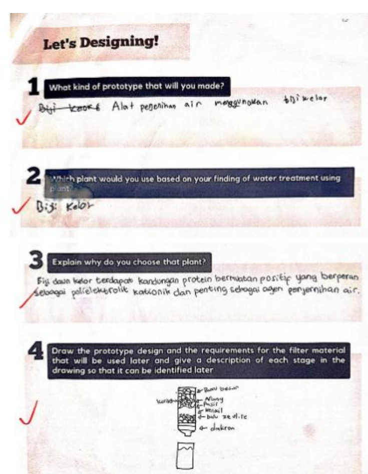

Figure 4 Answers on student's worksheet about designing the solutions

Figure 5 Questions on student's worksheet about construct and testing the solution

students were shown the physical condition of water pollution around the school environment and asked to explain what happens and why. Conceptual knowledge may assist students in identifying key features of a problem based on a deeper understanding. Students can also identify essential elements of correct procedures by contemplating whether alternative procedures are worth trying (Streveler et al., 2008).

Designing

The second indicator, modeling the system, was trained in this stage (Figure 4). The students began designing the tools and materials and selecting the plants they would use to treat the wastewater. The lesson centered around group discussions among the students. Each group had a different arrangement of tools for filtration. In systems thinking competency, students are required to provide alternative complex problem analyses that do not only focus on the problems within components but also on the connectivity between components (Hidayatno, 2016).

Constructing and Testing

At this meeting, students were asked to present and test the prototype in front of the class (Figure 5). The indicator of solving problems using system models was trained in this stage by assessing the need to use a system model to process the present problem (Schuler et al., 2018). Each group had different types of plants to treat the wastewater. As a result, four groups used Lotus flowers, moringa seeds, aloe vera, and golden photos in this activity. The following is an example of a prototype made by students in this study, as shown in Figure 6.

The first group uses lotus flowers as an alternative plant to treat wastewater, the reason is that lotus flowers can reduce algae populations and maintain oxygen intake. The lotus showed the best pollutant removal in domestic wastewater; lotus could be efficient in removing suspended solids and dominant for phosphorus removal (Kanabkaew & Puetpaiboon, 2004). The second group chose golden photos (*Epipremnum aureum*) because they increase the water's oxygen supply. Several studies confirmed the phytoremediation potential of *E. aureum* by accumulating dissolved heavy metals such as lead, chromium, etc., and anionic contaminants such as chloride, fluoride, and sulfate in different plant parts. *E. aureum* proved its nutrient

Figure 6 Students testing and explain the prototype that they have made

removal capabilities from domestic wastewater and greywater (Yadav et al., 2021). Meanwhile, the other 2 groups use aloe vera and moringa seeds as the natural coagulants for treating the wastewater. Based on the student's group discussion, moringa seed contains positively charged protein, which acts as a polyelectrolyte and is essential as a water purification agent. The fine collision of Moringa seeds can cause clots (coagulants) to form in the impurities in the water (Ariyatun et al., 2018). The last group uses aloe vera since it is a plant that can be found and harvested; aloe vera can also be used as a natural coagulant. Aloe vera can decrease the turbidity of wastewater since it contains complex carbohydrates, sugars, and mucilages, which can bind particles in water (January et al., 2021). After making the natural coagulant, the next step is to put it into a filtering container.

The filter materials that they used were almost the same for each group. Using gravel, sand, charcoal, stone, dacron, and zeolite. The differences are the arrangement of the materials and the plant. The researcher allows the student to express their ideas during the learning activities. Analysis of case studies in systems thinking should direct the students in exploring the thinking patterns and how deeply they evaluate the course of decision-making (Hidayatno, 2016)

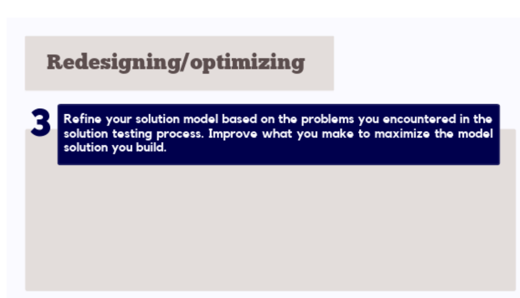

Figure 7 Questions on student's worksheet about redesigning the prototype

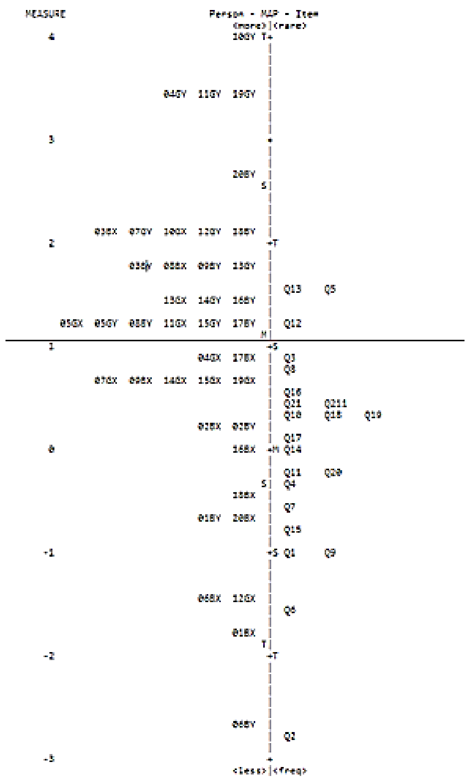

Figure 8 Wright Map of System Thinking Competency

Redesign

At the last stages: redesigning or optimizing (Figure 7). This stage also trained the last indicator of system thinking, which is the evaluation of system models. Through the redesigning process, students will know which prototype is the most effective for dealing with water pollution problems. Then, the students analyze the problem they encountered during the prototype testing based on the suggestions and comments from the teacher and friends. The group that succeeded in treating the wastewater was the Moringa seed group. They can produce clear water after finishing all procedures.

Meanwhile, the rest of the group needed to refine their prototype again. The lotus flower group did not get clear water because they did not wash the plants properly, so there was still soil on the plants, which made the water even dirtier. The *Epipremnum aureum* group also received a similar evaluation. They did not clean the gravel properly, which caused the dirt on the gravel to cloud the water. The aloe vera group obtained water using natural coagulants, which were almost transparent. However, the water became cloudy when it was continued in the filtration process because the material was not washed optimally.

The instrument used to measure students' system thinking competency in this study was a test item. Figure 8 shows the wright map of students' pre-test and post-test.

The Wright map in Figure 8 shows the pre-test (X) and post-test (Y) results of students with system thinking competency. The mean logit score in this test is 1.09.

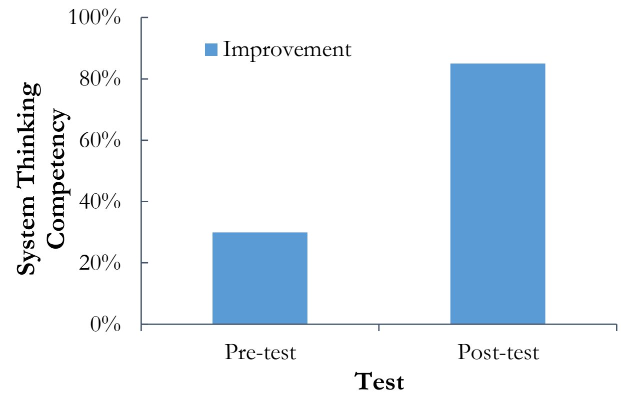

Figure 9 Percentage of students' system thinking pre-test and post-test

During the pre-test, only six students got a mean logit score of only 30 percent. However, during the post-test, it increased to 85 percent. As many as 17 students experienced an increase in logit scores during the post-test. The logit scores increase exceeds the average and even reaches 4.66 logit scores. There is a percentage showing improvement in students' pre-test and post-test.

Figure 9 shows that the average logit score of the post-test is more than the pre-test items. Seventy-five percent of students in grade 7 have increased their system thinking competency after doing the water treatment project. A total of 15 students experienced an increase in the post-test. There is a mean difference between the pre-test and post-test, which shows that the students given the treatment

Table 3 Logit score of students' pre-test and post-test

No	Student	Pre-test X (Logit)	Post-test Y (Logit)	The difference *Pre-Posttest* (Logit)
01	B	-1.76	-0.63	1.13
02	B	0.25	0.25	0.00
03	B	2.14	1.76	-0.38
04	G	0.93	3.40	2.47
05	G	1.18	1.18	0.00
06	B	-1.43	-2.71	-1.28
07	G	0.69	2.14	1.45
08	B	1.76	1.18	-0.58
09	B	0.69	1.76	1.07
10	G	2.14	4.66	2.52
11	G	1.18	3.40	2.22
12	G	-1.43	2.14	3.57
13	G	1.45	1.76	0.31
14	G	0.69	1.45	0.76
15	G	0.69	1.18	0.49
16	B	0.04	1.45	1.41
17	B	0.93	1.18	0.25
18	B	-0.40	2.14	2.54
19	G	0.69	3.40	2.71
20	B	-0.63	2.63	3.26
Mean			1.09	
SD			1.46	

Table 4 The scalogram post-test

Student	Number of questions																					
	2	6	1	9	15	7	4	11	20	14	17	10	18	19	21	22	16	8	3	12	5	13
02BY	1	0	1	1	0	1	1	0	1	1	0	1	0	1	0	0	1	1	0	0	1	0
05GY	1	1	0	1	1	0	0	1	1	0	1	0	1	1	1	1	1	1	1	0	0	1
06BY	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
09BY	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0
15GY	1	1	0	1	1	0	1	0	1	1	1	0	1	1	1	1	1	1	1	0	0	1

mostly have the ability of system thinking in understanding environmental pollution topics, which has increased compared to before. Another 10 percent of students show consistency in the logit score during the post-test. The logit scores of those two students were the same as the previous pre-test. Moreover, 15 percent or three students experienced a decrease in logit scores during the post-test (Table 3).

Furthermore, the starting point for determining student abilities is from the average logit person scores; this test's average average score is 1.09. A high logit score indicates the ability to solve high questions. This corresponds to the total score column. Students with high system thinking competency were 10GY with a logit score of 4.66, while students with low system thinking competency were 06BY with a logit value of -1.28

The MNSQ and PT MEASURE CORR outfit scores of students 02BY, 05GY, 06BY, 09BY, and 15GY do not meet the criteria, so they are classified as having an unfit response pattern and will be examined further through scalograms (Table 4).

Student 02BY has a logit score of 0.25, which is included in the students with low ability category. It can be seen from the Scalogram that students can answer 16 and 8 correctly. The logit score of these two questions is 0.58 and 0.72. Both of these questions have a higher logit score than the logit ability of students. 02BY also could not answer the easy questions, which is number 6 with a logit score of -1.53. In answering questions number 16 and 8, there was a lucky guess, while in answering question number 6, there was carelessness. This causes the response patterns of 02BY students to be unfit or not ideal.

Student 05GY has a score of 1.18 logit, which is included in the category of average-ability students. In the Scalogram, 05GY cannot answer questions 1, 14, and 10, where the item has a lower logit score compared to the logit ability of 05GY students, namely -0.99, -0.02, and 0.29. Questions 1, 14, and 10 should have been answered correctly by students 05GY. This identified that in answering questions number 1, 14, and 10, there was carelessness in answering the item items. This is what causes the response patterns of students 05GY to be unfit or not ideal.

Students 06BY has a score of -2.71 logit, which is included in the category of students with low abilities. It can be seen from the Scalogram that 06BY students can answer questions 20 and 21 correctly. Both of these questions have a higher logit score than the logit ability of student 06BY. The logit score of these two questions is -0.19 and 0.44. However, 06BY could not answer the most straightforward question, namely question number 2 which had a logit value of -2.79. There were lucky guesses in answering questions 20 and 21, while in answering question 2, there was carelessness. This is what causes the response patterns of 06BY students to be unfit or not ideal.

Meanwhile, students 09BY have a score of +1.76 logit which is included in the category of average-ability students. It can be seen from the Scalogram that 09BY students cannot answer questions 4, 11, 20, and 13 correctly, where the item has a lower logit score compared to the logit ability of 09BY students, namely -0.37, -.19, -0.19, and 1.54. Questions 4, 11, 20, and 13 should have been answered correctly by students 09BY. This identified that in answering questions 4, 11, 20, and 13, there was carelessness in answering the item items. This is what causes the response patterns of students 09BY to be unfit or not ideal.

The logit score of students 15GY is 1.18, included in the average-ability students category. In the Scalogram, student 15GY cannot correctly answer questions 1, 7, and 14, where the item has a lower logit score than the student's. The logit scores of the items are -0.99, -0.56, and -0.02. The questions should have been answered correctly by the student. This identified that the student was careless in answering items 1, 7, and 14. This causes the response of 15GY to be unfit or not ideal.

4. CONCLUSION

The implementation of water treatment using plant modification has a positive impact on students' system thinking competency. This competency was developed throughout all stages of the learning process. The Wilcoxon test result indicates a significant difference after students completed all the learning activities. Of the students, 3 experienced a decrease in mean rank, 2 had the same value, and 13 exhibited an increase in mean rank from the pre-test to the post-test. This aligns with Rasch's analysis, where 15 students demonstrated an increase in logit score in system thinking competency, representing a 50% improvement based on the Rasch analysis.

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