



Measuring changes of students' problem-solving skills for citizen science projects that integrated in ecology courses: Stacking analysis techniques in Rasch model

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Abstract

Authentic and practice-based learning approaches to develop students' problem-solving skills in the context of complex environmental problems are needed. This study aims to measure how students' problem-solving skills have changed through Citizen Science Project that integrated in ecology courses using stacking analysis techniques in the Rasch model. The method in this research used a descriptive quantitative approach by comparing the level of change in problem solving skills after the intervention of learning activities with citizen science projects through pre-test and post-test. There were thirty students participating in total. The results of the Rasch analysis show that the average problem-solving skills score is 0.73, with a Cronbach Alpha value of 0.97, person reliability of 0.97, and item reliability of 0.88. These values show very good interaction between students and question items, as well as very good consistency in student answers. Logit item measures of changes in students' problem-solving skills show that almost students experienced an increase in their ability to understand component of the questions construction. Students in this research were able to sharpen their problem-solving skills through the citizen science projects they completed.

Abstrak. Pendekatan pembelajaran yang autentik dan berbasis praktik untuk mengembangkan keterampilan pemecahan masalah mahasiswa dalam konteks permasalahan lingkungan yang kompleks diperlukan. Penelitian ini bertujuan untuk mengukur bagaimana perubahan kemampuan pemecahan masalah mahasiswa melalui proyek citizen science yang diintegrasikan dalam mata kuliah ekologi dengan menggunakan teknik analisis stacking dalam model Rasch. Metode dalam penelitian ini menggunakan pendekatan deskriptif kuantitatif dengan membandingkan tingkat perubahan keterampilan pemecahan masalah setelah diberikan intervensi kegiatan pembelajaran dengan proyek citizen science melalui pre-test dan post-test. Total ada tiga puluh mahasiswa yang berpartisipasi. Hasil analisis Rasch menunjukkan rata-rata skor kemampuan mahasiswa sebesar 0,73, dengan nilai Cronbach Alpha sebesar 0,97, person reliabilitas sebesar 0,97, dan reliabilitas item sebesar 0,88. Nilai-nilai tersebut menunjukkan interaksi yang sangat baik antara mahasiswa dengan item soal, serta konsistensi jawaban mahasiswa yang sangat baik. Proyek citizen science yang dilakukan oleh mahasiswa dalam penelitian ini efektif dalam meningkatkan kemampuan pemecahan masalah mereka.

A. Introduction

Citizen science projects integrated into ecology courses for biology education students provide a unique platform to apply theories recognized in the classroom to real-life situations. The integration of the Citizen Science Project into teaching ecology in the context of environmental pollution allows students to be directly involved in efforts to reduce the impact of environmental degradation. Through the project activities, students not only position themselves as observers, but also as active actors in environmental conservation and rehabilitation efforts (MacPhail & Colla, 2020). The projects undertaken by students offer the opportunity to apply ecological research methodologies in assessing and addressing critical environmental issues. The hands-on experience in implementing the project is particularly valuable, as it allows students to understand the complexity and dynamics of the affected ecosystem. The experience assists them in developing systematic thinking and the ability to integrate different scientific and social aspects in finding solutions (Roche et al., 2020). For example, analysing the data they have collected not only aids in mapping pollution levels, but also in designing interventions by finding solutions to problems that can be used to reduce or even eliminate the negative impacts of waste entering the environment.

Ecological studies in the context of ecosystems, consider gold mining activities as one of the contributors that may affect the balance of river, land, and forest ecosystems. Gold mining activities remove vegetation and natural habitats of animals around the mining area through land clearing, exploration, and excavation, as well as waste disposal that causes pollution to the environment. Under these circumstances, gold mining waste pollution is one of the most serious environmental problems, especially in areas with gold mining activities. The waste often pollutes rivers that serve as water sources for local communities. Mining processes that do not follow good standards can produce toxic waste such as mercury and cyanide, which are very harmful to river ecosystems (Song et al., 2019). Mercury, for example, is highly toxic and can accumulate in the food chain, potential causing neurological damage in humans and animals. In addition, excessive waste deposits can also alter the morphology of the river, resulting in erosion, flooding and loss of habitat for local flora and fauna (Staniszewska et al., 2023). The impacts on local communities are also significant, ranging from a reduction in water quality that impacts health (Mashifana, 2022), to a decrease in fish catches that many rely on as a source of protein. Contaminated soil quality also hampers agricultural practices, reducing soil fertility and agricultural productivity, which in turn impacts the local economy (Kimáková et al., 2019). Therefore, pollution from gold mining waste is not only an environmental issue but also a social and

economic issue that requires serious attention and collaboration between various parties to address.

Engaging students in citizen science projects that focus on gold mine effluent pollution in watersheds provides valuable practical experience. The presence of heavy metal pollution from gold mining activities and agricultural run-off, as revealed by Mandeng et al. (2019), indicates the presence of heavy metal contamination in certain areas. This pollution highlights the importance of evaluating and addressing the impacts of such pollution. Student involvement in citizen science projects shows that various projects, especially in the field of education, can encourage the improvement of students' skills (Mitchell et al., 2017; C. Phillips et al., 2018; Ryan et al., 2018).

Citizen science projects serve an important role in honing students' problem-solving skills, especially in addressing the problem of gold mine waste pollution in watersheds. In the context of this research, the main problem identified was the lack of practical skills of students in analysing and responding effectively to complex and dynamic environmental issues (Stylinski et al., 2020). Through participation in citizen science projects, students are given the opportunity to apply theories learnt in class to real-life situations, allowing them to develop the critical thinking and analytical skills needed to identify, analyse and formulate solutions to problems. In certain situations, stimulus for problem solving may also occur through reading, questioning, and answering (Trisianawati & Manisa, 2023). This process allows for an introduction to understanding the concepts to be explored as a basis for obtaining answers or solutions that can be used to address problems encountered in the community.

Exploring understanding of gold mine waste as a source of pollution to river ecosystems and sources that influence public health provides an opportunity for the education sector to broaden students' insights and enhance skills that can help solve problems. For example, Chetty et al. (2021) discuss transport and accumulation of pollutants in watersheds, emphasizing the importance of identifying pollution sources such as mine dumps to effectively mitigate environmental impacts. In the context of mine pollution, Byrne et al. (2021) highlighted the challenges of identifying and prioritizing pollution sources in watersheds due to their complexity. Understanding these pollution sources is critical to implementing targeted problem-solving strategies. This information can be used as a reference to construct relevant lessons to generate problem solving strategies to address the problem. On the other hand, research by (T. Phillips et al., 2018) showed that Citizen Science Project can improve students' problem-solving skills. They emphasised that facing challenges in these projects can lead to

improved skills. Furthermore, Adamou et al. (2021) in his literature analysis results revealed that various environmental-based citizen science projects currently do not support the improvement of problem solving skills, so it is necessary for citizen science projects to accommodate the growth of these skills. According to Jørgensen & Jørgensen, (2021), involvement in environment-based Citizen Science Project activities can foster environmental awareness including problem-solving skills, if the Citizen Science Project initiative is deliberately designed to achieve these skills. Hence, their studies have relevance to the context of this research. Where the Citizen Science Project implemented by students with 6 stages that have been prepared, focusing on gold mine waste pollution to provide a real challenge for students to overcome the problems faced, and then to exercise their problem solving skills (Susbiyanto et al., 2024).

Although there are several studies that demonstrate the importance of student engagement in citizen science projects and their impact on problem-solving skills, there is still a gap in the literature regarding the most effective methods to measure the development of problem-solving skills in the context of citizen science projects focused on environmental conservation. Various studies that emphasize the improvement of problem-solving skills through their involvement in citizen science projects include research that reveals that the implementation of citizen science projects in the classroom is a good way to instill awareness, critical thinking, problem solving, and practical experience in students (Shah & Martinez, 2016). Other research on participant engagement in citizen science projects through scientific discourse, where the development of scientific discourse was able to facilitate deeper learning in the context of problem solving (Huang et al., 2018). Meanwhile, another study revealed that citizen science projects build students' problem-solving capacity, which is essential for society because it is directly related to the relevant social context of their time (Turrini et al., 2018).

Currently, there are not many studies that specifically use the stacking analysis techniques in the Rasch model used to evaluate changes in students' problem-solving skills specifically in citizen science projects. The stacking analysis techniques in the Rasch model have great potential to provide deeper and more accurate (Laliyo et al., 2022) especially in relation by information about changes in students' problem solving abilities. The stacking analysis technique allows combining data from multiple sources, and then provides a more comprehensive yet in-depth picture of students' skill development. As such, the use of these techniques not only improves the accuracy and reliability of measurement, but also helps in identifying factors that influence students' problem-solving skills more precisely. The implementation of stacking techniques in citizen

science projects encourages better insights into the effectiveness of educational interventions and supports the development of better programs to improve students' problem-solving skills in real-world contexts.

Similar to the statement made by Saunders et al. (2018) that citizen science projects provide an important authentic context in the development of science process skills where hands-on experiences in real contexts may improve students' problem-solving skills. Yet, assessment of skill development in citizen science projects can be complex, as highlighted by Becker-Klein et al. (2016). They propose the use of integrated assessment as an effective method of measuring participants' skill improvement, where it contributes to understanding the impact of citizen science projects on students' problem-solving abilities. Therefore, this article attempts to use stacking as an approach to facilitate the analysis of integrated assessment results with the aim of improving the accuracy of assessment results. Through combining and analyzing assessment data, this technique can provide more in-depth and comprehensive information about students' abilities, especially in measuring changes in students' problem-solving skills in a Citizen Science Project focusing on gold mine waste pollution in the watershed. In addition, the data obtained also can be used to support the development of a more effective and targeted citizen science project-based ecology learning program. Furthermore, this research also strives to fill the literature gap on the evaluation of citizen science project-based ecological learning by providing a specific method used to measure problem-solving skills. Whereas, the scope of the study includes a Citizen Science Project focusing on gold mine waste pollution in the watershed, which emphasizes on evaluating changes in students' problem-solving skills.

B. Material and method

Measurement in this study uses a quantitative descriptive approach by comparing the level of change in problem-solving skills after intervention through Citizen Science Project learning activities on gold mine waste pollution in watersheds issue. The learning process was carried out for four meetings and at the end of the learning process a test was conducted to obtain data on the results of intervention and measurement. The participants involved in this research were 5th-semester students who were taking Ecology courses at the Biology Education Study Program at Merangin University in Jambi Province.

The change in problem-solving ability in this measurement was analyzed from the student's skills section. The analysis technique used was the stacking technique in the Rasch model. As a standard technique, stacking was introduced by Benjamin

Wright to measure the extent to which students' abilities and items changed before and after the intervention (Anselmi et al., 2015). Measurement of students' abilities is done by identifying students' problem solving skills that experience specific changes in response to the learning intervention (Laliyo et al., 2022). This in-depth information is very helpful for educational researchers and practitioners, especially in evaluating the weaknesses of applied pedagogical innovations and designing learning strategies that meet students' needs in learning.

The instrument used to measure problem-solving ability is done through a case study by raising a problem about river pollution that directs students to provide answers through predetermined problem-solving stages. These stages are an elaboration of the Problem-Solving Learning Environment (PSLE) stages developed by David H. Jonassen, and the problem-solving stages of the Groupe d'éducation et d'écovigilance de l'eau (G3E), as well as John Dewey's problem-solving stages (Dewey, 1910; G3E, 2016; Jonassen, 2010). The stages include: a) understanding the subject matter, b) understanding the root of the problem, c) proposing solutions or alternative solutions, d) choosing the best solution. The stages are an adaptation of the eight stages put forth, with each subsequent stage being a component of the real-world application outside of the classroom. This instrument is implemented before intervention (pre-test) and after intervention (post-test) with unchanged construction.

The instrument used to measure problem-solving skills consists of items with different case studies. The first question presents a case related to the increase in mercury concentration at one of the measurement stations, while the second question presents a case related to the expansion of unlicensed gold mining activities due to the economic needs of the people. Question three presents a case related to the identification of water quality using the pollution index method. Question four presents a case on identifying water quality from macrozoobenthos diversity, and question five presents a case on conflict between indigenous communities and gold miners. Meanwhile, measurement data before and after the test is still in the form of ordinal data, therefore the data analysis in this study utilized WINSTEPS software version 5.2.4.0 to convert ordinal data into interval data in order to have the same logit scale.

Rasch analysis was chosen based on its ability to model the relationship between item difficulty, person ability and possible responses (Bond & Fox, 2021). The result is the calibration of students' ability level and item difficulty data within the same interval. The stacking analysis technique places pre-test and post-test data vertically (Herrmann-Abell et al., 2013). The items will appear once allowing researchers to examine any changes in students after the intervention. The tests given are based on the same

items, so that changes in students' abilities during the pre and post tests can be measured (Wright, 2003). Therefore, each student was created two measures of ability, that is pre-test and post-test, as well as one measure for each item.

C. Results and discussion

Rasch analysis attributes

The important attributes of Rasch analysis in this study are the person measure, Cronbach alpha value, person reliability and item reliability values and fit statistics presented in Table 1. Person measure shows the average score of all students who work on the items given. Mean of person measure result in the study is 0.73 (> 0.0) which indicates that the average student has a good ability from the difficulty level of the questions. Cronbach's alpha value of the analysis used to identify the overall interaction between students and question items obtained a value of 0.97 (> 0.94) indicating a very good interaction both of them. Person reliability and item reliability showed the reliability of students and question items with respective values in this analysis of 0.97 and 0.88 (≥ 0.80) indicating that the consistency of answers from students was very good and the quality of question items was also good.

Table 1 Summary statistic

	Person	Item
N	30	5
Measure (logit)		
Mean	0.73	0
SD	2.31	0.64
SE	0.30	0.15
Infit MNSQ	0.99	0.98
Outfit MNSQ	0.98	0.98
Infit ZSTD	-0.06	-0.15
Outfit ZSTD	-0.04	-0.11
Reliability	0.97	0.88
Cronbach's Alpha	0.97	

Fit statistics in Rasch can identify whether the data used in this study is feasible or not. This identification can be done by looking at the INFIT and OUTFIT values (mean square and standardised values) of the person and item. Data will increasingly fit the Rasch model if the mean value on INFIT MNSQ and OUTFIT MNSQ is close to 1.0 or equal to 1.0. besides that, the data will also increasingly fit the Rasch model if the mean value on INFIT ZSTD and OUTFIT ZSTD is close to 0.0 or equal to 0.0 (Sumintono & Widhiarso, 2014). Normally, outfit is more sensitive to extreme responses than infit (Juandi et al., 2023). The results of the analysis in this study show the mean value on INFIT MNSQ and OUTFIT MNSQ is close to 1.0 and the mean value on INFIT ZSTD and OUTFIT ZSTD is close to 0.0. These results indicate that the data in this study are in the acceptable category with the Rasch statistical model.

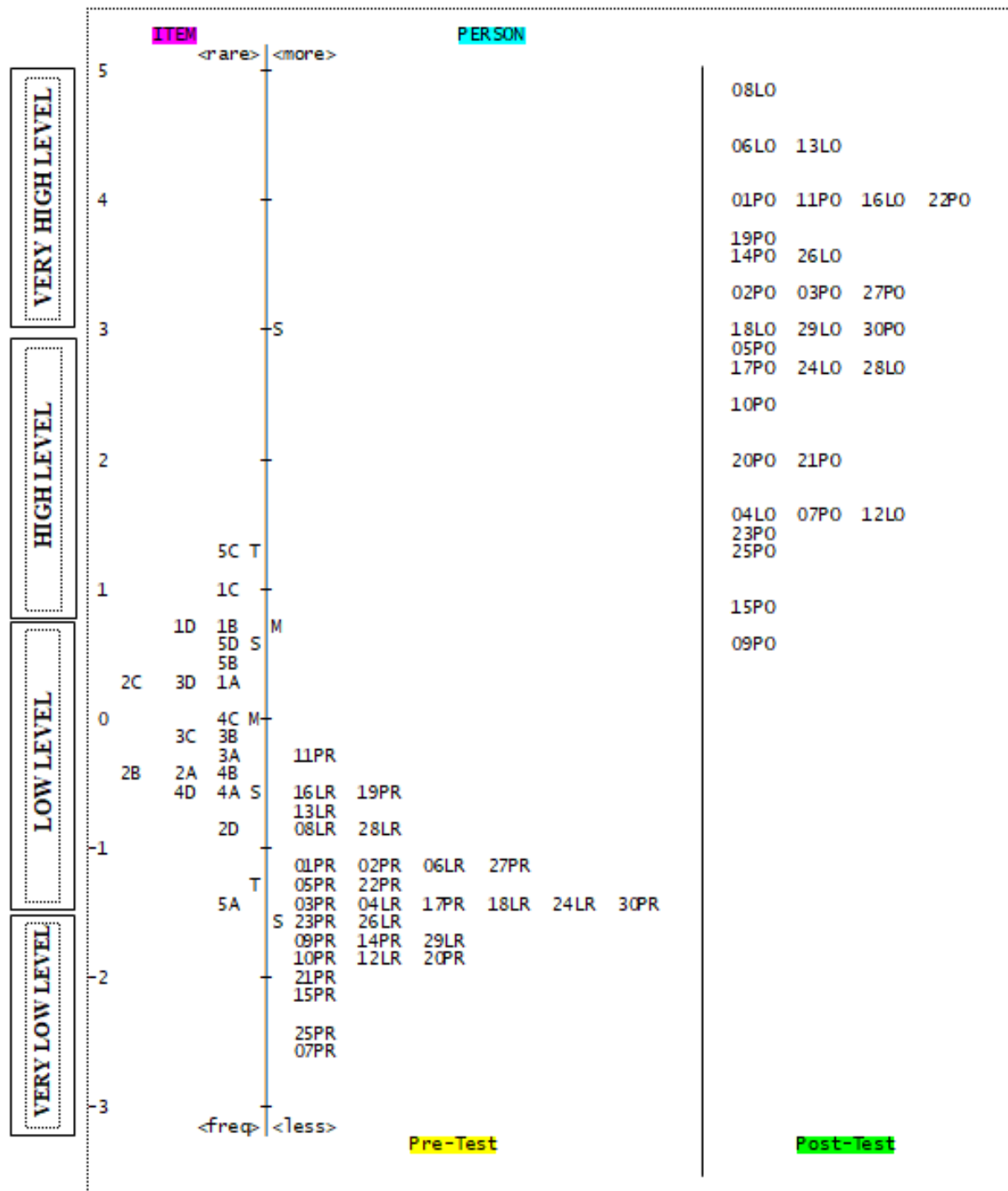


Figure 1
Wright Map stacking analysis of students' problem-solving skills

Description:

- The number on the person side is the order of the student
- P or L indicates gender. P = Female, L = Male
- The number on the item side is the order of the questions
- A, B, C, D after the item order is the order of the problem-solving stages
- R and O at the end of the item, Symbol R for Pretest and O for Post-test

The changes student's problem-solving skills

Measurement of changes in problem-solving skills through Citizen Science Project intervention in learning can be identified through the results of pre-

test and post-test logit assessment. The analysis results show significant positive changes in students' problem-solving skills from pre-test to post-test. The results of the analysis are presented in the form of a

distribution map called *wright map* which is displayed in Figure 1. Almost all students showed an increase in problem-solving skills in solving the cases presented in the questions. This indication shows an increase in students' ability to understand the main and root problems, then in proposing alternative solutions, and in choosing the best solution for the case presented in each question item. This improvement was found in all students' pre-test to post-test results.

The rate of each student's change can be seen in the position of the logit scale, for example, student 06L's position in the Wright map at the time of the pre-test was below logit -1, but at the time of the post-test, the value rose above +4 logit. The amount of change in the ability of students with code 06L is 5.52 logits. The logit scale on the Wright map is on the vertical axis, and the logit unit places the respondent's ability and item difficulty on the same continuous scale, usually from negative to positive values. More complete information regarding the logit value obtained by each student can be seen from the analysis output presented in Table 2.

Analysis of problems solving skill changes also refers to the Measure (LVP) results of the mean and standard deviation values. The average value of Mean on the vertical axis of the logit Wright map scale is given the symbol M, while the average value of standard deviation is given the symbol S. The average value of Standard Deviation and Mean is used as a reference to categories the ability level of students. The grouping of ability levels is determined by the dimension or distance between Standard Deviation and Mean where the distance tends to be the same between one point and another. In addition, the ability level grouping is also observed from the distribution of student logits on the Wright map. The logit distribution pattern that indicates the dominant student ability is under $+2 \times S$ and on top of $-2 \times S$, so that the classification can be determined into four categories, consisting of Very Low Level, Low Level, High Level, and Very High Level.

The resulting categorisation will assist in reading the results of the analysis of the students' ability level. In addition, based on Table 2, the amount of change in the size of the problem-solving skill level is consistent for all students, where at the pre-test the average LVP of -1.42 is in the low category and at the post-test the average value of LVP of 2.87 is in the high category. The results of the analysis of problem-solving skills show that all LVP pre-tests are negative and LVP post-tests are positive, indicating an increase in student abilities after the intervention of ecological learning based on citizen science projects. This indication provides information that students are better able to find the right solution to the case study given during the test after the intervention. An overview of the relationship between students' problem-solving skills during the pretest and posttest is shown in the percentage diagram in Figure 2.

Table 2 Data of person measures of pre-test and post-test

Person	Measure (LVP)		
	Pre-test logit value	Post-test logit values	Logit value changes
01P	-1.20	4.06	5.26
02P	-1.10	3.27	4.37
03P	-1.50	3.27	4.77
04L	-1.40	1.62	3.02
05P	-1.30	2.86	4.16
06P	-1.10	4.42	5.52
07P	-2.53	1.62	4.15
08L	-0.81	4.89	5.70
09P	-1.70	0.56	2.26
10P	-1.80	2.48	4.28
11P	-0.29	4.06	4.35
12L	-1.91	1.62	3.53
13L	-0.71	4.42	5.13
14P	-1.70	3.51	5.21
15P	-2.14	0.84	2.98
16L	-0.51	4.06	4.57
17P	-1.40	2.67	4.07
18L	-1.50	3.06	4.56
19P	-0.61	3.76	4.37
20P	-1.80	1.96	3.76
21P	-2.02	1.96	3.98
22P	-1.30	4.06	5.36
23P	-1.60	1.46	3.06
24L	-1.40	2.67	4.07
25P	-2.40	1.30	3.70
26L	-1.60	3.51	5.11
27P	-1.10	3.27	4.37
28L	-0.91	2.67	3.58
29L	-1.70	3.06	4.76
30P	-1.50	3.06	4.56
Mean	-1.42	2.87	4.29

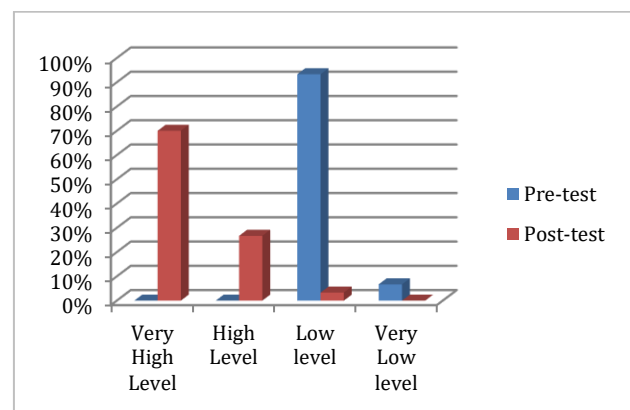


Figure 2
Percentage of students' problem-solving skill

The percentage of pre-test and post-test results indicated a significant increase in students' problem-solving skills after participating in the citizen science project-based learning programme focusing on the issue of gold mining waste pollution in rivers. Before the intervention, the majority of students, 93.3%, were in the low problem-solving skills category, while 6.7% were in the very low category. Before the

intervention, students' problem-solving skills on the issue of gold mining waste pollution in rivers, no students were in the high or very high ability category. These results showed that prior to the intervention, students' problem-solving skills related to ecological issues were relatively basic and required more in-depth strengthening of analytical and critical skills. After the intervention was given and then measured through the post-test, the change in students' solving skills was very striking, where 70% of students reached the very high level category, and 26.7% were in the high level category. Only 3.3% of students remained in the low level category, and there were no students in the very low level category.

Intervention through citizen science-based ecological learning is proven to be effective in improving students' problem-solving skills related to ecological issues because it integrates several important principles in learning theory and cognitive psychology. Project-based learning, such as citizen science, allows students to develop analytical skills through real-life experiences and reflection, both of which are important elements in addressing complex environmental problems such as river pollution due to gold mining waste (Fraisl et al., 2022; Yolcu, 2023). In this context, students are directly involved in the process of problem identification, data collection, information analysis, and development of evidence-based solutions, following the stages of problem solving (Beattie, 2019; Hong & Choi, 2015) and reinforced by Vygotsky's zone of proximal development (ZPD) approach, where learning is enriched through social interaction and collaboration (Fadeev, 2019; Svetlana Mylnikova, 2022; Vygotsky, 1962).

Furthermore, the programme emphasises metacognition, or students' awareness of their own thought processes. According to Wider & Wider, metacognition helps individuals to control and evaluate their thinking, which increases their effectiveness in solving problems (Wider & Wider, 2023). Citizen science learning encourages students to reflect on the strategies used, identify errors, and improve their approach, which contributes to the development of better and more effective solutions (Lüsse et al., 2022; Smith et al., 2021). On the other hand, the information processing theory described by Simon and Newell also plays an important role, as project-based learning provides students with the opportunity to manage complex information through data collection and analysis, which triggers a gradual critical thinking process (Lee, 2021; Newell & Simon, 2019). Through hands-on field practice as well as social collaboration and self-reflection, it strengthens the citizen science approach in learning to increase students' conceptual understanding of ecology (Fraisl et al., 2022). It also provides students with adaptive problem-solving skills that can be applied to real-life contexts (Beattie, 2019; Hong & Choi, 2015).

Unfortunately, based on the predetermined categorisation of problem-solving skill improvement, the analysis identified one student, 09P, who was still in the low-level category after the intervention. The increase in the student's problem-solving skills was only 2.3 logits and shifted from the very low category to the low category. Based on the fragment of the scalogram results displayed in Figure 3, student 09P had difficulty in mastering analytical skills, especially at the stages of problem solving with a higher level of complexity.

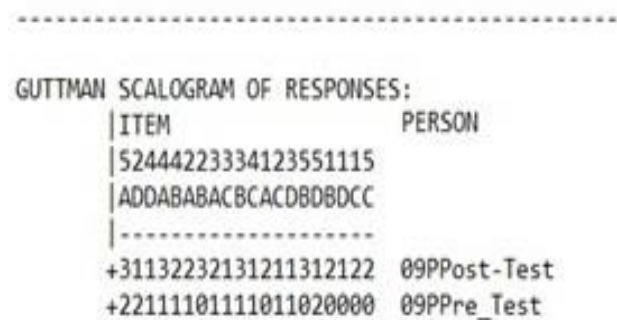


Figure 3
Scalogram of stacking analysis of problem-solving skills

The Scalogram data informs that 09P students' answer patterns are not optimal on items with codes C and D. Both parts are stages that demand high analytical skills. The Scalogram data on the post-test results showed that students faced difficulties on the high-level difficulty items, although they were successful on most of the easier basic items. This result is in line with the view of (Škėrienė & Jucevičienė, 2020), which states that analytical ability in problem solving is strongly influenced by the level of task complexity. In addition, students often struggle when faced with problems that require critical evaluation and strategic decision-making.

The problems experienced by 09P students occurred at the stages of formulating alternative solutions (stage C) and determining the best solution (stage D). This is in line with Sweller's (1988) cognitive load theory explained in Young et al.'s article that high cognitive load on complex problems can hinder information processing ability (Young et al., 2014). Students who lack adequate analytical skills often have difficulty in constructing effective solutions to complex problems that require evaluation. As a result, 09P students remain in the low ability category, due to their lack of mastery of key stages in solving more challenging problems. In addition, students with lower problem-solving skills often require additional guidance or more intensive support to understand complex concepts (Morsy & Darweesh, 2021). Without sufficient support, they might feel overwhelmed and unable to keep up with the learning pace of their peers. The results of this

diagnosis were obtained after the learning activities were completed. During the intervention, O9P students obtained the same assistance as their classmates. Hence, intensive guidance for these students was not carried out optimally. It is important to note that this research uses the pre-test data as a reference to check the students' ability level so that students who need special assistance may get more intensive guidance.

D. Conclusion

This research provides an overview of the analysis of stacking techniques in the Rasch model which was implemented to measure students' problem-solving skills in a Citizen Science Project regarding gold mining waste pollution in river watersheds. The results of the research show a significant increase in students' problem-solving skills after the project intervention. The average problem-solving skills score, identified from the person measure, shows very good interaction and consistency between students and question items. In addition, the change in logit scores from pre-test to post-test revealed an increase in students' problem-solving abilities. The analysis results from the logit measure also provide information that almost all students experienced an increase in problem solving skills where these skills refer to skills in understanding the main problem, identifying the root of the problem, proposing alternative solutions, and choosing the best solution. Analysis of the level of difficulty of the question items shows that the items become easier for students to answer after the intervention

The results of this analysis indicate that this Citizen Science Project has proven effective in improving students' problem-solving skills. Participation in this project provides practical experience that helps students apply the theory learned in class to real situations, improving their analytical and critical thinking skills. Direct interaction with real environmental problems, such as gold mining waste pollution, strengthens students' understanding of environmental impacts and the importance of science-based solutions.

Overall, participation in citizen science projects also has long-term positive impacts on students' academic, social, and cognitive skills. This project not only improves scientific literacy but also develops important skills such as observation, experimentation, and inference. The success of this project emphasizes the importance of a project-based learning approach in science education to educate students to be more adaptive in facing real problems. These results support broader implementation of this learning approach in higher education curricula to produce graduates who are better prepared to face environmental and social challenges.

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