

Enhancing decision-making skills through geoscience education for sustainable development

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ABSTRACT

Sustainable development (SD) can be achieved through education. The goal of incorporating SD principles into education is to enhance both the present and future quality of human life. This study analyzes learning effectiveness by developing education for sustainable development (ESD) based inquiry to improve students' decision-making skills. Specifically, this study aimed to explore ESD-based inquiry learning tools, analyze student decision-making skills, and analyze student responses to ESD-based inquiry learning tools. The development research used is a 4D model (define, design, develop, and disseminate) and a one-group pre-test-posttest design. Validation sheets, tests, and questionnaires are employed as data-gathering tools. Data analysis using percentage, mean, n-gain, and paired sample t-test techniques. The results showed the following: i) ESD-based inquiry learning tools developed according to the assessment of experts and practitioners are in the valid and reliable category in terms of both construction and substance; ii) the ESD-based inquiry learning is effective in improving students' decision-making skills with an average gain (gain score) in the high category; and iii) the student's response to each learning process using ESD-based inquiry learning is very good and is considered more exciting and motivating. This finding contributes to educators developing various ESD-based learning materials, especially geoscience materials, to achieve quality learning.

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1. INTRODUCTION

Indonesia has a long history of geological disasters that have garnered international attention. It is one of the tropical countries on the Pacific Ring of Fire, so volcanic phenomena have become an inseparable part of Indonesian people's lives [1]–[4]. These conditions certainly have both positive and negative impacts. The positive effect of the above conditions is that Indonesia has fertile soil. On the other hand, volcano eruptions can also cause extraordinary disasters. They can devastate economic, social, and environmental sectors [5]. In addition to adversely impacting the economy, geological disasters also trigger psychological trauma for the surrounding community. One of the factors attributed to the high number of disaster fatalities is the community's lack of awareness and expertise in disaster risk reduction. The ability to significantly reduce disaster risk benefits the community's ability to protect its people and economic resources [6], [7]. Building preparedness, vigilance, and awareness to minimize disaster risk are closely related to decision-making skills [8].

Making decisions entails considering and selecting several choices. Decision-making skills are essential in everyday problem-solving [9], [10]. As a result, decision-making skills are one of the soft skills students must have to make the best decisions about volcanic disasters, as Indonesia's conditions are inextricably linked to volcanic phenomena [11]. However, the number of physics students making decisions remains low. This can be seen in the behavior of those who frequently struggle to find solutions when given a case in lectures. Many of them are still undecided about which solution to pursue. They sometimes make snap decisions without giving them much thought. During studies, students are frequently required to make decisions [12], especially during geoscience courses. In line with research by Anggrayni *et al.* [13], students have not been able to visually analyze the parameters of volcanic activity and make decisions regarding the problems presented. Another reality is that the study of geoscience does not aid in developing geoscience knowledge and skills predominated by theoretical studies and does not emphasize attempts to prepare students for disasters, particularly volcanic eruptions [1]. It was discovered in a different research by Pujianto *et al.* [4] that teachers found it challenging to assess their students' preparedness for disasters.

Based on various considerations and efforts to transform vulnerable communities into earth disaster-resistant communities, it is necessary to study geosciences that can equip physics education students by incorporating sustainable geoscience competencies. Anggrayni *et al.* [13] stated that teaching science learning to students is critical, but school knowledge still tends to be theoretical and does not lead to continuous learning. Therefore, it is crucial to train prospective science teachers (especially physics teachers) to understand the concepts related to volcanology, the skills required to make rational decisions, and how to solve the earth's problems and disasters, namely, good quality geoscience learning. Education for sustainable development (ESD)-based learning is a very appropriate learning method. The basic idea behind ESD is to provide students with long-term competence through a holistic, interdisciplinary approach to content and to employ democratic learning strategies centered on student diversity by combining environmental, social, and economic development concerns [14]. Students are expected to be able to formulate problems, analyze them, think critically, and make sound decisions as a result of the ESD program, which is integrated with geoscience materials [15], [16].

Several researches on inquiry learning and decision-making has been carried out by previous researchers, such as Purkayastha *et al.* [17] related to comparing inquiry lab and guided inquiry learning models' efficacy in enhancing students' higher-order thinking abilities; Iskandar *et al.* [18] regarding the power of the guided inquiry learning model assisted by Edmodo to promote critical thinking skills; Ong *et al.* [19] regarding the 5E inquiry learning model's impact on Malaysian pupils' understanding of electricity; Elcokany *et al.* [20] regarding using computer-based scenarios for clinical teaching; Research by Yurtseven *et al.* [21] regarding the analysis of the relationships between primary school students' decision making and problem-solving skills. Lastly, research by Muhaimin *et al.* [22], namely research-integrated comprehensive online educational resources (RICOSRE), improving students' decision-making skills through online platform. Therefore, researchers can research integrating ESD into learning to improve decision-making skills.

The urgency of this research is the lack of student environmental awareness and a good disaster mitigation spirit in making decisions on earthly issues. This research is expected to produce ESD-based learning tools that can train understanding of the concept of volcanology and decision-making skills in dealing with issues from various kinds of earthly problems related to the concept of volcanoes or volcanology both now and in the future to produce graduates who are environmentally sound and have a good soul in disaster mitigation. Thus, this study analyzes learning effectiveness by developing ESD-based inquiry to improve students' decision-making skills. Specifically, this study aimed to explore ESD-based inquiry learning tools, analyze student decision-making skills, and analyze student responses to ESD-based inquiry learning tools.

2. RESEARCH METHOD

2.1. Research design

This study aims to determine the effectiveness of ESD-based geoscience learning tools in improving students' decision-making skills. This type of research is development research with a 4D development model (define, design, develop, and disseminate). The experimental design of the learning tools was carried out using a one-group pre-test and post-test experimental design [23]. The flowchart in this study is presented in Figure 1.

2.2. Population and sampling

The population of this study were students of Physics at the Faculty of Mathematics and Natural Sciences, University of Surabaya, Indonesia with a sample of 32 students. This small sample study may not be able to represent variation in generalizability or applicability to a wider population [24] due to limitations

of statistical analysis [25]. But researchers can pay more attention to each data collected, and monitor closely so that the data obtained is accurate and of high quality [26], [27]. In addition, researchers can also more easily identify and overcome potential biases or errors in data collection. Before implementing ESD-based learning tools, students are given decision-making test questions related to volcanology material, including volcanoes, volcanic eruptions, and fire disaster mitigation. Students were given a test due to ESD-based learning at the second and third meetings. Then at the last meeting, a test was given due to ESD-based learning. The test questions used are the same as the questions before being given ESD-based learning.

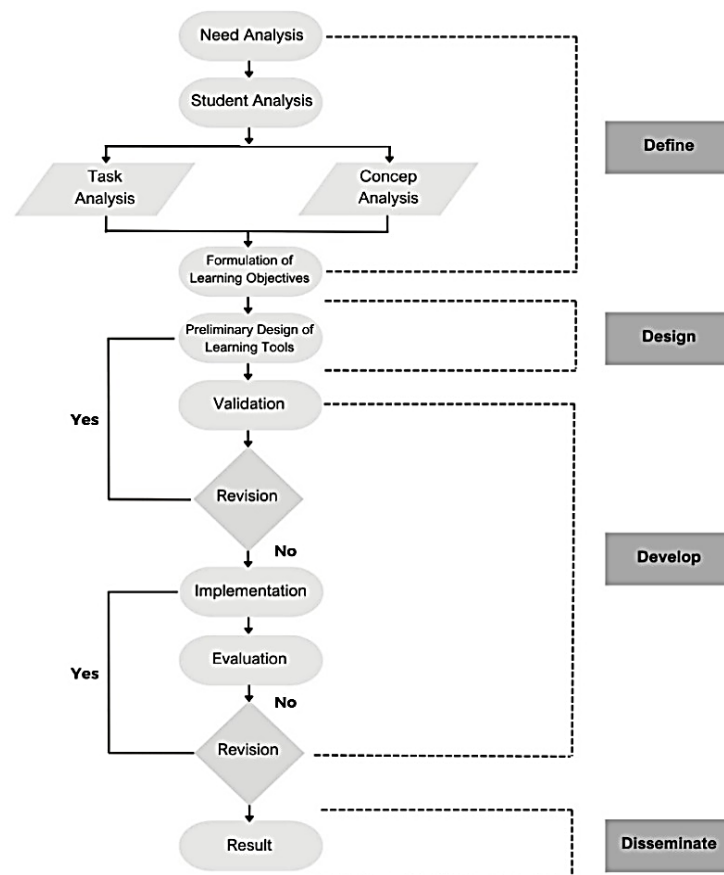


Figure 1. Flowchart of research

2.3. Data collection

The process of collecting data in this study is observation, giving tests, and questionnaires. Observations were made to obtain data on the implementation of the learning process, student activities, and obstacles encountered during the learning process. Observations were carried out by two observers whose job was to make observations while the teacher was implementing ESD-based learning. Tests were given to determine students' decision-making skills. The tests given are pre-test and post-test regarding decision-making skills. The aim is to determine the increase in students' abilities before and after ESD-based learning in geoscience material. Before the research is conducted, the researcher first prepares teaching tools or instruments [28], which include the following components: i) semester lecture activity program plans; ii) learning implementation plans; iii) student teaching materials; iv) student worksheets; and v) decision-making skills evaluation sheet. Data were collected using test instruments of decision-making skills and student response questionnaires.

2.4. Data analysis

A physics education expert lecturer assessed the validity of the ESD-based inquiry model learning tools in terms of content and constructs to determine the feasibility of the developed learning tools. For the learning instrument to be implemented, the learning instrument must meet valid and reliable requirements. Furthermore, data analysis to determine the effectiveness of ESD-based learning tools is performed by conducting a test for decision-making skills for students, which is carried out before (pre-test) and after the

implementation of learning (post-test). The test instrument of decision-making skills is in the form of a description question with the following indicators of decision-making including i) identifying the problem; ii) compiling the information needed to make decisions; iii) identifying alternative actions; iv) considerations in making decisions; and v) making decisions.

Before analyzing the significance between the pre-test and post-test scores, a normality test was performed through the statistical package for the social sciences (SPSS) software to determine the type of inferential statistics to use. The research data will be analyzed using parametric statistics (dependent T-test) if it is normally distributed. In contrast, if the data is not normally distributed, it will be analyzed using non-parametric statistics (Wilcoxon matched test). The dependent T-test and the Wilcoxon matched test are used to determine the significance of the same test instrument applied to the same subject after a certain time limit [29], [30]. After knowing the importance between the pre-test and post-test values, the difference can be calculated with the average normalized gain using the Hake formulation [31].

$$\langle g \rangle = \frac{S_{Post} - S_{Pre}}{S_{max} - S_{Pre}} \times 100\% \quad (1)$$

Where, $\langle g \rangle$ is normalized gain, S_{Pre} is pre-test score, S_{Post} is post-test score, and S_{max} is maximum score.

The gain score is then interpreted according to the criteria Hake [31], including learning or increasing the highest gain if $n\text{-gain} \geq 0.70$, there is a moderate increase if $0.30 \leq n\text{-gain} \leq 0.70$, and an increase in a score gain of a low category is observed if $n\text{-gain} \leq 0.30$. In comparison, assessing student response questionnaires to applying the ESD-based inquiry learning model is conducted by analyzing the response data for each statement item. Meanwhile, classical student learning completeness in one class can be determined using (2).

$$CP = \frac{TSC}{TS} \times 100\% \quad (2)$$

Where, CP is completeness percentage, TSC is number of students who completed, and TS is total number of students

Response analysis was carried out to find out opinions regarding the benefits, interests, and motivation of students in learning earth sciences. The calculation of student response values can be determined using (3).

$$Response = \frac{\text{total score}}{\text{maximum score}} \times 100\% \quad (3)$$

Questionnaire response indicators include student assessments of the benefits of geoscience courses, student assessments of their interests during the implementation of geoscience courses with the ESD approach, and student assessments of student motivation in participating in the implementation of ESD-based geoscience courses.

3. RESULTS AND DISCUSSION

3.1. Validation of education for sustainable development-based inquiry learning tools

Before the research is conducted, the prepared learning tools and research instruments must meet the requirements of validity and reliability in terms of content, construct, and language. In terms of the validity of learning instruments, the ESD-based inquiry learning model and research instruments were assessed by two expert lecturers. The results of the validation assessment of ESD-based inquiry learning tools on geoscience materials by expert lecturers are presented in Table 1.

Table 1 shows that the learning tools have a minimum validity percentage of 81.25%, greater than 60%, so the learning tools are said to be valid. On the other hand, reliability is measured by the percentage of approval, which is more than 75%, so all components are reliable. Teachers can use the learning implementation plan to determine how they conduct teaching and learning activities correctly, effectively, and efficiently so that the competency standards of graduates hired can be met optimally before implementing the developed ESD-based inquiry learning tools. The effectiveness of a teaching process is inextricably linked to the learning tools employed. One of the conditions is that the learning tools must be valid to be implemented to improve students' thinking skills [32], [33]. Anggrayni *et al.* [13], [34] claimed that by providing local scientific education appropriate to a place with issues that are highly important to the community, geoscience teachers who use ESD-based learning have significantly contributed to making education universal. Environmental phenomena are raised and addressed using three ESD concepts, ecology, economy, and social-ESD learning tools. Additionally, they need to develop and design systematic and

planned teaching, implementation, assessment methods, and improvements to Indonesia's educational system to raise the caliber of physics lecturers or teachers [35], [36]. As a result, it is essential to redesign the physics education strategy that emphasizes environmental phenomena.

Table 1. Percentage of validity and reliability scores of learning tools

Components	Validity and reliability of teaching and research instruments of ESD-based inquiry learning model							
	Validity and reliability				Construct validity			
	Percentage of validity		Percentage of agreement		Percentage of validity		Percentage of agreement	
Semester teaching plan	88.28%	Valid	94.35%	Reliable	95.83%	Valid	95.24%	Reliable
Lesson plan	91.45%	Valid	93.98%	Reliable	97.50%	Valid	97.14%	Reliable
Student worksheet	84.38%	Valid	89.29%	Reliable	83.33%	Valid	90.48%	Reliable
Student teaching materials	87.50%	Valid	91.43%	Reliable	91.67%	Valid	90.48%	Reliable
Decision-making skill test	92.50%	Valid	97.14%	Reliable	91.67%	Valid	90.48%	Reliable
Teaching model implementation sheet	87.50%	Valid	85.71%	Reliable	89.58%	Valid	87.30%	Reliable
Student response sheet	81.25%	Valid	92.86%	Reliable	97.50%	Valid	97.14%	Reliable

3.2. Students' decision-making skills result

Analyzing the stages or indicators of decision-making not only provides a window into the effectiveness of ESD based inquiry learning tools but also underscores their profound impact on enhancing decision-making skills. By scrutinizing these critical elements, we gain valuable insights into how ESD-based inquiry-learning tools actively contribute to the improvement of an individual's decision-making capabilities. The inherent connection between inquiry learning and the discernible decision-making indicators is meticulously expounded upon in Table 2.

Table 2. The relationship of inquiry learning with decision-making skills indicators and learning descriptions

No.	Stages of inquiry learning	Indicators of decision-making skills	Short description of learning
1.	Orientation	- Ability to identify problems	- The teacher explains the investigation process to students by explaining "What is ESD?" and the importance of ESD.
2.	Formulating the problem	- Ability to identify problems	- The teacher gives problems about geoscience (volcanology) through sustainable development goals (SDGs). - We are finding the relationship between the problem and the volcanic concepts studied.
3.	Formulating a hypothesis	- Information needed in making decisions	- Students try to state "what they should do about the problem presented."
4.	Collecting data to test hypotheses	- Information needed in making decisions - Identify alternative actions	- Students collect data based on the given problem. Then, they analyze the relationship to the problem.
5.	Formulating conclusions	- Considerations in making decisions	- Students find conclusions based on the data. Then they can decide "what they should do about the problem." Of course, the decision is considered from various points of view.
6.	Reflecting on the problem situation and thought process used for the investigation	- Considerations in making decisions - Decision-making	- The teacher gives simple problems to reflect on and examine the volcanological concepts found. - Students explain their difficulties in learning.

After the ESD-based inquiry learning tools are considered practically and empirically valid, ESD-based inquiry learning can be implemented to determine student learning outcomes. Learning outcomes are obtained through ESD-based inquiry learning tools, namely, training decision-making skills. Learning outcomes were obtained before (pre-test), and after (post-test), the ESD-based inquiry learning tool was implemented. Figure 2 shows the results of physics students' decision-making skills during the pre-test and post-test.

The pre-test results showed that 100% of students did not complete the decision-making indicators (the criteria for completeness were at least 70). The post-test results showed that about 84% of students met the criteria for the indicators of making decisions (minimum completeness criteria 70). Therefore, it can be said that the distribution of data between pre-test and post-test scores on decision-making skills is different, where the students' post-test scores are better than their pre-test scores, which shows that applying ESD-based inquiry learning tools can improve students' decision-making skills. Studying ESD allows students to combine a variety of topics, including environmental concerns with social transformation and economic development [37], [38]. In developing ESD-based tools, it is crucial to include sustainable development (SD) concepts in learning to enhance human existence's present and future quality. Additionally, integrating local

and global challenges, conducting process- and outcome-based evaluations, and using the environment as a learning resource is essential in education [39]–[41]. Hypothesis analysis of effect-based test results must also be carried out as a parametric test of assumptions. The results of the normality test using the Kolmogorov-Smirnov are presented in Table 3.

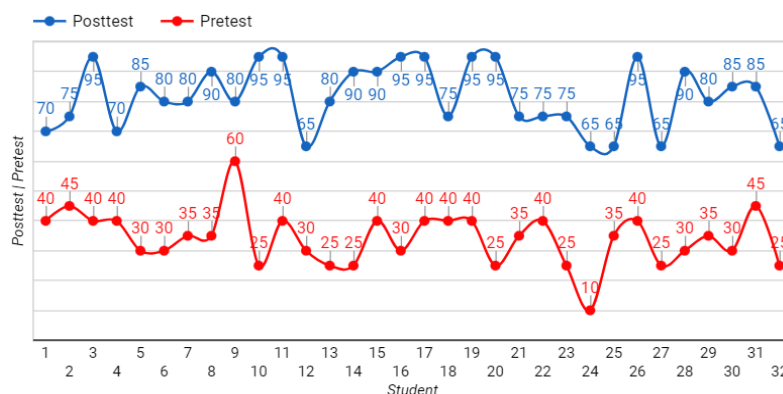


Figure 2. Student pre-test and post-test results

Table 3 shows the normality data using the Kolmogorov-Smirnov test. The table shows that the test scores for decision-making skills in the pre-test and post-test obtained an asymptotic significance value of less than 0.05. The results of the decision-making skills test in the pre-test are usually distributed, whereas the post-test scores are generally not. Because one of the test results meets the assumption test, to analyze the significance between the pre-test and post-test values, parametric statistics (T-test dependent) are used, which are presented in Table 4.

Table 3. Normality data with Kolmogorov-Smirnov test

Variable	Asymp. Sig. (2-tailed)
Decision-making skills Pretest	0.058*
Decision-making skills Posttest	0.032

Note. * $p > 0.05$.

Table 4. T-test result

Variable		Paired samples test		
		T	df	Sig. (2-tailed)
Decision-making skills	Pre-Post	-19.286	31	0.000*

Note. * $\alpha < 0.025$.

Table 4 shows a substantial influence on learning from the pre-test and post-test, with Sig. (2-tailed) < 0.05 and a difference between the two tests of 19.29. The difference between the pre-test and post-test scores can be calculated using the normalized average gain. Overall, the average n-gain of physics students' pre-test and post-test scores is high as shown in Table 2, which is > 0.70 [31]. Therefore, the ESD-based inquiry learning tool on the developed geoscience material has successfully trained or improved decision-making skills. Thus, this learning tool can realize the ESD paradigm. In this case, this tool can help students develop competence in taking action for survival in the future by having good decision-making skills.

The results are relevant to Rico *et al.* research [42], which stated that ESD competencies could influence students' awareness of SD issues, paving the way for a more sustainable future. Hsiao and Su [43] stated that SD is an inseparable part of the general education task of empowering the younger generation to design a responsible society regarding sustainable future development. Thus, ESD-based learning in schools and universities must instill sustainable living values early on. The goal is that students can maintain the sustainability of the natural, social, and cultural environment related to managing their natural resources and developing the special skills needed to decide and act.

The top 10 n-gain results of student decision-making skills from the total students are presented in Figure 3. Meanwhile, the n-gain for each indicator of decision-making skills is shown in Table 5. The top 10 ranks with the highest n-gain score of 0.93 were obtained by students with attendance numbers 10, 16, 20.

N-gain with a score of 0.92 in the high category was received by students with numbers 3, 11, 17, 19, and 26. Ranked 2nd, nine, and ten got n-gains in the high category, with scores of 0.87 and 0.86. Meanwhile, to improve decision-making skills for each indicator, it can be seen that the indicator of the ability to identify problems in making decisions shows the highest increase (n-gain). In addition, the indicators of consideration in making decisions and decision-making also increase in the high category. This indicates that students can better identify problems and consider and make decisions to solve problems. Meanwhile, the indicators for information needed in making decisions and alternative actions are in the moderate category.

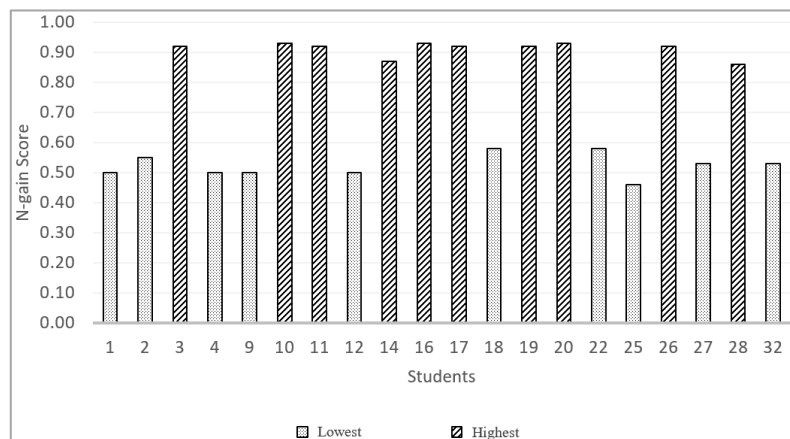


Figure 3. Top 10 highest and lowest n-gain scores

Table 5. Pre-test, post-test, and n-gain decision-making scores for each indicator

Indicators of decision-making skills	Mean score			Category
	Pre-test	Posttest	N-gain	
Ability to identify problems	1.97	3.94	0.97	High
Information needed in making decisions	0.88	2.84	0.63	Moderate
Alternative actions	1.84	2.97	0.52	Moderate
Consideration in making decisions	1.66	3.47	0.77	High
Decision-making	2.91	3.94	0.94	High

Note. $0 \leq \text{score} \leq 2$ (low category); $2 < \text{score} \leq 4$ (high category).

A high increase in the indicators was observed because students received guidance from the teacher. Then the indicators of plan implementation showed a decrease because students tend not to understand what they are making decisions about. This ESD-based inquiry learning has a positive and practical effect on improving decision-making skills. Through the development of ESD-based tools, it is hoped that students will be able to improve their quality of life for the present and future SD plan in 2030. According to earlier studies, ESD has been associated with the development of student competencies in critical thinking-based cooperation, decision-making based on problem-solving, enhanced communication abilities, teamwork, conflict resolution, and planning [44]–[46].

3.3. The students' response toward the inquiry learning model based on ESD

The students' responses toward teaching with the implemented model are analyzed by giving the student response sheet for physics students after the geoscience teaching process. This evaluation provides a valuable opportunity to gain insights into the students' perspectives, shedding light on their experiences and attitudes toward this innovative inquiry-based model. The results of the student's responses are meticulously recorded and thoughtfully presented in Table 6.

Table 6. The students' response toward the inquiry learning model based on ESD

Questionnaire indicator	Response (%)	Category
Students' assessments of the benefits of geoscience courses	88.13	Very positive
Students' assessments of their interest during the implementation of geoscience courses	87.66	Very positive
Students' assessments of their motivation in following the implementation of geoscience courses	87.66	Very positive

Table 6 shows that the student response scores are perfect indicators of benefits, interest, and motivation in ESD-based geoscience learning. Thus, it can be said that students gave an excellent positive response regarding learning using the developed ESD-based inquiry learning tool, where these tools can foster student motivation and interest in studying geoscience material. In addition, learning using developed learning tools also provides good benefits for students. The motivation indicators in geoscience learning can describe the spirit of disaster mitigation after the learning process. Students' success in improving their disaster mitigation skills is supported by student activities, which can help students decide about the volcanic disaster phenomenon. Thus, students can become accustomed to dealing with volcanic eruptions, so they know how to act when faced with volcanic eruption disasters.

These results are consistent with Hariyono and Rosdiana research [47] on applying the science curriculum model by integrating disaster mitigation. The results indicate that students know sound disaster mitigation and response techniques regarding management. Moreover, students can describe the potential for disaster and mention what activities cause disasters in coastal areas. This shows that students can practice and learn sound disaster mitigation techniques and management through sustainable learning. Furthermore, previous researchers stated that ESD is considered a way of forming new awareness and behavior in human development through modern education that can create positive ethics toward the environment [48]–[51]. The developed learning tools can be declared effective based on the description. This result is supported by the criteria for the effectiveness of learning tools according to Newby and Cheng [52], which stated that learning tools are said to be effective if they can achieve the expected results. In this case, the desired result is that the developed learning tools can train decision-making skills and get a very good response, with an average response percentage of 87.81%.

4. CONCLUSION

The following results of this study were obtained: i) ESD-based inquiry learning tools developed according to the assessment of experts and practitioners are in the valid and reliable category in terms of both construction and substance; ii) the ESD-based inquiry learning is effective in improving students' decision-making skills with an average gain (gain score) in the high category; and iii) the student's response to each learning process using ESD-based inquiry learning is very good and is considered more exciting and motivating. Based on these conclusions and findings, applying other learning models to be integrated with ESD is recommended. In addition, ESD-based learning tools can be used in other geoscience materials if the material is related to ESD concepts (social, ecological, and economic) by practicing other thinking skills. The ESD approach to learning is important to facilitate quality learning so that students understand the world based on their observations and develop competence in taking action for their survival in the present and the future.

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