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The Influence of Eco-STEM-based Sustainable Physics Project Learning Models to Reinforce Mitigation and Adaptation Capabilities of Climate Change Disasters

N. A. LESTARI, E. HARYONO, MADLAZIM

ABSTRACT

Introduction. The increasingly urgent climate change affects many aspects of life, including community, economy, and environment, in dealing with climate change problems, Eco-STEM (Science, Technology, Engineering, and Mathematics) based education which integrates the concept of ESD (Education for Sustainable Development) through an effective Project-based Physics Learning approach to equip students with knowledge and skills in mitigation and climate change adaptation. *This research aims* to develop and determine the consistency of the influence of an environmentally based physics learning model that has integrated project creation activities in Sustainable Education (ESD) and STEM as supporting climate action.

Research methods. The method used in this research design is Quantitative Descriptive, which aims to depict, investigate, and explain a subject as it is, and to draw conclusions from observable phenomena through the use of numerical data. This research begins by identifying the problem and designing a learning model based on the results of the analysis and using a previously tested research instrument in the form of a questionnaire. The population consisted of physics education students at the Universitas Negeri Surabaya, Indonesia, with a sample size of 87 respondents. In this study, data analysis was conducted using the Rasch model to examine the fit of each item in the statement instrument, consisting of 30 statements, with the parameters required by the Rasch model.

Research results. The analysis results indicate that the item reliability score of 0.95 suggests excellent consistency of the items in measuring mitigation and adaptation abilities. The person's reliability score of 0.86 shows that the students' measured abilities are stable and consistent. Therefore, the research results show that the STEM-ESD learning model developed is practical and influences the development of climate change mitigation and adaptation capabilities.

Conclusion. Climate change affects essential aspects of life, including disasters, food security, and water access, requiring urgent mitigation and adaptation efforts within sustainable development. STEM-focused education and ESD-integrated project learning empower the younger generation to create technology-based solutions grounded in local wisdom. Cross-sector collaboration and continuous education are vital to raising public awareness and building community resilience against climate-related challenges.

KEYWORDS

Eco-STEM, ESD, mitigation, adaptation, climate change

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INTRODUCTION

Climate change content, according to UNESCO, can be integrated into education because it is related to the environment [1]. Environmental problems arising from climate change have become crucial because they impact many aspects of life [2]. Rising global temperatures alter weather patterns, damage ecosystems, and threaten biodiversity. In addition, climate change is leading to more extreme natural disasters and the threat of extreme temperatures [3]. Agricultural productivity and clean water availability are also affected, threatening food and water security. All this results in substantial economic losses due to damaged infrastructure and reduced crop yields. At the social scale, climate change is also fuelling conflicts over limited resources and forcing some populations to migrate from vulnerable areas, creating new social and political challenges. Climate change caused by unstable weather dynamics requires preparedness to anticipate disasters [4; 5]. Addressing climate change is one of the Sustainable Development Goals (SDGs) [6; 7].

Climate Action (SDG 13) emphasizes the need for urgent action to address the impacts of climate change and build resilience to the risks posed. Before reaching implementation in the community, actions for climate are expected to be taught within the scope of education in schools [8; 9]. Implementing the *Merdeka Belajar* Curriculum facilitates the delivery of knowledge related to climate change through global warming material [10; 11].

However, especially in physics education, the relationship between physics concepts and real-world issues like climate change is often not explicitly taught [12]. Instruction on global warming typically relies on qualitative approaches, such as case studies, which offer limited opportunities for students to engage directly in climate action. As a result, this limits the development of their mitigation and adaptation attitudes [13]. Furthermore, the ability to apply knowledge through practical products remains underdeveloped [14; 15].

A promising physics learning approach that fosters the practical application of knowledge to address climate change is project-based learning [16; 17]. This method not only engages students in hands-on, real-world problem solving but also integrates the principles of Eco-STEM: an approach that emphasizes ecological awareness and the integration of local wisdom in interpreting physics phenomena. By grounding scientific concepts in the environmental and cultural context of students' communities, Eco-STEM enables learners to deeply understand the causes and effects of climate change within their immediate surroundings [18; 19]. This contextualized understanding empowers students to design science and technology-based solutions that are not only innovative but also locally relevant and sustainable [20; 21]. Through project-based learning infused with Eco-STEM values, students become active contributors to environmental resilience, blending traditional knowledge with modern scientific inquiry to tackle global challenges from the ground up [22]. Therefore, the purpose of this article is to foster real student action in the form of climate change mitigation through an environment-based physics learning model that integrates sustainable education project-making activities and STEM as climate action support.

MATERIALS AND METHODS

The research design employed is Quantitative Descriptive. Quantitative descriptive refers to statistical analysis used to describe, summarize, and analyze quantitative data. The aim of quantitative descriptive research is to depict, investigate, and explain a subject as it is, and to draw conclusions from observable phenomena through the use of numerical data [23]. The steps of the quantitative descriptive approach are interpreted through the flowchart in Figure 1.

The first step is problem identification, which involves explaining the issue and providing a measurable definition of the problem [24]. In this study, problem identification relates to climate change, a multidimensional issue that requires a holistic approach through mitigation, adaptation, and sustainable resource management. Once the problem is clearly defined, the next step is to formulate the research objective. The objective of this study is to develop mitigation and adaptation capabilities in response to climate change. To achieve this goal, the population was determined to be university students, with a sample size of 87 respondents. Based on the identified population and sample, instrument development and validation could be conducted.

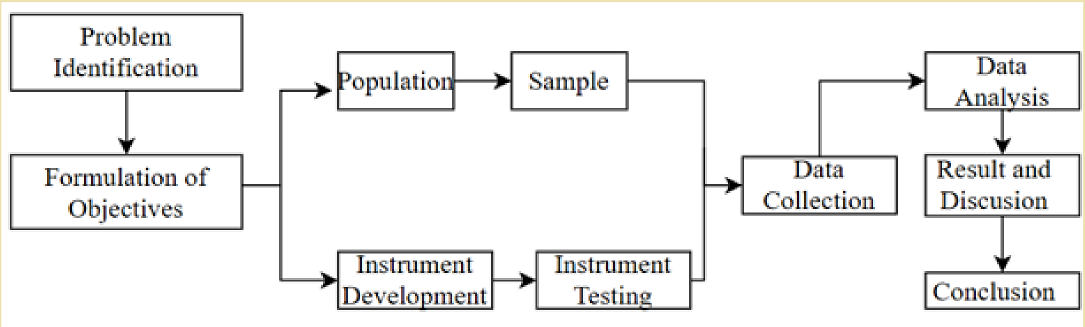

Figure 1 Quantitative Descriptive Research Design

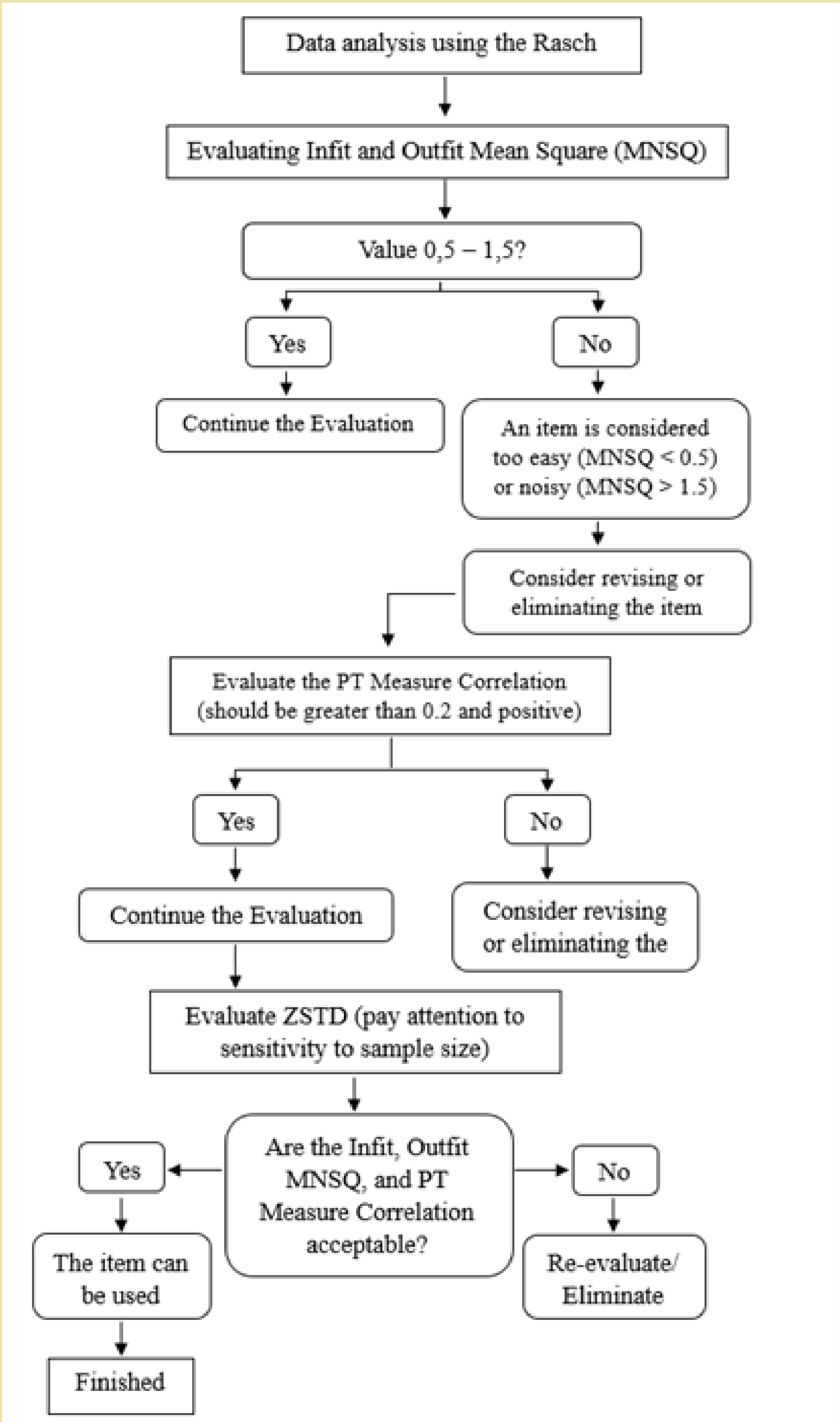

Figure 2 Rasch Model Flow Chart

A research instrument is a tool used to measure observed natural or social phenomena [25]. This study utilizes a questionnaire that has been previously tested. The subsequent stage involves data collection and analysis. The research data consists of instrument test scores and project outcomes. Data analysis refers to the systematic effort to organize notes from observations, interviews, and other sources to enhance the researcher's understanding of the studied case and present it as findings to others [26]. The analysis method applied is the Rasch model, selected for its appropriateness. The final stage of the research design is the conclusion.

In this study, data analysis was performed using the Rasch Model to determine the suitability of each item in the instrument, which consisted of 30 statements with parameters required by the Rasch Model. The analysis procedure followed the flow chart as described in Figure 2.

The data analysis process began by evaluating the Infit and Outfit Mean Square (MNSQ) values to identify items that were too easy (MNSQ < 0.5) or inappropriate (MNSQ > 1.5). Items that fall outside the tolerance limits are considered for revision or elimination. Next, the Point Measure Correlation (PT Measure), which must be positive and greater than 0.2, was evaluated. However, items that do not meet these criteria are also considered for revision or deletion. Then the evaluation continued on the Z-Standardized (ZSTD) value, taking into account the sensitivity to the sample size. Only items that meet all three main criteria are eligible for further analysis. This systematic approach of the Rasch Model ensures the validity and reliability of the instruments used in measuring the impact of the implementation of the developed learning model. The flow of the Rasch model approach is systematically explained in Figure 2.

RESULTS

Figure 3 is a Venn diagram showing the various aspects of climate change. This diagram divides climate change issues into four main interrelated categories: Environmental Impact, Living Things Activities, Disaster Risk Reduction, and Inanimate Activities. Environmental impact focuses on damage to ecosystems and biodiversity, such as climate change patterns, environmental degradation, and species extinction. Meanwhile, inanimate activities include adaptation and migration efforts by humans and wildlife due to changes in habitat conditions. By managing disaster-prone areas and disaster-resistant infrastructure, disaster risk reduction highlights the importance of minimizing the impact of increasingly extreme natural disasters, such as floods, droughts, and storms. On the other hand, inanimate activities emphasize the role of greenhouse gas emissions from fossil energy use in exacerbating global warming, making the transition to renewable energy an urgent solution. These four aspects are interrelated; for example, greenhouse gas emissions impact ecosystems, while environmental damage encourages living things to adapt and migrate. In addition, the increasing risk of disasters requires handling efforts that involve all sectors. Thus, the diagram in Figure 3 confirms that climate change is a multidimensional issue that requires a holistic approach through mitigation, adaptation, and sustainable resource management.

The survey results show that most respondents believe floods can be predicted using scientific tools and techniques. This data indicates a positive acceptance of technology and scientific methods in anticipating floods. However, further education is still needed for a minority. In addition, most respondents understand that climate change can trigger extreme weather events that cause flooding, indicating a near-universal awareness of the link between climate change and flood risk due to extreme weather events. This high level of agreement confirms the need for climate change mitigation measures to reduce the risk of future flood disasters. Adequate knowledge related to the causes of flooding in the area of residence that most already understand. However, a minority still needs to improve their understanding of the factors that cause localized flooding, such as land use change, river management, or extreme rainfall patterns. High optimism was also seen in individuals' readiness to develop disaster mitigation strategies, although some respondents felt the need for capacity building. Education and training are key to ensuring that the entire community can respond to disasters more effectively and in a planned manner. In addition, respondents were highly aware of the importance of following disaster prevention procedures, although a minority still considered them unnecessary due to trust in the annual response routine. To address this, better education on the long-term benefits of disaster prevention is needed to raise awareness of the importance of proactive preparedness. The same applies to the need for emergency medical kits as part of disaster preparedness.

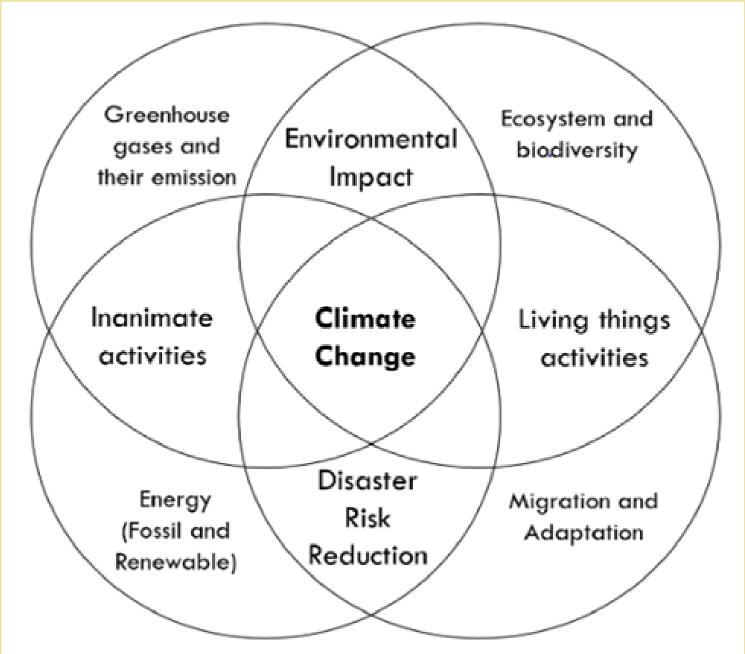

Figure 3 Content Mapping

Based on the content mapping regarding the climate change aspects above, a survey-based research has been conducted on students with the results represented in Table 1.

Table 1 Survey Results

No	Questions	Assesment				
		1	2	3	4	5
1.	Floods can be predicted using scientific tools and techniques	1	1	4	49	32
2.	Climate change can trigger extreme weather events that can cause flooding	0	0	2	47	38
3.	I can explain the reasons why floods occur in my neighborhood.	0	0	3	61	23
4.	I can organize the proper steps in disaster mitigation.	1	0	23	58	5
5.	I have a plan to prepare for disasters that may occur in my neighborhood	0	0	11	66	10
6.	I usually skip disaster prevention procedures because the countermeasures are the same every year	4	22	37	22	2
7.	I consider a first aid kit necessary to prepare in the event of a disaster	0	0	6	39	42
8.	I can help my friends do evacuation activities during the school simulation and make them understand what to do, how to help, and how to wait for the evacuation team.	0	0	5	70	12
9.	I will help check the damage to the house caused by the disaster	0	0	19	57	11
10.	I will donate items needed by people in the disaster-stricken area 10.	0	0	3	53	31
11.	I check whether there are signs of disaster in the neighborhood.	0	0	12	63	12
12.	I will pay attention to irregularities around me for the safety of myself and others.	0	0	4	67	16
13.	I will regularly check the safety of my neighborhood to reduce the impact of disasters	0	0	8	70	9
14.	I will explain to others the cause of casualties after hearing news of a disaster.	0	0	18	63	6
15.	I will remind my friends/others to prepare for floods at home before the news of flood warnings hits	0	1	6	64	16
16.	We can't predict the time and location of disasters, so we don't need to waste time on disaster preparation	13	25	24	24	1
17.	I agree that the government should first spend money on disaster rehabilitation preparation rather than disaster prevention education.	2	13	29	36	7

18.	I will invite students to discuss together how to solve problems in disaster mitigation education	0	0	0	73	14
19.	I agree that there should be information on disaster-prone areas by the government, even though it may cause house prices to fall	0	0	7	65	15
20.	I am aware of disaster shelters in schools, where people can be placed if they are affected by disasters.	0	3	23	54	7
21.	I will help plan and invite people to participate in disaster prevention promotion activities at school.	0	2	3	68	14
22.	I am not very clear about the disaster prevention and rescue plan in my neighborhood	6	21	32	26	2
23.	I identify the location of emergency exits and equipment when entering public buildings	0	1	14	62	10
24.	I understand school evacuation maps and plan proper evacuation routes	0	1	18	59	9
25.	I will participate in the planning of regular disaster prevention drills at school to help students understand evacuation routes and evacuation procedures	0	0	2	66	19
26.	I am not interested in when the school organizes disaster prevention drills repeatedly.	18	25	29	14	1
27.	While disaster prevention drills are held in my neighborhood, I will cooperate during the evacuation	1	0	3	70	13
28.	In the event of a disaster, I will protect myself and guide others to behave in a way that avoids disaster damage	1	0	4	70	12
29.	When a disaster occurs in a location other than a residential area, I can assist volunteers in helping the people affected by the disaster	0	0	3	71	13
30.	I can explain the impact on people and the environment during disasters, especially floods.	0	0	0	62	25
	Total	47	115	352	1669	427

Description: 1: Strongly disagree; 2: Disagree; 3: Neutral; 4: Agree; 5: Strongly agree

The same applies to the need for emergency medical supplies as part of disaster preparedness. In line with the survey results, further analysis of the research instrument was conducted to ensure its reliability and consistency. Reliability and separation values for both respondents and items, which illustrate the instrument's consistency and ability to differentiate student ability levels, are presented in Table 2.

Table 2 Reliability and Separation

Person	87 Input		87 Measured		Infit		Outfit	
	Total	Count	Measure	Realse	IMNSQ	ZSTD	OMNSQ	ZSTD
Mean	122.5	30.0	70.79	4.45	1.00	-0.1	0.98	-0.2
S.D.	7.3	0.0	12.05	0.77	0.60	1.9	0.67	1.9
Real RMSE	4.52	True SD	11.17	Separation		Person Reliability		
				2.47		0.86		
Item	30 Input		30 Measured		Infit		Outfit	
	Total	Count	Measure	Realse	IMNSQ	ZSTD	OMNSQ	ZSTD
Mean	355.1	87.0	50.00	2.49	0.99	0.0	0.98	-0.1
S.D	21.0	0.0	11.24	0.15	0.24	1.4	0.29	1.5
Real RMSE	2.50	True SD	10.96	Separation		Item Reliability		
				4.39		0.95		

*Cronbach Alpha (KR-20) = 0.88

The analysis results indicate that the item reliability score of 0.95 suggests excellent consistency of the items in measuring mitigation and adaptation abilities. The person reliability score of 0.86 shows that the students' measured abilities are stable and consistent. Moreover, the item separation value of 4.39 indicates a good differentiation in the difficulty levels between items. In contrast, the person separation value of 2.47 demonstrates the instrument's capacity to distinguish students based on their ability levels. The Cronbach's Alpha value of 0.88 indicates good internal reliability of the instrument, reflecting strong inter-item relationships. These results suggest that the instrument can consistently measure the constructs of mitigation and adaptation.

Item fit in Rasch analysis refers to the extent to which the items in the instrument meet the assumptions of the Rasch model, namely, unidimensionality and the ability of each item to measure the same construct consistently. This analysis examines several indicators, such as Infit and Outfit Mean Square (MNSQ), Point Measure Correlation (PT Measure Corr), and Z-standardized fit statistics (ZSTD).

Infit and Outfit MNSQ values are used to evaluate how well participants' responses to an item align with the predictions of the Rasch model. Ideally, these values range from 0.5 to 1.5, where values below 0.5 indicate redundancy or overly predictable items, while values above 1.5 suggest noise or inconsistency with the model. PT Measure Corr indicates the correlation between participants' responses to a specific item and their total scores on the instrument. This value should be positive and within a reasonable range (usually > 0.2), as negative values indicate that the item is irrelevant to the measured construct.

ZSTD, which measures the statistical significance of item fit, may occasionally yield unsuitable values, especially with large samples, as this statistic is highly sensitive to sample size. Therefore, if Infit and Outfit MNSQ and PT Measure Corr are within acceptable ranges, non-compliant ZSTD values are not necessarily grounds for item elimination.

The results of the item fit analysis which show the suitability of each statement item with the Rasch model, so that it can be ensured that the instrument items have met the good measurement criteria are presented in Table 3.

Table 3 Item Fit

Item	Infit		Outfit		PT-Measure Corr	Conclusion
	MNSQ	ZSTD	MNSQ	ZSTD		
Statement 1	0.68	-1.8	0.64	-1.9	0.52	Fit
Statement 2	1.15	1.2	1.16	0.9	0.40	Fit
Statement 3	0.90	-0.5	0.86	-0.7	0.56	Fit
Statement 4	0.89	-0.6	0.86	-0.8	0.56	Fit
Statement 5	1.07	0.4	1.07	0.4	0.41	Fit
Statement 6	1.15	1.2	1.16	0.9	0.40	Fit
Statement 7	1.20	1.8	1.36	1.6	0.41	Fit
Statement 8	0.68	-1.8	0.64	-1.9	0.52	Fit
Statement 9	1.40	2.6	1.66	3.7	0.05	Fit
Statement 10	0.87	-1.0	0.85	-0.7	0.52	Fit
Statement 11	0.88	-0.5	0.86	-0.6	0.62	Fit
Statement 12	0.67	-1.9	0.62	-1.9	0.62	Fit
Statement 13	0.87	-0.6	0.88	-0.5	0.39	Fit
Statement 14	1.46	2.1	1.46	1.9	0.24	Fit
Statement 15	1.01	-0.1	0.99	-0.0	0.57	Fit
Statement 16	0.95	-0.2	0.84	-0.7	0.55	Fit
Statement 17	0.92	-0.4	0.87	-0.6	0.61	Fit
Statement 18	1.07	0.4	1.04	0.3	0.48	Fit

Statement 19	0.95	-0.2	0.84	-0.7	0.55	Fit
Statement 20	1.44	2.4	1.50	2.5	0.48	Fit
Statement 21	1.11	0.6	1.03	0.2	0.56	Fit
Statement 22	0.67	-2.3	0.60	-2.3	0.59	Fit
Statement 23	0.92	-0.4	0.87	-0.6	0.61	Fit
Statement 24	1.14	0.8	1.11	0.6	0.54	Fit
Statement 25	0.67	-1.9	0.63	-2.0	0.59	Fit
Statement 26	1.44	2.8	1.62	3.5	0.03	Fit
Statement 27	1.14	0.8	1.04	-0.3	0.32	Fit
Statement 28	0.74	-1.3	0.69	-1.5	0.63	Fit
Statement 29	1.04	0.3	1.07	0.4	0.54	Fit
Statement 30	0.67	-2.3	0.60	-2.3	0.59	Fit

Based on the Rasch analysis results in this study, the item fit indicates that each item's infit and outfit Mean Square (MNSQ) value falls within the range consistent with the Rasch model criteria, which is between 0.5 and 1.5. This suggests that each item in the instrument can consistently measure the students' mitigation and adaptation abilities, and is in line with the model's predictions. The Point Measure Correlation (PT Measure Corr) values for each item also meet the positive criteria, indicating that all items contribute significantly to the overall measurement of the mitigation and adaptation construct.

However, the results show that the ZSTD values for some items do not meet the criteria. Nevertheless, according to the Rasch model approach, if at least one of the key indicators, such as infit or outfit MNSQ, meets the criteria, the item is still considered a good fit. In the context of this study, this approach is relevant because ZSTD is often sensitive to sample size, and the study sample of 87 respondents is large enough to influence the ZSTD results. Therefore, despite some discrepancies in the ZSTD values, these items can still be used in the analysis since the infit and outfit MNSQ values indicate a good fit.

The results of the raw residual variance analysis used to measure the dimensionality of the instrument, so that it can be seen to what extent the instrument is able to explain variations in climate disaster mitigation and adaptation abilities in students, are presented in Table 4.

Table 4 Raw Residual Variance in Eigenvalue Units

	Eigenvalue	Observed (%)	Expected (%)	Expected (%)
Total raw variance in observations	46.7	100.0		100.0
Raw variance explained by measures	16.7	35.8		36.8
Raw variance explained by persons	6.0	12.9		13.2
Raw variance explained by items	10.7	22.9		23.6
Raw unexplained variance (total)	30.0	64.2	100.0	63.2
Unexplained variance in 1st contrast	3.7	7.8	12.2	
Unexplained variance in 2nd contrast	3.2	6.9	10.8	
Unexplained variance in 3rd contrast	2.8	5.9	9.2	
Unexplained variance in 4tt contrast	2.3	4.9	7.7	
Unexplained variance in 5tt contrast	1.8	3.9	6.1	

Based on the Rasch test results conducted in this study, the dimensionality value was measured using raw variance explained by measures, which reached 35.8%. This value indicates how variation can be explained by the factors measured in the Rasch model, such as students' abilities in mitigation and adaptation related to climate change disasters. The 35.8% value indicates that about 36% of the data variation can be explained by the main factor being tested: the students' abilities in disaster mitigation and adaptation. However, this value is generally relatively low, which may suggest that other variables or additional factors not measured in this study also influence the results. In the context of the Rasch test, these results indicate that while variation can be explained, the model may still need to consider additional dimensions to provide a more comprehensive picture of the students’ abilities.

DISCUSSION OF RESULTS

The majority of respondents demonstrated an understanding of this urgency, but a minority still require further education on the important role of medical supplies in emergency response efforts. Good readiness is also reflected in respondents' ability to fulfill their responsibilities, which is a positive indicator of building disaster resilience. Mitigation and adaptation efforts to climate change can be realized through this preparedness, as trained communities will be better able to deal with disaster risks effectively [27]. In the context of mitigation, flood prediction technology, environmentally friendly infrastructure improvements, and reduction of greenhouse gas emissions are strategic steps to reduce disaster intensity. Meanwhile, adaptation is carried out through continuing education, strengthening individual capacity, and implementing proactive habits in dealing with disaster risks. The survey results confirm that combining technology acceptance, understanding the causes of disasters, individual preparedness, and continuing education is the primary foundation in mitigation and adaptation efforts to climate change [28]. By increasing community awareness and capacity, it is hoped that a more resilient environment will be created and will be able to respond to the impacts of climate change in a sustainable manner.

The level of community concern for disaster-damaged housing shows positive development. However, there is still room to increase awareness and involvement, especially for groups that are hesitant or less supportive of disaster mitigation initiatives. The community, in general, has high empathy and readiness to participate in humanitarian action. This is reflected in the good acceptance of disaster signage, an important effort to increase awareness of potential disasters.

The community's understanding of personal responsibility to pay attention to potential hazards around them is growing, with the realization that preventive action protects oneself and others. Disasters can happen at any time, and an active role in maintaining cleanliness, awareness of potential hazards, and efforts to maintain environmental resilience are important factors in disaster mitigation. Many people are beginning to understand that poorly managed information dissemination can contribute to high casualty rates in disasters. This further emphasises the importance of accurate information management and prevention efforts through effective education and campaigns. As such, communities increasingly recognise the urgency of preparing early, despite some doubts from a small number of respondents regarding its effectiveness. Most respondents, however, showed confidence that early preparedness could reduce the risk and minimize the impact of disasters.

The results of this study reflect that people are increasingly aware of the importance of preparing for disasters, even before official warnings are issued. Disaster preparedness as an anticipatory measure is becoming more widely accepted, despite views that cast doubt on the effectiveness of early preparation. A 50% majority of respondents were in favour of the budget being focused on post-disaster rehabilitation, reflecting the importance of preparedness and recovery after a disaster has occurred.

Concerns about the negative impacts of climate change, such as decreased property values due to disasters or environmental damage, reinforce the importance of climate change mitigation and adaptation [29]. Communities increasingly appreciate the benefits of information related to potential disasters and climate change and realize that mitigation efforts, such as tree planting, waste management, and reducing greenhouse gas emissions, play a significant role in reducing the impact of disasters caused by climate change. Disaster mitigation and adaptation to climate change must go hand in hand [30]. Communities should be encouraged to focus on preparedness for existing disasters and understand how climate change may exacerbate future disaster risks. This understanding will lead to more proactive behavior in reducing carbon emissions, improving environmental sustainability, and building community resilience to the impacts of climate change.

Most respondents showed good awareness of disaster shelters in schools, although a small number lacked understanding or felt unsure about their existence. This suggests that despite socialization efforts, there is still an opportunity to improve the understanding and confidence of some individuals regarding the facilities available to protect them in emergency situations. Efforts to plan and invite people to participate in school disaster prevention promotion activities are important, especially to encourage wider involvement and ensure everyone understands their role in disaster prevention efforts.

The positive spirit among respondents to participate in school disaster prevention efforts is high, although there is a slight challenge in convincing some people who may feel less interested or doubt the benefits [16; 31]. This suggests that while there is excellent support, there is still a need for more effective and engaging approaches to overcome the challenges of increasing participation. Increased socialization of disaster prevention and rescue plans at the community level is also crucial to ensure that individuals understand their roles and responsibilities in dealing with disasters.

The overall survey results show a high level of safety awareness, with respondents having a good understanding of evacuation planning. However, a small number still require further briefing to improve preparedness. Awareness of the importance of evacuation drills is also relatively high, reflecting a significant commitment to safety and disaster preparedness. However, some respondents may lack interest in such activities, indicating the need for more engaging or innovative approaches to increase participation and interest.

Most communities find collaborating in evacuation activities during disaster prevention drills important, although some individuals still doubt or do not fully agree with this. This indicates that while awareness of the importance of collaboration is high, some obstacles still exist to building broader agreements and cooperation. Most respondents feel they have a responsibility to protect themselves and others. However, a minority may need further motivation or understanding of the urgency of disaster preparedness and training at the school level and within the broader community. A community-based approach that involves various societal layers in disaster mitigation and adaptation processes will enhance the effectiveness of these efforts. An innovative approach that integrates science, technology, and local culture in STEM (Science, Technology, Engineering, and Mathematics) education can significantly impact students' ability to address challenges posed by climate change-induced disasters [32]. Combining cutting-edge science and technology with proven local wisdom in disaster response allows students to develop solutions that are not only locally relevant but also sustainable in the long term.

STEM-based Project-Based Learning (PjBL-STEM) can enhance 21st-century skills such as collaboration, critical thinking, and creativity. In the context of disaster mitigation, this is relevant as these skills are fundamental in designing data-driven technologies and solutions, such as flood early warning systems or drought monitoring [33]. Moreover, the STEM-PjBL approach is not only effective in improving HOTS but also helps to develop understanding and solutions to contextual problems, including environmental disasters. That is, through projects that integrate science and technology, it can train complex and critical thinking skills in designing data-driven technologies for climate change adaptation, such as smart irrigation systems to overcome drought. (STEM projects can be specifically designed for disaster mitigation contexts, such as the creation of learning modules that combine science and technology to respond to natural disasters. STEM-PjBL-based learning tools are effective in developing students' 4C (Critical thinking, Creativity, Collaboration, Communication) skills in the context of environmental change. [35; 36]. Where STEM projects can be directly used to create solutions to disaster impacts, for example, digital flood risk maps or sensor-based extreme temperature detection systems.

This approach also fosters deeper climate awareness among students while enhancing critical thinking skills [37]. STEM-based education facilitates a better understanding of climate change, including its direct and long-term impacts on the environment and socio-economic life. Students are encouraged to think analytically, identify cause-and-effect relationships between human activities and climate change, and understand the importance of preventive actions [38]. Additionally, they are trained to critically evaluate information, which can help filter out inaccurate data or news that could worsen situations in disaster management [39].

Based on the research results, the authors agree with Zayyinah et.al. [40] that the success of STEM-based education in addressing climate change depends heavily on students' mastery of technology and their ability to collaborate and apply it directly in real-life situations. Our data also aligns with Krisnaningsih et.al. [41], who emphasized that student involvement in active discussions can improve their ability to identify problems and formulate actions and solutions through community collaboration. This creates a stronger sense of ownership of the resulting solutions and increases the likelihood of successful implementation at the local level. These discussions also serve as a forum to raise collective awareness of the importance of disaster mitigation and adaptation to climate change.

According to Ramandani [42], this approach can motivate students to take further action to create change by learning how to mitigate disasters and adapt to climate change. This aligns with the results obtained, where students become agents of change who influence public policy and actively contribute to collective efforts to address the climate crisis. Equipping students with the right skills, knowledge, and attitudes can help prepare them to become leaders who can design and implement effective mitigation strategies and develop innovative, community-based adaptation solutions to future climate change challenges. Perwitasari's [43] findings strengthen the argument that action-oriented education has a significant contribution to community resilience amidst the climate crisis.

The Trash Cleaning Tool and Water Level Detection Tool projects are closely related to disaster mitigation and climate change adaptation while supporting the implementation of sustainability-based STEM education (STEM ESD).

a) (b)

Figure 4 Mitigation and Adaptation Project (a) Waste Cleaning Tool (b) Water Level Detection Tool

The Trash Cleaning Tool contributes to mitigation by reducing greenhouse gas emissions from organic waste and preventing environmental pollution caused by plastic, thus preserving the ecosystem's function in carbon absorption. In terms of adaptation, this tool helps prevent flooding due to blocked drainage systems and creates a clean environment to reduce the risk of disease, which is in line with the opinions of Fathurohman et al. [44] and Sari et al. [45]. Meanwhile, the Water Level Detection Tool supports mitigation by providing data that can be used for planning disaster-resistant infrastructure and helps communities adapt by providing early warnings of potential floods. Both tools integrate STEM elements such as science, technology, engineering, and mathematics in their design while educating students on the importance of sustainability. Thus, the aim of this project is to address climate change challenges and empower the younger generation to think critically, innovate, and contribute to sustainable development.

CONCLUSION

Climate change significantly impacts various aspects of life, including natural disasters, food security, and water availability. Addressing climate change is crucial in the sustainable development agenda, with a focus on mitigation and adaptation actions. Education, especially STEM-based (Science, Technology, Engineering, and Mathematics) education, can be essential in educating society, particularly the younger generation, to develop technology-based solutions and local wisdom to tackle climate change-related disasters. Environment-based project-based learning integrating ESD

(Education for Sustainable Development) concepts and climate action in schools can enhance student engagement, foster critical thinking skills, and strengthen disaster preparedness and mitigation. Furthermore, continuous education that involves collaboration across sectors is necessary to strengthen public understanding of disaster preparedness and the importance of preventive actions. Raising awareness and building community capacity aims to create more resilient environments to face the impacts of climate change.

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Authors

Nurita Apridiana Lestari
(Indonesian, Surabaya)
Lecturer, Physics Education Program,
Faculty of Mathematics and Natural Science
Surabaya State University
E-mail: nuritalestari@unesa.ac.id
ORCID ID: 0000-0002-3773-3369

Eko Hariyono
(Indonesian, Surabaya)
Professor, Lecturer, Science Education Program,
Faculty of Mathematics and Natural Science
Surabaya State University
E-mail: ekohariyono@unesa.ac.id
ORCID ID: 0000-0002-9371-7988

Madlazim
(Indonesian, Surabaya)
Professor, Lecturer, Physics Program,
Faculty of Mathematics and Natural Science
Surabaya State University
E-mail: madlazim@unesa.ac.id
ORCID ID: 0000-0002-6059-1119

Author’s contribution

Nurita Apridiana Lestari: Conceptualization, Methodology, Investigation, Formal analysis, Writing – Original Draft
Eko Hariyono: Validation, Writing - Review & Editing, Supervision
Madlazim: Visualization, Writing - Review & Editing, Supervision

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