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IMPROVING CLIMATE LITERACY OF HIGH SCHOOL STUDENTS THROUGH PHYSICS TEACHING MATERIALS BASED ON STEM

A. Hakim*[1], S. Efwinda[2], P. Damayanti[3], M. Syam[4], O. Mutmainah[5], A. Norsaputra[6]

[1,2,3,4,5]Department of Physics Education, Faculty of Teacher Training and Education, Mulawarman University, Samarinda, Indonesia
[6]Science and Technology Education, Institute for Innovative Learning, Mahidol University, Nakhon Pathom, Thailand

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ABSTRACT

Climate change is a problem that has received attention from various countries around the world. Climate change disrupts the balance of the ecosystem, which, if allowed to continue, can threaten the continuity of life on Earth. In education, addressing the challenges of learning about climate change can be done by selecting appropriate teaching materials. This study aims to examine Science, Technology, Engineering, and Mathematics (STEM) based physics teaching materials on climate change developed and designed to improve the climate literacy of high school students. The research uses the Analyze, Design, Development, Implementation, and Evaluation (ADDIE) Model. The teaching materials developed are then implemented in learning climate change in high school students. The research design was one group pretest-posttest with a sample of 37 high school students in Indonesia. The sampling technique used cluster random sampling. The instrument used was a test technique for the aspects of knowledge and action consisting of 30 multiple-choice questions and a questionnaire for the attitude aspect comprising 15 statements. The results show that the STEM-based physics teaching material on climate change improves the climate literacy of Indonesian high school students, with an average N-Gain score of 0.51 in the moderate category. Based on these results, it can be concluded that STEM-based teaching materials on climate change materials can be used to improve the climate literacy of high school students.

Keywords: climate change; climate literacy; STEM; teaching materials

INTRODUCTION

In recent times, climate change has emerged as a significant global issue, with widespread adverse effects felt across the globe (Leuzinger et al., 2019; Widiyawati, 2020; Trémolière & Djeriouat, 2021; Leal Filho et al., 2023; Queiroz et al., 2023). The influence of human activities on climate change has altered extreme weather patterns in all regions of the world (Fleischhut et al., 2020; IPCC, 2021). Indirectly, climate change involves nature's unique components: the atmosphere, hydrosphere, and biosphere (Nayan et al., 2020). All aspects associated with climate change are anticipated to cause disruptions to social systems, infrastructure, and even ecosystems (Nabilah & Hariyono, 2021). Climate change also increases extreme events, such as harsh climate La Nina and El Nino, which can cause crop failure (Mardiyati et al., 2021). Uncontrolled climate change can result in natural disasters like severe flooding triggered by intense rainfall (Nayan et al., 2018). On the other hand, unchecked climate change can also cause extreme drought, increasing the risk of forest fires, water shortages, migration, and extinction of plants and livestock

***Correspondence Address**
E-mail: abdul.hakim@fkip.unmul.ac.id

(Sanaz et al., 2022). Both present and future generations will have to confront the consequences of climate change, with potentially more concerning repercussions in the future (Gunamantha & Dantes, 2019).

Enhancing students' knowledge and character is a crucial function of education (Nabilah & Hariyono, 2021). Moreover, multiple studies have identified education as the primary factor in fostering individual awareness of climate change (Lee et al., 2015; Pan et al., 2023). According to Shi et al. (2016), education has been demonstrated to enhance consciousness regarding climate change. Familiarity with climate change and its consequences is crucial for making informed choices concerning future adaptation and mitigation initiatives (Harker-Schuch et al., 2020) to maintain the Earth's sustainability (Kumar et al., 2023). In climate change education, strategies or learning methods that can influence the younger generation's behavior regarding climate issues are still being debated (Kolenatý et al., 2022). Mittenzwei et al. (2019) assert that communities should be given the means to evaluate scientific evidence and comprehend the consequences of their actions, and this is especially vital for elementary and upper-level students, as they represent potential future leaders who must grasp and address the implications of climate change (Oliver & Adkins, 2020). Challenges related to the issue of climate change can be faced, one of which is by forming community climate literacy through education (Wu & Otsuka, 2021). It is crucial to garner public attention towards climate change, and students play a significant role in enhancing climate literacy. This knowledge is valuable in identifying community-based solutions for addressing the challenges posed by climate change (Hestness et al., 2019; Toffaletti et al., 2022).

Issues related to increasing climate literacy have become an exciting topic (Suhaimi & Mahmud, 2022), essential (Pacini et al., 2022), and need to be carried out throughout the world (Foy & Foy, 2019; Brannon et al., 2022). Studies on climate change education and climate literacy have been conducted in Taiwan, Africa, Malaysia, Nigeria, England, Australia, and Indonesia. In Taiwan, the problem of drought or water shortage due to climate change has become a significant concern for the government and residents of Taiwan (Mardiyati et al., 2021). Helbling et al. (2021) state that in Africa, individuals with high climate literacy tend to live in urban areas and are highly educated. These results are also supported by Simpson et al.'s (2021) research, which shows that education strongly predicts one's climate literacy. Alenda-Demoutiez's (2022) research focuses on what shapes African climate literacy.

Research conducted by Nayan et al. (2020) in Malaysia shows that students' climate literacy in the behavioral aspect is lower than their knowledge. Research by Eze et al. (2022) on Nigerian teachers shows that teachers' climate literacy is in the medium to low category. Science teachers are essential in increasing students' scientific literacy (Plutzer & Hannah, 2018). Climate change education is necessary in England, especially for young people (Rushton et al., 2023). In Australia, the natural environment of Australia and its people are facing new challenges due to climate change; therefore, the integration of climate change issues into education programs is urgently needed (Yasukawa, 2023). Climate change is integrated into the physics curriculum taught in grade XI high schools in Indonesia, particularly within global warming discussions. However, research suggests that the climate literacy level of Indonesian students is still insufficient. For instance, an analysis of climate literacy among high school students in Surabaya, Indonesia, indicates that the indicators related to identifying scientific phenomena are categorized as low. In contrast, those for explaining scientific phenomena and using scientific evidence are classified as medium (Nabilah & Hariyono, 2021). Similarly, findings from a study on high school students' perceptions of climate change in Samboja, Indonesia, demonstrate that a majority of students do not have a complete understanding of climate change, and only about one-third of the participants view it as a global threat (Nugroho, 2020).

The problems above indicate the need to integrate climate change content into learning in secondary schools to improve students' climate literacy as a whole, knowledge, actions, and attitudes. In Indonesia, the presence of inaccuracies in the selection of teaching materials used during the learning process is one of the factors contributing to low scientific literacy, including climate literacy (Rusilowati et al., 2016). Apart from the learning materials, instructional methods also play a crucial role in determining the effectiveness of the learning process. One viable approach to teaching climate change is the Science, Technology, Engineering, and Mathematics (STEM) approach, as it integrates essential skills necessary for designing effective climate change mitigation solutions (Kumar et al., 2023). STEM education can increase students' knowledge of Climate Change Topics (Phanphet et al., 2019). The STEM approach integrates multiple scienti-

fic disciplines, such as science, technology, engineering, and mathematics, and is believed to improve students' thinking skills and problem-solving skills (Duffy et al., 2019; Gupta et al., 2020). The STEM learning approach addresses practical, real-world challenges related to everyday life, and this can be achieved through inquiry-based methods and collaborative efforts with peers to foster an efficient and productive learning environment (Savran Gencer & Dogan, 2020). The activities of STEM learning or programs have also proven successful in increasing students' climate literacy, for example, those carried out by Choi et al. (2021) through learning programs with the SSI-STEAM approach, which is an approach that integrates socio-scientific issues (SSI) and Science, Technology, Engineering, Arts, and Mathematics (STEAM). Research by Nafidiah et al. (2023) also shows that integrating STEM into learning media can stimulate students' scientific literacy on climate change.

The implementation of the STEM approach can also be integrated into teaching materials. Studies show that there is a high need for the provision and use of STEM-based teaching materials to improve student learning outcomes, for example, research by Widarti et al. (2020), Sustiningsih et al. (2021), Laila and Asrizal (2021), and Handayani et al. (2022). The use of STEM-integrated teaching materials has been proven to improve various types of student learning outcomes, among others are students' problem-solving skills (Purwaningsih et al., 2020), STEM literacy (Hikmawati et al., 2020), and 21st-century skills (Yulianti et al., 2020). Research by DeWaters et al. (2014), who examine students in rural and suburban public school districts across New York, shows a significant increase in Climate literacy levels of junior and senior high school students measured on the cognitive scale through STEM-based teaching materials. Therefore, one way that can be used to teach climate change topics is through the use of teaching materials by integrating them with STEM learning approaches.

Increasing climate literacy is urgently needed (Powers et al., 2021; Pacini et al., 2022). Climate literacy is required so that individuals can understand how climate affects all life, acquire skills to communicate about climate change, and be aware of ways to increase local resilience in climate change adaptation and mitigation efforts (Cooper et al., 2019). However, research on developing STEM-integrated teaching materials in Indonesia to improve students' climate literacy is still limited. Therefore, we developed teaching materials integrated with the STEM approach to increase students' climate literacy, which was declared very valid and received excellent student responses (Mutmainah et al., 2022). This follow-up research explores how students' climate literacy increased after implementing STEM-integrated teaching materials on the topic of climate change. This research on implementing teaching materials integrated with the STEM approach was conducted in a high school in Indonesia, where initial observations showed that students' climate literacy was still low. As a guideline in research, the research questions include: 1) How does climate literacy increase in the knowledge aspect of high school students in Indonesia after implementing STEM-based teaching materials on climate change?; 2) How does climate literacy increase in the action aspect of high school students in Indonesia after implementing STEM-based teaching materials on climate change?; 3) How does climate literacy increase in the attitude aspect of high school students in Indonesia after implementing STEM-based teaching materials on climate change?

METHODS

Materials are an essential factor in determining the quality of learning. Since the development of teaching materials is a linear process with the learning process, when designing teaching materials, it is necessary to consider the development model to ensure the quality of teaching materials that support the learning effect. One commonly used design for developing instructional materials is the five-step: Analyze, Design, Development, Implementation, and Evaluation (ADDIE) model. The ADDIE model is a learning system design model that describes the primary phases of an easy-to-implement learning system (Cahyadi, 2019). According to Mayfield (2011), the ADDIE process has become a general framework for creating training programs. Mayfield further claims that many instructors, trainers, and universities use this instructional design model. This can be seen from Usta and Güntepe's (2017) test of the e-book design process based on the ADDIE model used by prospective teachers in the Computer and Instructional Technology department. Therefore, according to Puspasari (2019), there needs to be a step in producing a textbook that has suitable qualifications and is appropriate for application in lectures using the ADDIE model.

This research used a type of development research with the ADDIE development model,

which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Aldoobie, 2015). The products developed and tested for feasibility were physics teaching materials for STEM-based climate change materials.

The special case design was employed in this study to explore one or more cases and provide the findings thoroughly. Yin (2018) asserts that case studies are the best methodology for situations requiring in-depth analysis. In the first stage, it is necessary to analyze the intended school's needs and curriculum by formulating indicators of competency achievement and objectives through teaching materials developed to improve the climate literacy of high school students. This analysis was carried out to obtain information related to the needs of teaching materials, the curriculum used, and the material presented in teaching materials. This approach is useful for developing a learning system that adapts to student needs so that learning objectives can be achieved optimally (Yu et al., 2021).

Attention should be considered if there is a need to change and manipulate specific design aspects while adapting educational materials to a particular learning environment. From the perspective of why this is done and the standards utilized, there is a direct correlation between the evaluation and adaption of materials (Ataboyev & Tursunovich, 2023). Several educational and methodological manuals illustrate the essential guidelines and ideas teachers should consider when creating teaching materials in light of the transition to new academic standards (Tursunovich, 2022). The second stage was designing teaching materials by sorting content into teaching materials and making concept maps. So basically, the designed teaching materials emphasized integrating the four aspects of STEM and their relation to climate literacy and realizing the design into a product.

Next, the third stage was developing teaching materials in the form of the realization of the design into a product and testing for feasibility by experts. The goal was to assess the feasibility of the product and produce a product that students in learning can use. The number of variables that influence the success or failure of textbooks in specific contexts has made it necessary to define appropriate criteria under which these decisions are based (Tomlinson, 2023).

The fourth stage was applying teaching material products that were considered feasible for students through the learning process to describe students' responses to teaching materials and increase student climate literacy after using these products. The sampling technique used cluster random sampling, a sample based on an arbitrary class where students were seen as class members (Dhivyadeepa., 2015). So, the development test of STEM-based teaching materials on climate change material was conducted at Senior High School in Samarinda. The trial was conducted for students of class XI MIPA. The design at the implementation stage used an experimental group subjected to pretest and posttest treatment with the samples, totaling 37 students. This design used one experimental group that was subjected to pretest and posttest treatments, as in Table 1 (Fraenkel et al., 2023)

Table 1. One Group Pretest-Posttest Design

Pretest	Treatment	Posttest
O_1	X	O_2

The final stage was evaluating the results obtained from the previous stage and improving the product until it reached the outcome of teaching materials for STEM-based physics climate change material. The data generated came from the pretest given before the treatment, namely the use of STEM-based physics teaching materials, and the posttest given after using STEM-based physics teaching materials. The instruments used were climate literacy questions in knowledge and action, totaling 30 multiple-choice questions, and a questionnaire on attitude related to climate change, which amounted to 15 statements (Christensen & Knezek, 2015). The questionnaire grids used for attitude questionnaires contained indicators of intention beliefs.

The improvement of students' climate literacy was analyzed using the N-gain test with the following equation:

$$< g > = \frac{<S_{post} - S_{pre}>}{<S_{maks} - S_{pre}>}$$

Then, the result of these calculations was converted into the categories of score-taking rates as shown in Table 2.

Table 2. N-Gain Score Categories

N-Gain Score	Category
(< g >) > 0,70	High
0,70 > (<g>) > 0,30	Medium
(< g >) < 0,30	Low

The acquisition of the N-Gain score became the answer to this study which is described into one of the categories.

RESULTS AND DISCUSSION

This research was initiated by developing teaching materials that were developed and tested for their feasibility to be implemented on 37 Indonesian high school students consisting of 12 male students and 25 female students. Three aspects of climate literacy will be seen as improved, including the aspects of knowledge, actions, and attitudes. Improving the climate literacy of high school students includes solving problems and solutions that consider the complex interactions between engineering or engineering activities, the Earth's climate system, and social systems that include benefits, costs, and risks (Powers et al., 2021). Improving climate literacy can motivate students to work towards climate change-related solutions. Learning is carried out using STEM approaches and EDP models. The EDP model can facilitate students to simulate thinking and acting like a technique to create the most effective solutions to solve problems (Duong et al., 2022). The STEM learning stages used have adjusted the EDP syntax: define, learn, plan, try, test, and decide. Students are directed to work on creating flood-resistant houses in groups. Group activities can encourage students to discuss with each other, exchange ideas, and work together to solve problems (Efwinda et al., 2022).

The define and learn stage is the first step for students to get to know the problems that occur, while in the planning stage, students begin to think about plans that will be developed to solve issues related to climate change's impacts. Student involvement in learning can be connected to how they interact with their peers in STEM activities (Sulaeman et al., 2021); therefore, this also needs to get the teacher's attention when applying STEM-based teaching materials. Teachers must continue developing themselves to develop learning that suits current needs (Efwinda & Mannan, 2021). Teacher readiness to implement the STEM Approach plays an essential role in the success of its implementation (Sulaeman et al., 2022).

The define stage leads students to be able to define the problem that occurs. Compared with conventional problem-solving methods, it is proven that the use of EDP can further improve students' ability to find problems and develop engineering design thinking in solving problems (Lin et al., 2021). The define stage is one of the EDP stages that is commonly used by experts or researchers in science learning (Winarno et al., 2020). This stage can facilitate students to learn how to know the difficulties faced by people and help those people so that the issue can be resolved. Climate literacy that wants to be formed in the STEM component at the define stage is the engineering aspect. In this aspect, climate literacy is the ability of students to provide solutions and design tools that can reduce the impact of climate change. The results show that five groups can understand the problems that occurred, and one group does not understand the issues that arose. This result indicates that students have differences in receiving the information obtained in defining the problem.

The learning stage leads students to provide problem-solving through scientific concepts, and students answer questions about climate change's triggers and impacts at this stage. These results are in accordance with findings by Abdurrahman et al. (2023) which show that at the "learn" stage in EDP, students who carry out EDP activities have a higher level of attention to developing alternative problem solutions because at this stage they are also given more space to investigate and explore information. Climate literacy that wants to be formed in STEM components at the learning stage is the science and mathematics aspect. Climate literacy in the science aspect is the ability of students to understand how the Earth's climate system is and make responsible decisions in connection with actions that can affect the climate. In contrast, climate literacy in mathematics is the student's ability to analyze graphs related to climate change. The planning stage directs students to be able to make a flood-resistant home solution plan that matches the criteria given by the person who needs the solution and develop it in the form of a picture. Students obtain information from the previous stages and begin to think of solutions that can provide answers to the problems faced. Students conduct material strength and absorption tests to manufacture a flood-resistant house prototype. They proceed to create a design for a flood-resistant house, as shown in Figure 1.

(a) (b)

Figure 1. (a) Material Strength Tests; (b) Material Absorption Test

Climate literacy that wants to be formed in STEM components at the plan stage is aspects of science, technology, engineering, and mathematics. All STEM aspects are needed in this stage, and students will integrate all four aspects to design solutions to problems arising in the previous step. Climate literacy in science is the ability of students to understand the Earth's climate system and make responsible decisions concerning actions that can affect the climate. Climate literacy in the technology aspect is the ability of students to sort and assess scientifically credible information about the climate change topic circulating on the internet. Climate literacy in the engineering aspect is students' ability to provide solutions and design tools that can reduce the impact of climate change. Climate literacy in mathematics is the ability of students to model and calculate the costs required of the tools they want to design to reduce the impacts of extreme climate change. An example of a design for a prototype of a flood-resistant house is presented in Figure 2.

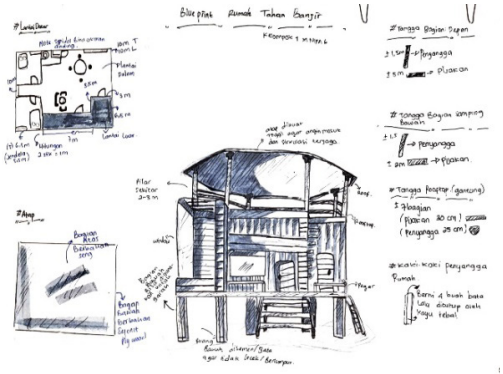

Figure 2. Examples of Flood Resistant House Designs

The try stage directs students to include the design in the previous step in the form of action and consider the risks and ways to optimize the design that has been made. Students are directed to use predetermined criteria and limitations to create a flood-resistant model or prototype of a house. Climate literacy that wants to be formed in STEM components at the trial stage is the engineering and mathematics aspects. Climate literacy in the engineering aspect is the ability of students to provide solutions and design tools that can reduce the impact of climate change. Climate literacy in mathematics is the ability of students to model and calculate the costs required of the tools they want to design to reduce the impacts of extreme climate change. Students are directed to continue making models or prototypes of flood resistant houses at home at this stage due to limited face-to-face time at school. An example of a prototype of a flood-resistant house that students have made is shown in Figure 3.

The test stage directs students to develop a design to determine whether the solution meets the criteria, limitations, and needs. Climate literacy that wants to be formed in STEM components at the test stage is the technology and mathematics aspects. Climate literacy in the technology aspect is the ability of students to sort and assess scientifically credible information about the climate circulating on the internet. Climate literacy in mathematics is the ability of students to model and calculate the costs required of the tools they want to design to reduce the impacts of extreme climate change.

(a) (b)

Figure 3. (a) Flood Resistant House Model Group 1; (b) Flood Resistant House Model Group 2

The decide stage directs students to determine if the design or prototype of the flood-resistant house made by each group can be a solution and provide answers to the problems that occur. This stage leads each group to present the results that have been created. The engineering aspect is climate literacy, which wants to be formed in STEM components at the decision stage. In this aspect, climate literacy is the ability of students to provide solutions and design tools that can reduce the impact of climate change.

The increase in student climate literacy is seen in pretest and posttest scores. The results of improving student climate literacy are presented in Figure 4.

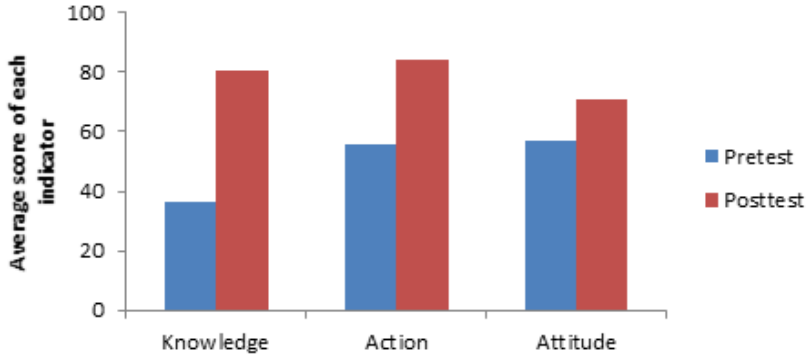

Figure 4. Results of Improving Climate Literacy by Each Indicator

The N-Gain score for each aspect of climate literacy is presented in Table 3. Table 3 shows that using STEM-based teaching materials on Climate Change topics can improve the climate literacy of high school students in the medium category. The average N-Gain score for all aspects of climate literacy is 0.51, with an N-Gain score of 0.70 for the knowledge aspect, an N-Gain score of 0.46 for the action aspect, and an N-Gain score of 0.37 for the attitude aspect.

Table 3. The N-Gain Scores obtained for Each Aspect of Climate Literacy

No.	Climate Literacy Aspects	N-Gain	Category
1.	Knowledge	0,70	High
2.	Action	0,46	Medium
3.	Attitude	0,37	Medium
	Average	0,51	Medium

Based on the N-Gain score division categorBased on the N-Gain score division category, the increase in climate literacy of high school students after using the STEM-based physics teaching materials developed is in the medium category. These results show the benefits of implementing STEM-based teaching materials in improving climate literacy. The STEM approach integrated with the EDP model can facilitate students' involvement in every stage of learning

activities (Duong et al., 2022). Project activities created by students encourage the construction of their knowledge themselves (Kuthe et al., 2020). Teaching materials with student worksheets containing project activities related to climate change can help students understand the problems faced and solve the impacts of climate change. STEM-based teaching materials also receive a positive response from students and are suitable for senior high school-level learning (Mutmainah et al., 2022). Teaching materials with a STEM approach are excellent to implement because the STEM approach facilitates students' learning by integrating various disciplines' knowledge (Sustiningsih et al., 2021); it is needed in social life to solve real problems in everyday life (Widarti et al., 2020). Using STEM-based teaching materials can improve students' problem-solving skills, make learning fun and interesting (Purwaningsih et al., 2020), and increase students' STEM literacy (Hikmawati et al., 2020). Improving students' climate literacy seeks to improve climate-related knowledge content and improves students' ability to solve problems through teaching materials to motivate students to move towards climate change solutions. This teaching material is one of the product's contributions to improving students' climate literacy.

Teaching materials are needed by students as a source of learning; they can be developed based on specific approaches, for example, integrated with the STEM approach while still paying attention to the suitability of topic characteristics (Widarti et al., 2020). The results of this study also support other relevant studies that implement STEM-based teaching materials in science subjects, including physics and chemistry. For example, Asrizal et al. (2022) shows that using STEM-based electronic teaching materials in physics subject can support students' 21st-century skills. In addition, the use of STEM-based teaching materials in chemistry subjects can also improve learning outcomes (Handayani et al., 2022) and students' scientific literacy (Kusasi et al., 2021). Research by Asrizal et al. (2023) also indicates that using STEM-based physics teaching materials is proven to develop new conceptual understanding and literacy for students.

Based on these results, we recommend the need for an evaluation of the high school education curriculum, especially on topics related to climate change, to integrate the STEM approach to learning. Climate change topics contain multidisciplinary sub-topics, not only associated with physics subjects but also can be integrated with other fields, including technology, engineering, mathematics, other science fields, and even social sciences related to this problem. Students must study following real-world contexts to solve real-world problems (Widarti et al., 2020). Teaching climate change topics needs to be carried out through a meaningful process. In science learning, the learning outcomes are formed from individual experience, intuition, imagination, and cultural and sustainable sociopolitical values in everyday life, which involve students in developing their critical scientific literacy (Ryu & Daniel, 2020). The limitation of this study is that it was implemented on a small scale, with only 37 Indonesian senior high school students. Further research needs to be done to implement teaching materials on a larger scale to strengthen the results of this study further.

Further research needs to be conducted considering that students' climate knowledge still needs to be improved, in terms of essential knowledge, attitudes, and behaviors, to prevent the negative impacts of climate change in the future (Hakim et al., 2023). Therefore, this novel approach demonstrates the significance of creating STEM education programs that are tailored to different age groups and result in a high capacity to improve learning outcomes in climate change (Kumar et al., 2023).

CONCLUSION

Based on the study results, it can be concluded that STEM-based teaching materials on climate change topics can improve the climate literacy of high school students. Increasing climate literacy is in the medium category, with an average N-Gain score of 0.51, and can be used as a source of learning support. STEM-integrated teaching materials support students in learning to integrate various disciplines needed to solve real everyday problems. The research results can be helpful for teachers in increasing students' climate literacy and as a reference for teaching materials on the topic of climate change that have been adapted to current needs, namely by integrating with the STEM approach.

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