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Belajar Sains Berkelanjutan Website: Enhancing High School Education for Sustainable Development (ESD) Competencies in Global Warming and Renewable Energy

Nuris Shobah[1], Eko Hariyono[1]*, Mita Anggaryani[2], Fasih Bintang Ilhami[3], Nina Fajriyah Citra[4]

[1]Magister Science Education Department, Faculty of Mathematics and Natural Sciences, State University of Surabaya, Surabaya, Indonesia
[2]Physics Education Department, Faculty of Mathematics and Natural Sciences, State University of Surabaya, Surabaya, Indonesia
[3]Science Education Department, Faculty of Mathematics and Natural Sciences, State University of Surabaya, Surabaya, Indonesia
[4]Master of Educationin Digital Learning, Faculty of Education, Monash University, Australia

*Corresponding author: ekohariyono@unesa.ac.id

ABSTRACT Sustainable living is critical for the next generation, and ESD competencies are required to handle global concerns. Education of Sustainable Development (ESD) helps to overcome this gap, however, technological integration is restricted and lacking in a complete framework. To overcome these problems, this study designed a website as an interactive learning medium to equip ESD competencies to realize science education with the PBL-STEAM model in the digital era. This learning website helps students learn about global warming and renewable energy in the learning process both inside and outside the classroom. The website development process using waterfall design. This research method was a descriptive and validation method carried out by content, language, and media experts to evaluate learning websites. The questionnaire statements were developed based on five dimensions of interactivity to understand the perspectives of physics teachers and pre-service science teachers. Physics teachers and pre-service science teachers as research subjects, consisting of 5 teachers and 12 students in Surabaya. This study succeeded in developing the BSB website which has an average validation score of 3.94. All respondents responded very good in every aspect of the interactive dimension. Overall it shows good results, from the validity of the *Belajar Sains Berkelanjutan* (BSB) website and responses related to the learning website after using it. The development of the BSB website has implications for increasing ESD's competence in global warming and renewable energy materials. It is recommended for further research to develop a website in other learning materials that integrate the improvement of ESD competencies.

Keywords Science learning website, Global warming, Renewable energy, Waterfall design, Dimensional interactivity

1. INTRODUCTION

Learning delivery skills include the use of learning media. Websites are one of the effective media for the learning process in increasing student interest. The development of technology has provided various digital tools, which increase the effectiveness of online education and make it more dynamic and interesting (Francis & Santhakumar, 2020; Krishnaprabu, 2019). Integration of conventional techniques by combining digital learning is a new approach to teaching and learning that can be provided. So that this digital learning helps to describe the abstractness of subject matter that is difficult to explain, reach, and feel directly, such as the solar system, global warming, and earth disasters. Globally, education that utilizes digital learning continues to be improved along with technological advances for sustainable development

The Sustainable Development Goals (SDGs) seek to harmonize social, economic, and environmental sustainability, acknowledging that actions taken in one domain can influence results in others (Beverelli, Kurtz, & Raess, 2020; Kurtböke, 2023). SDGs embody fundamental principles that focus on environmental sustainability, the challenges associated with their implementation, and the contributions of technology and innovation in realizing

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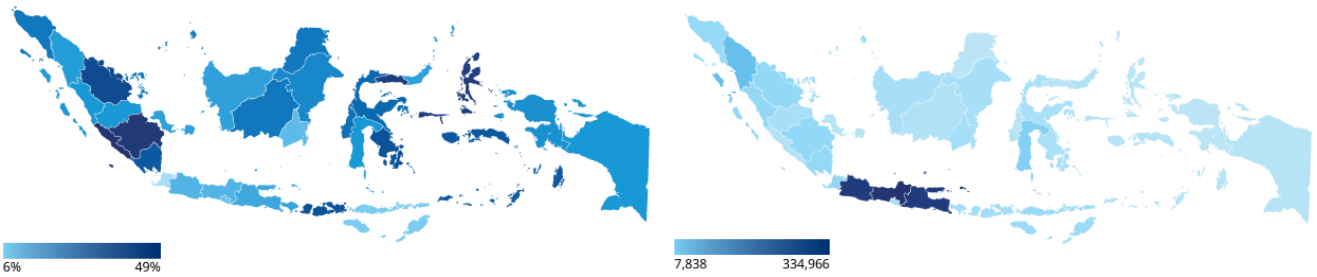


Figure 1 A comparison of laptop distribution and the Platform Merdeka Mengajar (PMM) utilization. (a) Nearly 1.25 million laptops were allocated to schools nationwide from 2020 to 2023. (b) The total number of user logins to the PMM as of October 2023. (Wang et al., 2023)

these objectives. UNESCO introduced Education for Sustainable Development (ESD) which are connected to SDGs (UNESCO, 2017). Sustainable development aims to achieve sustainable welfare and care for the environment through globalization and digitalization through education. ESD is a multidisciplinary concept that examines development from an economic, social, and environmental perspective. Furthermore, education is thought to be the most effective way to support sustainable development and boost people's ability to solve environmental and developmental challenges by fostering and putting its principles into practice (Vilmala et al., 2022). An international research project demonstrates how ESD supports high-quality education in a variety of ways. Primary and secondary education is transformed in all circumstances when the curriculum incorporates sustainability content, which is presented in terms of local, social, economic, and environmental contexts. Additionally, research shows that ESD pedagogies support the acquisition of knowledge as well as the development of the perspectives, values, and abilities required to create and preserve sustainable societies (Laurie, Nonoyama-Tarumi, Mckeown, & Hopkins, 2016). This is in line with UNESCO's claim that ESD has been acknowledged as a crucial component of high-quality education and a major enabler of sustainable development, becoming the core of 2030 Sustainable Development Agenda (UNESCO, 2018).

However, the implementation of digital learning has not been directed towards the ESD goals because there are obstacles in its implementation, such as a lack of understanding of the material, ineffective teaching approaches, and different perspectives and characteristics, making it difficult to build an integrated approach (Keengwe & Nyatuka, 2023; Vargas-Merino et al., 2024). In Indonesia, digital education is still not comprehensive based on Figure 1. Data from 2020 to 2023 shows that nearly 1.25 million laptops have been distributed nationwide to support teaching, learning, and school management activities. These efforts are critical to ensuring the effective implementation of the National Assessment and the overall reform of the Self-Learning initiative. However, this stands in contrast to the utilization of *Platform Merdeka Belajar* (PMM) within the *Kurikulum Merdeka*, which is particularly effective in the Java region. These platforms are designed to promote learning, teaching, and community engagement among educators, with the aim of enhancing their pedagogical competence and fostering a mindset of sustainable development (Wang et al., 2023). ESD has emerged as the primary focus of worldwide education's digital transformation. Websites, as digital learning platforms, play a crucial role in facilitating the implementation of ESD since they can provide broad and flexible access to information (Rusmini, Lasmawan, & Candiasa, 2023). The incorporation of website technology into ESD allows students to delve deeper into sustainability issues using multimedia features such as videos, simulations, and interactive visualizations, which can help students understand complex concepts about the environment and sustainable development (Nugroho, 2020; Rismayanti, Anriani, & Sukirwan, 2022). Research Chusni, Saputro, Rahardjo, & Suranto (2021) and Rihatno et al. (2021) found that using learning websites in the context of sustainability can improve students' environmental awareness, critical thinking skills, and problem-solving abilities. The website also promotes collaborative learning and knowledge exchange among education stakeholders from various geographical and cultural backgrounds, which is critical for accomplishing sustainable development goals (Hawa, Zakaria, Razman, & Majid, 2021). Furthermore, the website platform promotes ESD pedagogical principles such as problem-based learning, transformative learning, and lifelong learning by providing interactive features that allow students to actively participate in the learning process (Mulyadiprana et al., 2022; Zainal, 2022). The website's presence in ESD is also in accordance with UNESCO's digital agenda, which promotes access to quality and sustainable education through the use of information and communication technologies.

The *Kurikulum Merdeka* has the achievement of physics learning objectives on the topic of global warming and renewable energy which are directed to achieve sustainable

development goals. This is because one of the problems in the world and Indonesia, namely the largest CO_2 producer comes from the combustion of fossil fuels and petroleum as the use of electrical energy and transportation which affects climate change (Anwar, Ramdani, Fawaid, Abdillah, & Nurtanto, 2021; Harsanto & Pradipta, 2021; IESR, 2021). In addition, the world of education which is identical to the younger generation entering the community arena still has little interdisciplinary collaboration and a relatively low understanding of climate change science knowledge (Fernandez & Shaw, 2013; Hariyono et al., 2023; Ying & Osman, 2021). So it is necessary to reorient sustainable science education by utilizing digitalization at all levels to address sustainability problems comprehensively.

Website-based learning media has been shown to have a substantial impact on science education, particularly in the areas of global warming and renewable energy. The use of websites as a learning medium enables students to visualize abstract concepts through interactive simulations and animations, which can improve their comprehension of complicated phenomena such as the greenhouse effect and the operating principles of renewable energy (El Azzouzi, Elachqar, & Kaddari, 2023). Zhang et al. (2022) found that website-based learning improves student learning outcomes on the issue of global warming by 35% compared to traditional techniques. The website platform also promotes autonomous and collaborative learning by allowing students to access information at any time and from any location, as well as participate in online discussions that help them better comprehend environmental issues (Núñez et al., 2020; Sebastián-López & de Miguel González, 2020). Furthermore, learning websites can incorporate real-time data on climate change and renewable energy use, providing authentic context and increasing the relevance of learning for students (Kurup, Levinson, & Li, 2021; Zhang et al., 2022).

The media website "*Belajar Sains Berkelanjutan*" aims to integrate Education for Sustainable Development (ESD) concepts into science education, particularly in topics related to renewable energy and global warming. This approach ensures that students not only acquire scientific knowledge but also learn how to apply it for sustainable development. Consequently, this website serves as a valuable resource for Problem-Based Learning (PBL) in STEAM education within the context of ESD, supporting science education initiatives effectively. Therefore, researchers developed website-based learning with the PBL-STEAM approach to training ESD competencies, especially critical thinking competencies and integrated problem-solving competencies.

The usage of websites as a learning medium has been shown to improve students' critical thinking and problem-solving capabilities. Website-based learning with interactive and simulation components can improve students' critical thinking skills by up to 42% when compared to traditional learning (Sentriyo et al., 2023). Through virtual case studies, students can explore different perspectives, examine complex facts, and apply their knowledge in real-world scenarios (Cao & Yu, 2023; Zhang & Ma, 2023). Online discussion forums and collaborative activities in learning sites encourage students to create logistical arguments and critically evaluate solutions given by their peers (Lin & Wang, 2024; Xu, Wang, & Wang, 2023). Websites also offer real-time feedback and organized assistance to assist students in systematically identifying, analyzing, and solving problems , while website-based self-assessment features allow them to reflect on and refine problem-solving strategies on an ongoing basis (Hsu et al., 2024; Steinert et al., 2024).

Many websites are used to support science learning, Astuti, Wihardi, & Rochintaniawati (2020), Rosyida & Hasanah (2021), and Calvo & Lucha (2024) are function can provide time efficiency and accessibility anywhere to get effective learning. In this study, the website implements global warming and renewable energy materials. Website development does not only present teaching materials or knowledge such as educational websites about plastic waste recycling in research Soegoto, Ramana, & Rafif (2021) and environmental science in research Rihatno et al. (2021). The website is arranged interactively with a flow or learning step. Research by Purba, Riris, & Muchtar (2021) and Srisawasdi et al. (2023) using inquiry learning, this science learning website is designed interactively with PBL-STEAM. In addition, this website was developed to train ESD competencies in contrast to other research such as the development of physics edutainment website to improve students' critical thinking skills (Salsabila & Kholiq, 2021). In the field of sustainability, in the coming years, ESD competencies will become the main focus of measuring and evaluating the development of student and educator competencies (Cebrián, Junyent, & Mulà, 2020). ESD competencies are trained by integrating ESD into learning websites, especially SDGs 7-Affordable and Clean Energy and SDGs 13-Climate Action. This is because the application of ESD is generally applied to the use of e-books and worksheets (Fatiyah, Riandi, & Solihat, 2021; Insani, Hamdu, & Putri, 2023).

Research conducted by Ramadhany et al. (2024) has developed digital comic media to increase students' cultural and citizenship literacy based on ESD. Another study conducted by Purnawati, Suhendar, & Ratnasari (2023) has developed a flipped e-module in ESD contexts to increase students' self-awareness competency. Both of them show positive impacts on students' capabilities regarding the implementation of ESD in schools. In line with those findings, this research aims to develop a more interactive learning-based media while applying ESD competencies to support the SDGs agenda. The research has developed educational website called *'Belajar Sains Berkelanjutan'* for web-based learning that not only contains reading materials

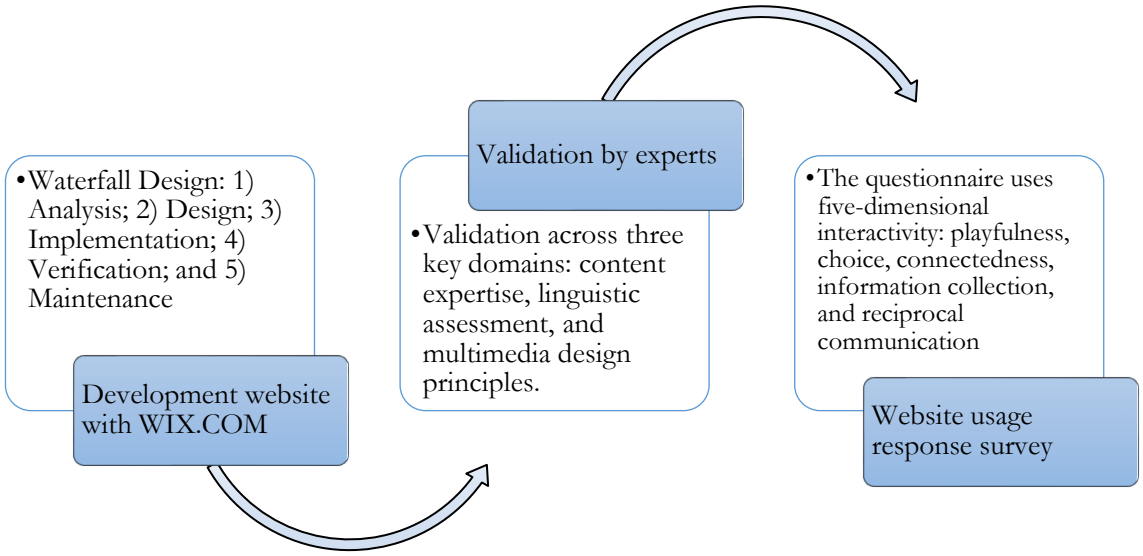


Figure 2 Steps of the research flow *Belajar Sains Berkelanjutan* website

but is also supported by practices, games, and a set of learning tools per activity. The interactive educational web will use five dimensions of website interactivity (Barri, 2020; Zhao, Luo, & Chen., 2020). Interactivity five dimensions are: (1) Pleasure, (2) Choice, (3) Connectedness, (4) Information Gathering, and (5) Communication Reciprocal (Prasetya et al., 2023). These interactivity measures assess the effectiveness of educational websites by providing feedback through a quiz game, which evaluates reader understanding after engaging with the content (Astuti, Wihardi, & Rochintaniawati, 2020). In this research, the website will be designed as an educational website for learning that can provide feedback for readers. The website will be judged based on experts' assessments (Rosyida & Hasanah, 2021). The use of the website before implementation on students is applied to physics teachers and pre-service science teachers to get responses in using the website.

2. METHOD

This research method was descriptive research. Based on Loeb et al. (2017) descriptive studies, it aims to thoroughly describe a specific state of affairs. In educational research, the most commonly used descriptive methodology is the survey. The survey was used by researchers to find out the responses of physics teachers and science teachers regarding the 'Belajar Sains Berkelanjutan' website that was developed.

2.1 Research Design

The researchers implemented an educational web-based platform using Wix.com's content management system, which facilitated the development of customizable learning interfaces aligned with user specifications. Although website development was performed on a laptop workstation, the final web-based learning environment is device-agnostic and can be accessed via standard web browsers on both mobile devices and personal computers, requiring only a stable internet connection for optimal functionality. The learning website underwent a comprehensive evaluation process by subject matter experts across three key domains: content expertise (focusing on Physics concepts related to global warming and renewable energy), linguistic assessment (Indonesian language proficiency), and multimedia design principles. The full research design can be seen in Figure 2.

2.2 Research Subject

The location of this research was carried out in several schools and one of the universities in Surabaya in the 2024/2025 academic year. The school implements the *Kurikulum Merdeka*. Physics teachers access the learning website and the population of this study is pre-service science teacher who have accessed the *'Belajar Sains Berkelanjutan'* website to find out the perceived response from the use of the website.

2.3 Content Analysis

The development of educational websites necessitates rigorous content analysis to ensure pedagogical effectiveness. This is particularly crucial when addressing Education for Sustainable Development (ESD) competencies, specifically critical thinking and integrated problem-solving capabilities. These competencies are essential for addressing global challenges, particularly global warming, and fostering the transformative thinking required for sustainable living practices. Formal education programs require a comprehensive curriculum so that they are able to develop these competencies in an effort to build a sustainable life. Formal educational programs require a comprehensive and well-structured curriculum that effectively develops sustainability competencies, thereby fostering the knowledge, skills, and mindsets necessary for building sustainable societies (Evans, 2019). In this research, the content focusing on global warming and

renewable energy is aligned with Phase E Physics learning outcomes specified in the Indonesia Curriculum 'Kurikulum Merdeka', which is implemented for tenth-grade high school students.

The learning outcomes established in Phase E of the *Kurikulum Merdeka* for Physics learning define the desired student competencies. Students are expected to (1) respond to global concerns by actively participating in problem-solving activities. (2) Students should also be proficient in scientific processes such as observation, inquiry formulation, hypothesis generation, experimental design and implementation, data analysis and interpretation, critical evaluation and reflection, and effective communication of findings via basic projects or technology-enhanced visual simulations, particularly in the context of alternative energy systems and global warming phenomena.

The importance of providing problem-solving skills, utilizing problem-based learning models as a framework for website development, and selecting the two previously mentioned ESD competencies. The STEAM approach is used in simple project activities. The material on global warming and renewable energy is integrated to understand the content in achieving two SDGs, namely SDG 7: Affordable and Clean Energy which is connected to SDG 13: Climate Action. These three considerations and learning objectives adopt from the ESD learning objectives indicator which includes SDGs 7 and 13 (UNESCO, 2017). ESD learning objectives indicators consist of three, (1) Cognitive: 1. The learner understands the current climate change as an anthropogenic phenomenon resulting from the increased greenhouse gas emissions; 2. The learner understands about harmful impacts of unsustainable energy production, and understands how renewable energy technologies can help to drive sustainable development and understands the need for new and innovative technologies and especially technology transfer in collaborations between countries; (2) Socio-emotional: 1. The learner is able to collaborate with others and develop an overview of solar panel technology ideas as sustainable electrical energy that is mutually agreed upon to deal with climate change; 2. The learner is able to develop a prototype *of* solar panel technology as sustainable electrical energy that represents an overview of the development of sustainable electrical energy in their country; (3) Behavioural: 1. The learner is able to anticipate, estimate, and assess the impact of personal, local and national decisions or activities on other people and regions of the world in developing a prototype of solar panel technology as sustainable electrical energy; 2. The learner is able to compare and assess prototype models of solar panel technology as different sustainable electrical energy and their suitability for different energy solutions and influence solar panel technology to produce safe, reliable, and sustainable energy.

2.4 Research Instruments

Three types of instruments were used in this study, namely the development of the learning website, the validation of the learning website, and the response of the views of physics teachers and prospective teacher students. First, the development of a learning website uses the waterfall design method which consists of five stages, namely requirements analysis, design, implementation, verification, and maintenance (Prasetya et al., 2023). The first stage is requirements analysis, this very important initial stage by collecting and documenting all project requirements. This stage consists of (1) material and curriculum analysis, where materials are selected based on the field of study in high school science subjects, especially physics material; (2) Analysis of the use and suitability of schools that apply a lot of technology using digital learning media; (3) Analyze the appropriate software and hardware for website development and ensure the personal laptop is capable of accessing the software. The second stage is design, consisting of (1) The design of learning materials in the learning website is global warming and renewable energy; (2) Flow chart design as an illustration of the flow in the process of developing a learning website that refers to the problem-based learning phase; (3) Storyboard design as a multimedia plan that will be developed based on a flow chart to create a good flow or website scheme that is easy to use. The third stage is implementation, the design that has been made is implemented in the process of creating the BSB website. BSB's website is built based on storyboard design through (1) Coding, done for interface creation and feature processing to function properly; (2) Website development, based on design needs that have been designed in the previous stage. The fourth stage is verification, and the third stage of designing the BSB website is tested using the black box testing method by researchers to ensure the success rate of website development. In addition, it involves testing by Physics teachers and prospective science teacher students. The fifth stage is maintenance which aims to update and fix some shortcomings, such as errors in accessing the website. Second, validation by experts on learning websites consisting of content, language, and media experts. Assessment instruments are given to all validators without any differences in aspects. This is because it is to find out the perspective of experts on all indicators and aspects. The assessment rubric utilizes a 4-point Likert scale and includes a comment column for each indicator. Validation is needed before the implementation of the learning website on students as a form of evaluation of development by experts (Cahyani & Mardiana, 2018). Third, the response of physics teachers and prospective science teacher students to the learning website 'Learning Sustainable Science'. Indirectly, the response given by physics teachers and prospective science teacher students is a limited trial. These validation standards affect not only

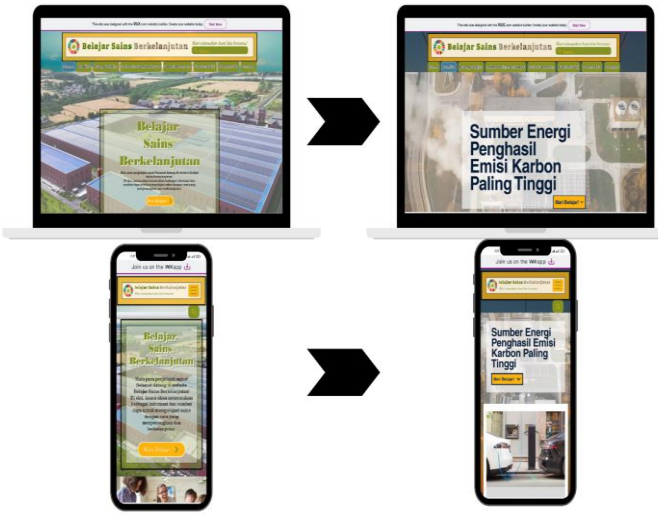


Figure 3 The BSB website interfaces in two different devices, with links https://nuriss074.wixsite.com/sainsberkelanjutan

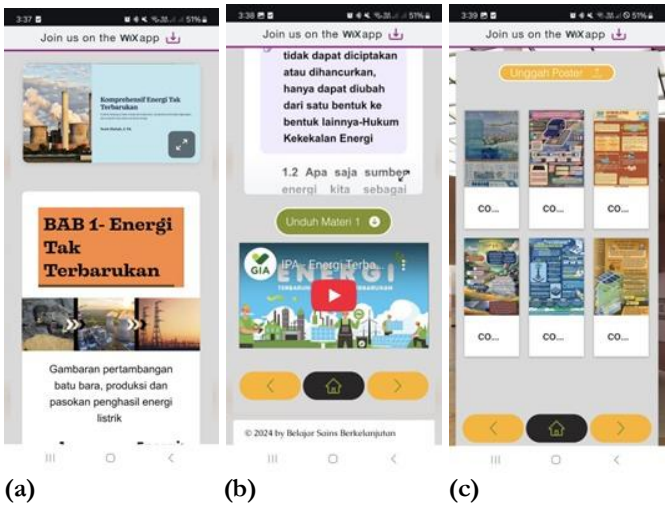


Figure 4 The BSB website accommodates materials explanation by (a) slide, (b) downloadable summary and animation video, and (c) infographics

the technical components of the website but also the perspectives and experiences of both instructors and pre-service teachers who use the platform for educational reasons (Ragan, Lacey, & Nagy, 2003). The questionnaire will use five-dimensional interactivity that will affect the communication needs and motivate students in the use and operation of the website (Prasetya et al., 2023). The five-dimensional interactivity consists of playfulness, choice, connectedness, information collection, and reciprocal communication. The scale used in this study is a Likert scale from 1 to a higher reliability on a five-point scale. This research survey with heterogeneous items shows the level of internal consistency that can be accepted through the results of questionnaires for physics teachers and pre-service science teachers (Loeb et al., 2017). Cronbach's alpha is used to know the internal consistency of teacher and pre-service teacher questionnaires, with a minimum score of 0.7 (Gönen, Deveci, & Aydede, 2022)

The data obtained are quantitative and qualitative. Quantitatively, it is used in the analysis of the results of the validation of experts with a Likert scale of 1-4, the results of the response survey of physics teachers and pre-service science teachers with a Likert scale of 1-5, and internal consistency. Meanwhile, qualitative data is based on feedback from experts and the results of prospective responses from physics teachers and pre-service science teachers after gaining experience in exploring the BSB website.

3. RESULT AND DISCUSSION

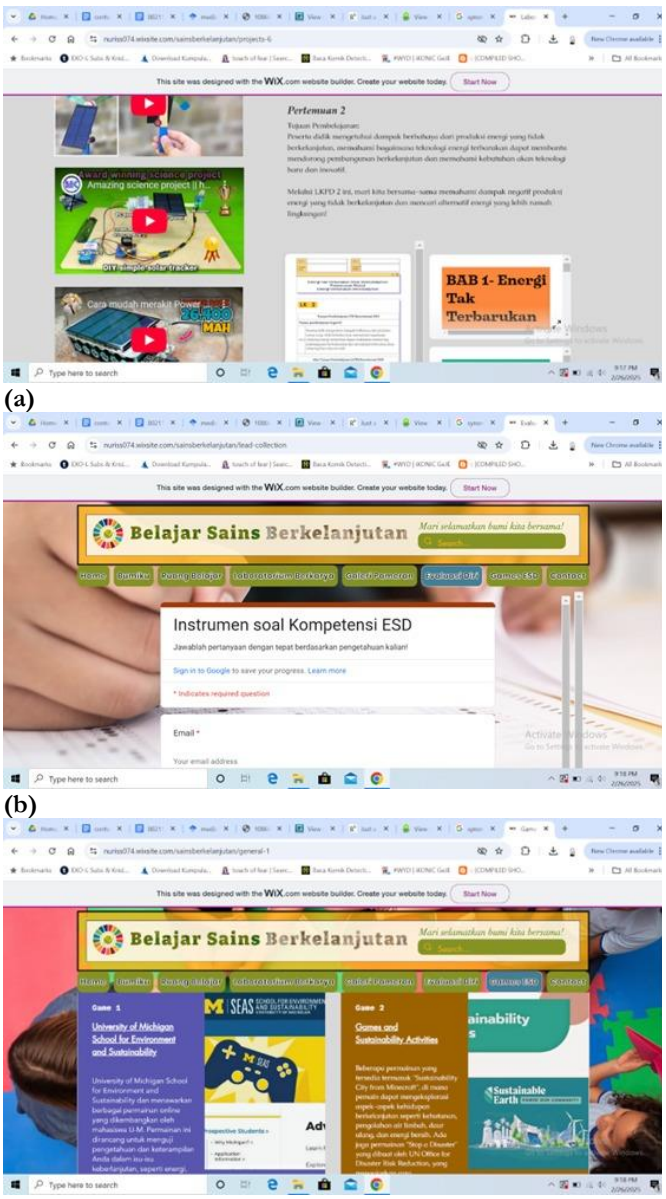
The research findings encompass both quantitative and qualitative data analysis. Before implementation on students, expert validation was conducted to assess the BSB website's efficacy. To evaluate the perceptions of physics teachers and pre-service science teachers regarding the BSB website, the study employed a five-dimensional interactivity framework to measure the website's interactive learning capabilities. Qualitative analytical methods were utilized to interpret expert feedback and analyze the perspectives obtained from both physics teachers and pre-service science teachers.

3.1 Learning Website BSB Development

This educational website was created to offer a flexible interaction space for teachers and students in the learning process. This learning website was developed with a frame of reference for the PBL learning model and the STEAM approach. In addition, it has adjusted the integrated learning content with ESD that is suitable for high school students in tenth-grade. The interface of the BSB website is shown in Figure 3 or can be accessed through this website link https://nuriss074.wixsite.com/sainsberkelanjutan

This website does not hinder students who have different learning styles. Visuals, presented images that interpret the material, such as illustrations of the greenhouse effect that cannot be directly known; auditorial, containing videos that explain the material, such as the relationship between non-renewable energy, climate change, and global warming will be explained in detail; and kinesthetic. Details of the explanation of the material on the BSB website can be seen in Figure 4.

In addition, there is a simple project in this interactive multimedia that students can practice to use solar panel technology as sustainable electrical energy. The website also provides some games related to sustainable energy materials. At the end, students can evaluate their understanding by filling out an evaluation form on the website. An overview of the interactive features of the website can be seen through Figure 5.



(a)

(b)

(c)

Figure 5 Other BSB website features contained (a) practical learning, (b) evaluation form, and (c) games

Through this website, students are trained to have ESD competencies, especially critical thinking and integrated problem-solving. The indicators of these two competencies are different from critical thinking and problem-solving skills in general because they contain sustainability competencies. In accordance with the research of Chusni, Saputro, Rahardjo, & Suranto (2021) and Rihatno et al. (2021) found that using learning websites in the context of sustainability can improve students' environmental awareness, critical thinking skills, and problem-solving abilities. Indirectly, learning activities with the BSB website contain communication and collaboration that can be carried out by students. This is in line with Núñez et al. (2020) and Sebastián-López & de Miguel González (2020) that the website platform also promotes autonomous and collaborative learning by allowing students to access information at any time and from any location, as well as participate in online discussions that help them better comprehend environmental issues. Between students and students or students and teachers can connect and interact with each other on this BSB website, give each other comments, or submit assignments/projects. Consequently, an interactive learning website is essential, featuring videos, animations, and educational games to facilitate understanding and make learning enjoyable.

3.2 Expert Validation

This social learning website will be implemented for physics teachers and high school students in tenth-grade. All items of the content of the website need to be evaluated in detail and determined to prove the validity of the content based on assessments by experts (Loeb et al., 2017). The assessment of the experts was carried out according to the fields of content (physics), language, and media carried out by three physics teachers of tenth-grade from several different schools. This can provide different perspectives based on different school environments, public schools, schools under the auspices of the foundation, and schools under the auspices of the foundation in the boarding school system. However, the rubric of assessment used includes the same aspects and indicators for experts to assess. Examine all aspects and indicators without differentiating between content, language, and media reviews. Based on the assessment rubric used by experts, the final results of validity are shown in Table 1.

The Likert scale used 1-4 is categorized into 4 points, consisting of 1 = not at all valid; 2 = moderately valid; 3 = valid; 4= very valid. The assessment aspect refers to Astuti, Wihardi, & Rochintaniawati (2020), with indicators adapted by the researcher to adjust the content of the BSB website. After the mode of each indicator from the three validators was known, the overall indicator showed an average of 3.94 which was very valid (Jiniarti, Harjono, & Makhrus, 2019). It means that the BSB website is suitable to be used in ESD-based learning. The content of the BSB website meets the needs of ESD learning goals, especially in global warming and renewable energy materials. The design and usability are attractive and easily accessible. Thus, the BSB website can be implemented for the students in the schools to build ESD-based learning. To be highlighted, an e-learning website is possible to support teaching and learning activities between teachers and students; (2) uploading and downloading materials and assignment files; (3) holding virtual classes with instructional videos and online discussion forums between teachers and students; and (4) online evaluation of learning activities (Septyanto, Hamid, & Aribowo, 2020). By integrating with ESD competencies, this kind of website can enhance students' problem-solving abilities and increase their awareness of surrounding environmental phenomena (Pradipta,

Tabel 1 Expert validation rubric's results

Aspects	Indicator	Validator			Mode of Each Indicator
		V1	V 2	V3	
Alignment of Learning Objectives	The content of the website is in line with the ESD learning goals that you want to achieve.	4	4	4	4
	The material presented is relevant to the ESD competencies to be trained.	4	4	4	4
Relevance of Content Items	The content of the website is relevant to global warming and renewable energy materials.	4	4	4	4
	The information presented is accurate and up-to-date.	4	3	4	4
Item Scope Balance	The material coverage of global warming and renewable energy is balanced.	4	4	3	4
	The material is presented thoroughly and does not focus too much on one aspect only.	4	4	4	4
Word and Sentence Structuring	The language used is easy for students to understand.	4	3	4	4
	The sentences used are varied and interesting.	4	4	4	4
Motivation	The website is able to motivate students to learn about ESD.	4	4	4	4
	The design and appearance attract students' attention.	4	4	4	4
Display Presentation	The website's appearance is attractive and aesthetic.	4	4	4	4
	The layout of the website elements is clear and easy to navigate.	3	4	3	3
Design	Website design supports interactive learning.	4	4	4	4
	There are interactive elements such as videos, animations, or quizzes.	4	4	4	4
Interaction and Usability	The website is easy to use and access.	4	3	4	4
	The features of the website work well.	3	4	4	4
Average					**3.94**

Notice: V1= First Expert validator; V2= Second Expert validator; V3= Third Expert

Madlazim, & Hariyono, 2021). These criteria have meaning in the assessment of experts, are very valid, and show the suitability of the website based on the indicators, so there is no need for revision. However, it should not be closed to the points of advice or notes given by experts, which are described as follows:

Expert Content Validation Results

The content on the website combines global warming and renewable energy materials. The assessment was carried out to determine the suitability of the content presented on the website with global warming and renewable energy materials in physics tenth-grade. The results of the validation of experts in the content aspect are shown in Table 2. One of the validators responded that this website has provided various kinds of multimedia presented to support learning. Based on these responses, the researcher optimizes website interactivity by adding illustrations in the form of videos, not just photos or images. The ESD-related games provided are connected to the material so that students are motivated to delve into the material to complete it. Therefore, the incorporation of website technology into ESD allows students to delve deeper into sustainability issues using multimedia features such as videos, simulations, and interactive visualizations, which can help students understand complex concepts about the environment and sustainable development (Nugroho, 2020; Rismayanti, Anriani, & Sukirwan, 2022).

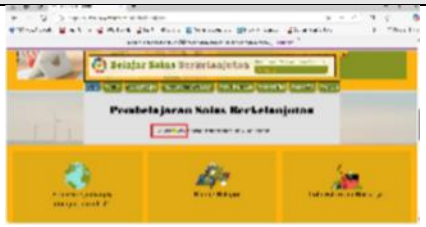
Expert Language Validation Results

Assessment related to grammar in Indonesian, the use of sentences and their structure must be adjusted to the readers, namely students. There are several writing errors based on the assessment of the second validator, such as in giving the numbering of the image in a paragraph that is different from the description number on the image. The third validator suggested that the material be displayed according to the terms of scientific writing, such as the perception that carbon dioxide can be understood as a chemical compound written on CO_2, not 'CO2'. Proper visualization can provide a good depiction to understand the material, in accordance with El Azzouzi, Elachqar, & Kaddari (2023) that the use of websites as a learning medium allows students to visualize abstract concepts through interactive simulations and animations, which can improve their understanding of complex phenomena such as the greenhouse effect and the operating principles of renewable energy. Furthermore, learning websites can

Table 2 Expert assessment results based on content-related comments

Expert validator	Description	Before revision	After revision
3rd Expert validator	Wide variety of multimedia (ESD games, videos, illustrations, text, graphics, and more)	 No video illustration of the greenhouse effect in the display of global warming materials	 In the global warming material, there is an additional video illustrating the greenhouse effect process

Table 3 Expert assessment results based on language-related comments

Expert validator	Description	Before revision	After revision
2nd Expert validator	There are a few writing errors that could be corrected	 Spelling or writing of the word knowladge using 'a' in it	 Writing errors have been justified into knowledge using the 'e' in it
	Some misspellings in the captions of the referenced images or tables	 In renewable energy materials, the table description is called figure 1.1	 Table mentions have been fixed and added captions to tables
3rd Expert validator	It's good, in writing down the chemical compound carbon dioxide is not exactly 'CO2' should be CO_2	 Miswriting of chemical compounds in carbon dioxide	 The writing of the chemical compound carbon dioxide has been replaced correctly to CO_2

incorporate real-time data on climate change and renewable energy use, providing authentic context and increasing the relevance of learning for students (Kurup, Levinson, & Li, 2021; J. Zhang et al., 2022). Comments related to the language provided by the validator are found in Table 3.

Expert Design Validation Results

The appearance of the learning website considers the theme of balanced and contrasting colors, layout, features, drawings, the selection of graphics, videos, illustrations, and ESD-related games is applied to this website. Developed websites require adequate loading times for their elements and features, this is important because research shows that website loading speed has a significant impact on user experience and engagement (Cai, Li, & Zhang, 2020; López-Gorozabel et al., 2021). Researchers should consider revising the size of the elements used on the BSB website. Another form of response is that the use of email as a contact person is suggested to be the same as writing as a website link. Experts said in Table 4 that there are features that are difficult to click because the process of loading all elements such as animations, videos, documents, and games, in the website takes time to be ready to use so that it can run.

Table 4 Expert assessment results based on design-related comments

Expert validator	Description	Before revision	After revision
1st Expert validator	The website is very good, just fix some features that seem difficult when clicked.	 Some features are difficult to click, this is because it is still in the process of loading animations, images and videos contained in the website.	 When browsing or navigating between navigation, it is expected that the feature is not immediately clicked and waited for a few seconds (5-10 seconds) for the feature to appear clearly. In addition, for faster appearance, by reducing the size of images, illustrations or videos.
2nd Expert validator	Developer emails in the initial display and in contacts are different, maybe they can be equated.	 The email presented on the initial display (Home) is different from Contact	 Use a single email, by changing the email on Home

3.3 The Response of Physics Teachers and Pre-Service Science Teachers

The responses of physics teachers and pre-service science teachers were used to find out responses and feedback related to the use of the BSB learning website, which was carried out through the results of a survey with the following explanation:

Physics Teacher's Respond

The interactivity of the learning website was assessed by 5 physics teachers who taught physics subjects in tenth-grade X, with each individual teaching in a different school in the Surabaya area. Before being implemented on students, feedback from physics teachers is needed as a consideration and improvement for the development of the BSB website. The results of the physics teacher's response are shown in Table 5.

All statements given in the survey resulted in a score above 84 to 100 which was categorized as very good (Latifah, Yuberti, & Agestiana, 2020). The results of the response illustrate that website development has a five-dimensional interactivity which includes playfulness, choice, connectedness, information collection, and reciprocal communication. Each of the five dimensions scored in order, namely 91, 89, 91, 92, and 94. Each dimension has 5 statements, also showing positive results with the details of the statements in Table 6.

Each statement has been graded on a scale of 1 to 5, with a scale decision 5: Strongly agree; 4: Agree; 3: Slightly disagree; 2: Disagree; 1: Strongly disagree (Krisnaningsih & Hariyono, 2022). The assessment of all teachers showed an average of responses that agreed that the website could be used for teachers and students as a learning support technology medium in accordance with the PBL-STEAM model and materials on global warming and renewable energy. Some research also supports that the development of technology has provided various digital tools, which increase the effectiveness of online education and make it more dynamic and interesting (Francis & Santhakumar, 2020; Krishnaprabu, 2019).

Table 5 Physics teachers' responses related to learning websites

Dimension	Item	Physic Teacher					Average	Score	Result	Average Score
		T1	T2	T3	T4	T5				
Playfulness	1	5	5	5	5	3	4.6	92	Very good	91
	2	5	5	4	4	3	4.2	84	Very good	
	3	5	5	5	4	4	4.6	92	Very good	
	4	5	5	5	5	3	4.6	92	Very good	
	5	5	5	5	5	4	4.8	96	Very good	
Choice	6	5	5	4	5	3	4.4	88	Very good	89
	7	4	5	5	5	4	4.6	92	Very good	
	8	5	5	5	5	4	4.8	96	Very good	
	9	5	4	4	4	4	4.2	84	Very good	
	10	5	5	4	4	3	4.2	84	Very good	
Connectedness	11	5	5	5	5	3	4.6	92	Very good	91
	12	5	4	5	5	4	4.6	92	Very good	
	13	5	5	4	4	3	4.2	84	Very good	
	14	5	5	5	5	4	4.8	96	Very good	
	15	5	5	4	5	4	4.6	92	Very good	
Information Collection	16	5	5	4	5	3	4.4	88	Very good	92
	17	5	5	4	4	3	4.2	84	Very good	
	18	5	5	5	5	4	4.8	96	Very good	
	19	5	5	5	5	4	4.8	96	Very good	
	20	5	5	5	5	4	4.8	96	Very good	
Reciprocal communication	21	5	5	5	5	4	4.8	96	Very good	94
	22	5	5	5	5	5	5	100	Very good	
	23	5	4	5	5	4	4.6	92	Very good	
	24	5	5	5	5	3	4.6	92	Very good	
	25	5	5	5	4	4	4.6	92	Very good	
Rata-rata							**4.6**	**92**	**Very good**	

Table 6 Statements of the questionnaire as a survey of the use of the BSB website

Dimension	Item	Statement
Playfulness	1	The learning website is easy to use in teaching global warming and renewable energy materials
	2	The website provides clear guidelines for the implementation of PBL-STEAM learning
	3	The content and activities in the website make me feel satisfied with the learning process
	4	The website content makes me enthusiastic in teaching the material
	5	The website content motivates me to explore more about global warming and renewable energy
Choice	6	The website provides a variety of learning activities that are in accordance with the PBL-STEAM approach
	7	Navigation buttons on the main page make it easy to operate the website
	8	Menu options and links help me access various learning resources easily
	9	The website provides flexibility in choosing learning strategies
	10	The navigation structure of the website makes it easy to find the content needed
Connectedness	11	Each part of the website has a clear connection in supporting learning
	12	The links between the pages of the website work well
	13	The website integrates various aspects of PBL, STEAM, and ESD coherently
	14	The website content is connected to the real-world context
	15	The website facilitates the connection between theory and practice
Information Collection	16	The website helps access students' initial knowledge about global warming and renewable energy
	17	Website content enriches insights into PBL-STEAM implementation
	18	The website provides relevant sources of information for learning
	19	The website facilitates the collection of data and learning information
	20	Website content supports the development of ESD competencies
Reciprocal communication	21	The website provides a feature to provide learning feedback
	22	Contact pages make it easy to communicate with website developers
	23	The website facilitates interaction between users
	24	The website supports collaboration in the implementation of learning
	25	The communication feature of the website supports learning reflection

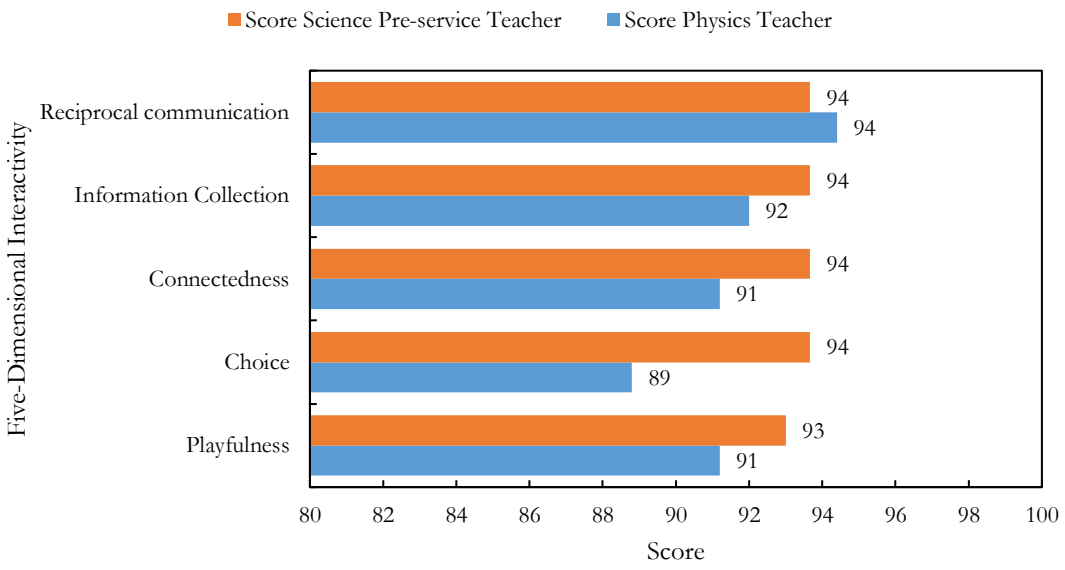


Figure 6 Comparison of response scores between physics teachers and pre-service science teachers

The findings in this assessment of the physics teacher's response, in the reciprocal communication dimension, provide an overview that the website provides excellent mutual communication with the highest score compared to other interactivity dimension scores. This illustrates that mutual communication between teachers and students has been available on this learning website, either between students and students, teachers and students, or any visitor with the website developer. Communication in the world of education, teaching, and delivering any information is very important, especially when it comes to humans to convey sustainable behavior. As a bridge, the development of this learning website, platforms are designed to promote learning, teaching, and community engagement among educators, with the aim of enhancing their pedagogical competence and fostering a mindset of sustainable development (Wang et al., 2023).

Pre-Service Science Teacher's Respond

The website was conducted on a limited trial to pre-service science teachers as many as 12 science education students in Surabaya. Assessment based on five-dimensional interactivity shows that four of the five dimensions of magnitude score are almost the same overall. The four dimensions have an average score of 94, consisting of choice, connectedness, information collection, and reciprocal communication. The response is divided into five aspects based on five-dimensional interactivity (Prasetya et al., 2023). Each dimension of interactivity has a meaning that describes the interactivity of the website being developed. A score that has a very good meaning describes that the website has been successfully developed by covering the dimension of interactivity. The results of the pre-service science teacher's response are shown in Figure 6.

The graph in Figure 6 illustrates the differences in playfulness. These aspects describe the comfort, satisfaction, and motivation after using the learning website. Even though it has the lowest score in the fifth position, this dimension is still in the very good category with a score of 93. This is because there are animations, videos, and games related to ESD that will provide deep meaning for students when applied to learning. In accordance with research Taira, Agustin, & Rochintaniawati, (2024) that learning media can accommodate and facilitate students' curiosity and understanding, showing the effectiveness of the media.

Then the four dimensions assessed by pre-service science teachers have the same score and also have a very good category, the choice dimension of interaction can be defined as the availability of options and unrestricted navigation in cyberspace. In the development of this learning website, navigation options are available to provide unlimited navigation in understanding the global management and renewable energy materials in the website. When navigation provides convenience, the process of accessing, and assisting in PBL-STEAM learning activities will have an impact on student learning outcomes related to ESD competencies. This will continue in the aspect of connectedness, giving the impression of meaningful learning practices and increased understanding. Students who receive information about what they need, then build their connection and trust in using this website. Information collection, providing data that is a reference for tenth-grade students who study global warming and renewable energy. In addition, the learning website is built within the framework of PBL and the STEAM approach. Learning with an approach through the implementation stage to use their knowledge in the fields of science, technology, engineering, and mathematics to solve

Table 7 Results of internal consistency of physics teacher response questionnaire

Reliability Statistics Cronbach's Alpha	N of Items
.978	25

Table 8 Results of internal consistency of pre-service science teacher response questionnaire

Reliability Statistics Cronbach's Alpha	N of Items
.905	25

problems (Kartini, Widodo, Winarno, & Astuti, 2021; Yuni, Sahyar, & Bukit, 2021; Lestari, Ibrahim, & Iriani, 2023). The information on the learning website provided to students aims to equip ESD competencies, especially critical thinking and problem-solving. It is hoped that through these competencies, students can address various global issues, particularly concerning SDGs 7 and 13. One of the 17 sustainable development goals is SDGs 7—Affordable and Clean Energy, and SDGs 13—Climate Action (UNESCO, 2017). The relationship between affordable and clean energy with climate action is essential for creating a sustainable future. Based on the basis of learning outcomes, the curriculum is directed to be connected to sustainable development goals. The website platform encourages ESD pedagogical ideas including problem-based learning, transformative learning, and lifelong learning by offering interactive features that allow students to actively participate in the learning process (Mulyadiprana et al., 2022; Zainal, 2022). Finally, reciprocal communication from visitors can be sent through the available email field. Communication is carried out by students as participation in active learning and can be monitored through the learning website.

All responses from physics teachers and pre-service science teachers show a positive picture to be applied to high school students. The assessment and suggestions provided will be revision material to develop a better learning website in the future. The excellent response to the BSB website can be used for PBL-STEAM learning activities in equipping ESD competencies. The development of this learning website supports the realization of sustainable science education for students.

Internal Consistency of Pre-Service Science Teachers' and Physics Teachers' Respond

In knowing the internal consistency, Cronbach alpha is used to see all items in the instrument interconnected with each other as a whole of other items (Gönen, Deveci, & Aydede, 2022). Internal consistency in the responses of physics teachers and pre-service science teachers is shown in Tables 7 and 8. The results showed a high Cronbach alpha score of 0.978 so the physics teacher's response questionnaire instrument to the BSB website was interpreted as reliable. The Cronbach alpha of pre-service science teachers is smaller than that of teachers, but the value still exceeds the minimum limit of 0.7 so the pre-service science teacher response questionnaire instrument has reliable internal consistency.

Cronbach's alpha statistical test is an important tool for determining the internal consistency reliability of questionnaire responses in media development studies (Barbera, Naibert, Komperda, & Pentecost, 2021). The reliability coefficient measures the degree of correlation among a set of items (Miller & Simmering, 2020). In the development of this learning website, the response questionnaire showed a high connection between five-dimensional interactivity items which explained that the BSB website supports being a learning medium for high school students. Cronbach's alpha is especially useful in educational media development studies because it helps researchers validate the consistency of participant responses across multiple questionnaire items, thereby strengthening the credibility of the evaluation instrument (Miller & Simmering, 2020). Both physics teachers and pre-service science teachers' responses show a Cronbach alpha above 0.7 demonstrating that the questionnaire items effectively measure the same underlying construct of the developed media's effectiveness. It shows the instrument's internal consistency and dependability by determining how each item in the instrument relates to every other item and to the entire instrument (Astuti, Wihardi, & Rochintaniawati, 2020). Electronic communication technologies are speeding up their invasion of every sphere of life, and educational institutions have been struggling for decades to recognize how these gadgets can share information, be useful, and have an interactive style (Ansari & Khan, 2020). Indeed, the future generation finds learning more enticing due to the versatility and non-intrusive nature of today's technologies (Haleem, Javaid, Qadri, & Suman, 2022). Physics teachers and pre-service science teachers recognize the potential of websites as digital learning tools that can enhance the teaching and learning process. E-learning has several advantages that help accomplish SDGs, including flexibility, diversity, inclusion, equality, internationalization, accessibility, and lifelong learning (Ghanem, 2020). This is particularly relevant for topics related to global warming and renewable energy, which align with the Sustainable Development Goals (SDGs). The development of the BSB website has significant implications for enhancing ESD's competence of global warming and renewable energy materials.

4. CONCLUSION

The BSB learning website is designed using a waterfall model, featuring requirements analysis, design, implementation, verification, and maintenance stages. The requirements analysis stage consists of material and curriculum analysis, analysis of school use and suitability, and analysis of appropriate software and hardware. Then the design stage, which consists of the design of learning

materials, flow chart design, and storyboard design. The implementation consists of two stages, namely coding and website development. The researcher conducted verification using the black box testing method. The last stage of maintenance is the maintenance of the BSB website to update and fix several shortcomings, such as errors in accessing the website. Before being applied to students, the website is evaluated by experts in the aspects of content, language, and media. The website media validity got a very valid result with the average of all validators being 3.94. It is necessary to make revisions based on comments or responses from experts' assessments. In addition, the responses from the responses of physics teachers and pre-service science teachers have several considerations for the BSB website to be evaluated regarding five-dimensional interactivity. The physics teacher's response had excellent results with scores ranging from 84 to 100. Perspective for pre-service science teachers also had a positive response with an average score above 93. Based on internal consistency from questionnaires, physics teachers and pre-service science teachers have Cronbach alphas of 0.978 and 0.905, respectively. Both showed that the approval of the questionnaire was very reliable because it was above the minimum limit of 0.7. Furthermore, physics teachers and pre-service science teachers realize that learning using websites can help the learning process be more structured as presented in digitalization. The discussion on global warming and renewable energy can be presented more clearly without unrealistic optimism that is merely expressed through writing. In addition, the connection of the two materials is an urgent topic for now in shaping a sustainable life for future generations. However, it is a form of one of the shortcomings of this research because it only discusses the two materials. It is recommended that further research be conducted to create additional websites focused on other learning materials that support the improvement of ESD competencies. In addition, the user group of this website is limited to tenth-grade and in formal learning activities. So that further research can develop ESD-related education websites that can be accessed more widely for all groups and levels of education, both formal and non-formal.

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