

Development of an Earth Nullschool-Assisted Learning E-Module on Climate Change Topic

Puan Cahyani Gusmer^{1,2}, Tugiyu Aminoto and Erlida Amnie¹

¹Department of Physics Education, Universitas Jambi, Jl. Jambi-Muaro Bulian, Muaro Jambi, Jambi, Indonesia

²E-mail: apuanchn@gmail.com

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Abstract. Climate change is a global issue requiring a strong scientific understanding, particularly of atmospheric dynamics and the factors driving rising global temperatures. However, physics learning on this topic remains dominated by theoretical approaches, limiting students' opportunities to analyze real-time data. This study aims to develop an Earth Nullschool-assisted learning e-module on climate change materials as an interactive, contextual digital learning medium that supports 21st-century skill enhancement. This research employed a research and development (R&D) method using the 4D development model, comprising define, design, develop, and disseminate stages. The study was limited to the development stage, as the main objective was to produce a valid and feasible model. The research subjects were grade X students of SMAN 10 Kota Jambi, selected using random sampling. The instruments included validation questionnaires from material, media, and pedagogical experts, as well as student response questionnaires. Quantitative data were analyzed using a Likert scale, while qualitative analysis was obtained from comments, critiques, and suggestions from validators and teachers. The results show that the e-module received a "very feasible" rating from the three experts and a positive response from the teacher and students. Thus, the Earth Nullschool-assisted e-module meets feasibility criteria as learning medium for climate change topic.

Keywords: e-module, climate change, Earth Nullschool, 4D model

1. Introduction

The 21st century marks an era of educational transformation that requires students to master skills far beyond memorizing and understanding concepts alone. The Partnership for 21st Century Skills identifies six core competencies that today's generation must possess, known as the 6 Cs: Critical Thinking, Creativity, Collaboration, Communication, Character, and Citizenship [1]. Critical thinking occupies a fundamental position among these skills and serves as the foundation for the development of the others. It is widely recognized as an essential need of the 21st century [2]. Critical thinking is a fundamental intellectual ability in modern education. It requires individuals not only to accept information passively but also to examine and evaluate their beliefs, assumptions, and knowledge by using valid evidence [3].

The importance of critical thinking also aligns with the direction of national education as outlined in the Kurikulum Merdeka, particularly through the Profil Pelajar Pancasila, which emphasizes "Critical Reasoning" as one of the main characteristics Indonesian learners must possess. Critical reasoning in the Profil Pelajar Pancasila includes the ability to process information objectively, build connections among different pieces of information, analyze data to make decisions, and reflect on one's thoughts. [4]. Critical thinking is a mental process of researching ideas or information in greater detail [5]. It not only relies on existing knowledge but also involves connecting learning concepts with real-life contexts so that students' ability to discover concepts independently through reasoning continues to develop [6]. In the context of science learning, particularly physics, critical thinking skills not only help students understand natural phenomena but also prepare them to face global challenges that require science- and technology-based solutions [7].

One of the most urgent global challenges requiring strong scientific understanding and critical thinking skills is climate change. Phenomena such as global warming, sea level rise, changes in extreme weather patterns, and ecosystem degradation are realities that cannot be ignored. Data from the Intergovernmental Panel on Climate Change (IPCC) indicate that Earth's average surface temperature has increased by about 1.1 °C since the pre-industrial era, with impacts increasingly felt worldwide, including in Indonesia. Climate change is not merely theoretical learning material, but a real issue that affects everyday life and the future of younger generations. Therefore, climate change learning must be designed so that students not only understand the scientific concepts but also analyze the causes, impacts, and solutions through deep critical thinking.

Climate change material in the senior high school physics curriculum includes essential concepts such as the greenhouse effect, energy transfer within the Earth system, the carbon cycle, and the relationship between human activities and changes in global climate patterns. This material is highly relevant to students' lives, as it connects physics principles to the environmental phenomena they observe. However, the complexity of climate change, involving numerous interrelated variables and processes, requires learning approaches capable of visualizing abstract phenomena into more concrete and comprehensible forms. Students need to see how climate data change in real time, how wind patterns and temperatures vary across regions, and how different factors interact within the global climate system. Without adequate visualization, climate change concepts remain abstract and complex for students to understand comprehensively.

Field observations show that climate change learning in schools remains theoretical and conventional. Interviews with a physics teacher at SMAN 10 Kota Jambi indicate that the learning process is dominated by lectures and textbook explanations, with little real-world visualization or exploration of actual data. Students struggle to imagine how climate change occurs globally, how atmospheric circulation affects local weather, and how different climate parameters are interconnected. Such abstract learning leads to low cognitive engagement, causing students to memorize concepts without truly understanding or applying them in real-life contexts. Consequently, the development of critical thinking, an essential aspect of science learning, becomes suboptimal. Students are not trained to ask investigative questions, analyze data, evaluate information, or draw conclusions based on empirical evidence.

Another problem faced in schools is the limited availability of teaching materials. Textbooks typically present climate change material linearly, using static illustrations that fail to capture the constantly changing dynamics of the climate system. Teachers have limited access to interactive, contextual, and up-to-date learning resources. Students need teaching materials that not only present theory but also facilitate meaningful learning about climate change. They require resources to observe, analyze, and interpret climate data directly. These limitations also reduce opportunities for students to engage in exploratory and independent investigative activities. Learning becomes monotonous, less stimulating, and fails to ignite curiosity and motivation. This further complicates the development of critical thinking, which requires continuous practice through meaningful and challenging learning activities.

To address these challenges, innovation is needed to develop teaching materials that bridge the gap between theoretical learning and real-world climate change phenomena. Learning e-modules emerge as an alternative solution that combines the advantages of printed modules with interactive digital technology. An electronic module is a digitally formatted module that contains text, images, or both, and includes digital electronics material accompanied by simulations that are feasible and suitable for learning [8]. An Earth Nullschool-assisted e-module offers an innovative learning approach by presenting real-time and interactive global climate data visualizations. Earth Nullschool is a climate data visualization platform that displays wind patterns, temperature, humidity, ocean currents, and other atmospheric parameters in dynamic, easy-to-understand animations. Students can explore actual climate data, observe changing patterns, compare conditions across regions, and analyze cause-and-effect relationships of climate phenomena. This interactive visualization provides a more concrete and engaging learning experience while allowing students to develop higher-order thinking skills through exploration and discovery.

The development of this e-module adopts the Problem-Based Learning (PBL) syntax, which has been proven effective in developing critical thinking skills. Problem-Based Learning (PBL) gives students responsibility for finding solutions to problems and motivates them to learn independently or in groups [9]. PBL places learners in authentic problem situations that require them to identify problems, formulate hypotheses, gather information, analyze data, and construct solutions logically and systematically. Through the PBL syntax integrated into the e-module, students are guided through the stages of problem orientation, planning for learning, independent and group investigation using Earth Nullschool visualizations, developing and presenting findings, and analyzing and evaluating the problem-solving process. Each stage is designed to stimulate students' critical thinking skills from analyzing situations, evaluating information, making inferences, constructing arguments, to making decisions based on data and scientific evidence [10].

The Earth Nullschool-assisted e-module with PBL syntax is expected to bridge theoretical learning with deep conceptual understanding and the development of critical thinking. Students do not merely learn concepts passively but engage actively in exploration, investigation, and problem-solving using real data and visualizations. Learning becomes more meaningful because students can see the relevance of the material to real-world issues and better understand the complexities of climate change. Physics learning on climate change topics at SMAN 10 Kota Jambi can thus become more contextual and interactive, equipping students with the essential 21st-century skills needed to face future challenges.

Based on the explanation above, this study aims to develop a valid, practical, and effective Earth Nullschool-assisted learning e-module on climate change material to facilitate the development of students' critical thinking skills at SMAN 10 Kota Jambi. This research is expected to significantly improve the quality of physics education and the development of innovative teaching materials aligned with the demands of 21st-century education.

2. Methods

This study employed a Research and Development (R&D) design to develop a learning e-module on climate change, with assistance from Earth Nullschool. The development model used was the 4D model proposed by Thiagarajan, Semmel, and Sammel (1974). The 4D model consists of four stages: define, design, develop, and disseminate. The main objective of this research was to produce a valid and feasible e-module for instructional use, rather than to test its effectiveness on a large scale. The 4D model was chosen because its procedures are simple, systematic, and flexible, making it easy to apply in the development of learning media, particularly for digital products such as e-modules.

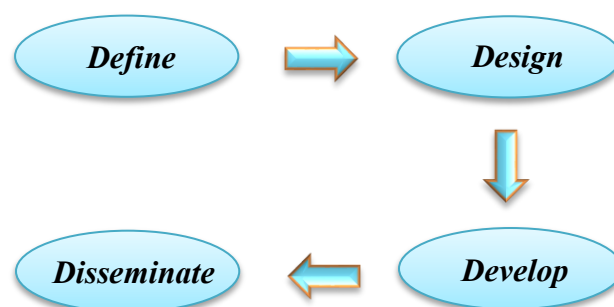


Figure 1. Model 4D.

The subjects of this research were grade X students at SMA Negeri 10 Kota Jambi. Data collection was carried out in November 2025. The subjects were selected using random sampling, in which students were chosen randomly without considering specific criteria, giving each student an equal opportunity to become a respondent. The selected students were asked to complete a questionnaire about the e-module that had been developed.

Data analysis in this study was conducted using both quantitative and qualitative approaches. Quantitative analysis was obtained from validation questionnaire scores filled out by two lecturer validators (a material expert and a media expert) and one expert teacher, along with student responses

to the e-module. These scores were used to assess the validity and feasibility level of the Earth Nullschool-assisted e-module on climate change material. Qualitative analysis was obtained from comments, critiques, and suggestions from validators and expert teachers, which served as the basis for revising the e-module before and after the trial stages.

The product trial was conducted in two stages: Small Group Test (Uji Kelompok Kecil/UKK) and Large Group Test (Uji Kelompok Besar/UKB). The UKK was administered to tenth-grade students about to study eleventh-grade material, as well as to eleventh-grade students who had already studied the material. Each class involved 10 students, so the UKK was used to assess readability, initial understanding, and the suitability of the e-module's presentation. The sample of 10 students in the UKK aligns with other development studies at UNY, which used 10 students for the UKK and 36 students for the UKB, as well as studies that employed 10 students as UKK participants before proceeding to large-scale testing. The UKB was conducted with an entire tenth-grade class to obtain a broader picture of user responses and to evaluate the practicality of the e-module in actual learning situations. The sample selection was conducted using random sampling, ensuring that every student had an equal chance of being selected and minimizing bias in the data collection process.

Data obtained from the questionnaires were then converted into a Likert scale for further analysis. The scale used to evaluate the questionnaire instruments was as follows.

Table 1. Rating scale for initial observation questionnaire instruments [11].

Category	Score
Strongly Disagree	1
Disagree	2
Agree	3
Strongly Agree	4

The data obtained from the questionnaires were then converted into a Likert scale for further analysis. The scale used to assess the questionnaire instruments is as follows:

Table 2. Rating Scale for Research Instruments [12].

Category	Score
Strongly Inappropriate	1
Inappropriate	2
Appropriate	3
Strongly Appropriate	4

The feasibility of the e-module was evaluated based on assessments from media, material, and pedagogical experts. The data from each validator were analyzed using a five-category Likert scale. The feasibility level was determined using the following percentage calculation formula. [13] :

$$Percentage = \frac{Total\ Score\ Obtained}{Maximum\ Possible\ Score} \times 100\% \quad (1)$$

The resulting percentage was then interpreted into feasibility categories using the following reference:

Table 3. Validity Level Interpretation Scale [14].

Percentage Scale	Validity Level
85%-100%	Very Valid
70%-85%	Valid Enough
50%-70%	Less Valid
0%-50%	Not Valid

3. Results and Discussion

The outcome of this Research and Development (R&D) study is an Earth Nullschool-assisted learning e-module on climate change material. The developed e-module is an interactive digital learning resource that integrates the syntax of Problem-Based Learning (PBL) with real-time climate data visualizations from the Earth Nullschool platform. In developing this instructional media, the researcher used the Canva application for visual design and layout, as well as an interactive PDF format accessible on various digital devices, including smartphones, laptops, tablets, and computers.

The development of this e-module employed the 4D model developed by Thiagarajan, Semmel, and Semmel, which comprises four main stages: Define, Design, Develop, and Disseminate. However, this study was carried out only up to the development stage, as the research focused on producing an e-module that is valid and practical.

3.1. Define Stage

An initial-final analysis was conducted using a student needs questionnaire and interviews with physics teachers at SMA Negeri 10 Kota Jambi. The results showed that climate change learning was still dominated by lectures and relied solely on textbooks with static illustrations, leaving students struggling to understand global climate dynamics. The lack of visualization and data exploration made learning less engaging, reduced student involvement, and hindered the optimal development of critical thinking skills.

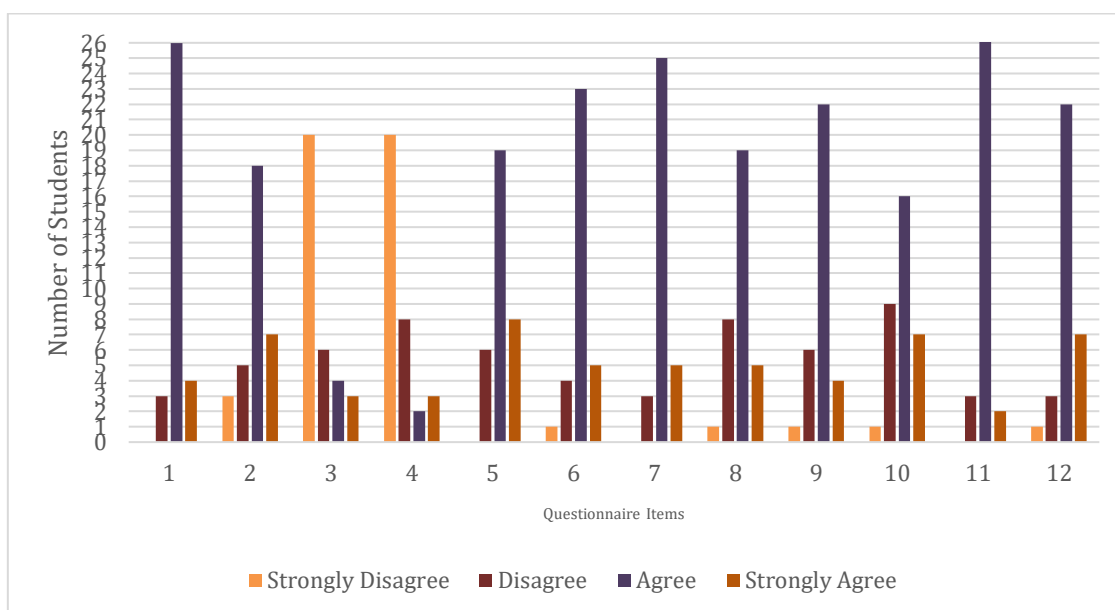


Figure 2. Distribution of students' responses to the learning needs questionnaire on climate change.

The student needs questionnaire consisted of 12 statements that explored students' interest in climate change topics, their level of difficulty in understanding climate change concepts, the use of visual media in classroom instruction, students' experience in using real-time data-based learning media, as well as their interest and readiness to use learning media based on real environmental data in physics learning.

The interview with the physics teacher revealed that climate change instruction is still dominated by lecture-based teaching and reliance on textbooks with static illustrations. The teacher reported that the limited use of interactive visual media makes it difficult for students to understand climate dynamics and the concept of the greenhouse effect. The teacher also stated that real-time data-based learning media have not yet been implemented in classroom instruction, but expressed strong support for developing innovative digital learning media to enhance student engagement and understanding.

3.2. Design Stage

The initial design of the e-module and the development of a storyboard were carried out as a guide in the product development process. The storyboard contained layout sketches for each e-module page, descriptions of the content to be presented, specifications of visual elements (images, diagrams, icons), placement of interactive links, and navigation flow between pages. The storyboard preparation included several stages: determining the overall structure of the e-module from beginning to end, designing the layout of each page by applying principles of visual design, selecting an appealing color scheme that does not distract from learning dominated by blue, which is associated with climate themes choosing readable digital fonts using Times New Roman for body text, designing intuitive and consistent navigation icons and buttons, determining the placement of illustrations, images, and diagrams that support conceptual understanding, and organizing text content according to the PBL syntax for each learning unit.

3.3. Develop Stage

The storyboard created during the design stage was realized as an interactive learning e-module using the Canva application. The realization process included developing an engaging front cover that reflects the theme of climate change, preparing the introductory section consisting of a foreword, user instructions, and concept map, developing the learning content with consistent layout and appealing visuals, integrating links directing students to Earth Nullschool with clear usage guidelines, organizing learning activities based on PBL syntax, creating evaluation questions with varying difficulty levels, and preparing a glossary and reference list.

The developed e-module has the following specifications: (1) Format: Heyzine for easy access; (2) Structure: Comprising the introductory section (cover, foreword, user instructions, competencies and learning objectives, concept map), content section (PBL-based learning materials, Earth Nullschool links, investigation activities, evaluation and reflection), and closing section (author profile, glossary, references); (3) Visual Design: Using a blue color scheme aligned with the climate theme, Times New Roman font for readability, high-quality illustrations and diagrams, and consistent, neat layouts; (4) Interactive Elements: Links to Earth Nullschool and intuitive navigation buttons; (5) Content: Organized following the PBL syntax, equipped with contextual climate change case examples, detailed and easy-to-follow Earth Nullschool exploration guidance, and evaluation questions that support critical thinking skills.

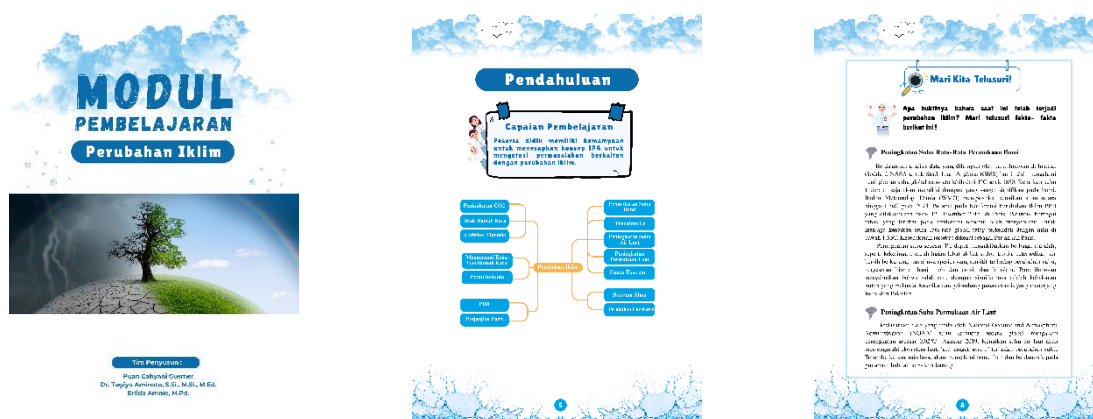


Figure 3. Cover page, introduction, and material section.

The e-module's cover page is designed with a simple yet informative appearance. It includes the e-module title, the author's identity, and thematic illustrations relevant to climate change, providing an engaging and professional first impression for students. The introductory page contains the learning objectives and a concept map that offer an initial overview of the material and the competencies to be

achieved, helping students understand the context before entering the core learning section. The material pages present the PBL syntax, simplified to make it easier for students to understand. Each step of the PBL process is explained in clearer, more concise language, enabling students to follow the problem-solving sequence more effectively and in a more structured manner.

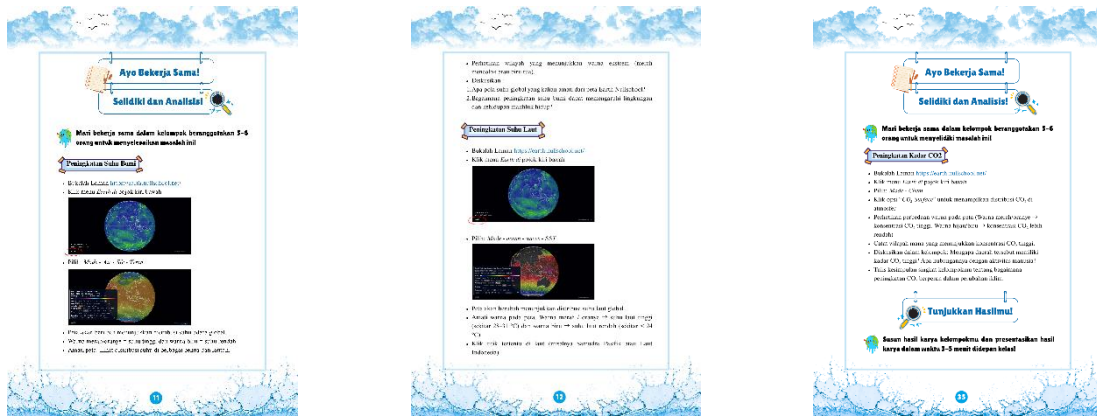


Figure 4. Investigation page.

The investigation section allows students to explore data according to the needs of the given problem. In several activities, students use Earth Nullschool to analyze real-time climate data, while in other activities, more relevant data sources are used. This section is designed to ensure that the investigation remains contextual and aligned with the objectives of each stage of the PBL process.

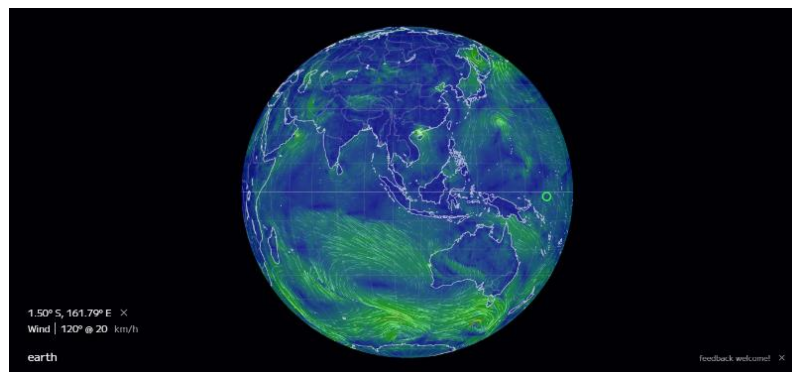


Figure 5. Earth nullschool homepage display.

The developed e-module can be accessed at the following link: <https://heyzine.com/flip-book/b48cda9df8.html>. To access the Earth Nullschool platform used in the learning activities, students can visit: Earth Nullschool Link: <https://earth.nullschool.net>.

3.3.1. Expert Validation Results

The validation process for this Earth Nullschool-assisted learning e-module was carried out in two stages, involving material and media expert validators. Validation was conducted to ensure that the developed product met the eligibility standards for both the content substance and the technical aspects of digital learning media.

Material validation stage I was conducted by three expert validators, who assessed four key aspects: the suitability and accuracy of the material, language and terminology, the presentation of the material and media, and learning evaluation. The results of the material validation stage I are presented in Table 5.

Table 5. Stage I material validation scores by three validators.

Aspect	Percentage	Category
Suitability and Accuracy of Material	91.6%	Very Eligible
Language and Terminology	88.8%	Very Eligible
Presentation of Material and Media	89.5%	Very Eligible
Learning Evaluation	81%	Very Eligible

Based on Table 5, all aspects received percentages above 80% and were categorized as very eligible. The element of material suitability and accuracy received the highest rate, 91.6%, indicating that the climate change material presented in the e-module aligns with the Learning Outcomes (CP) and Learning Objectives (TP) of the Merdeka Curriculum. The aspect of language and terminology obtained 88.8%, indicating that the language used is communicative and the physics terminology is appropriate. The presentation aspect received 89.5%, indicating that the material is systematically presented and well-integrated with Earth Nullschool visualisations. Meanwhile, the learning evaluation aspect received the lowest percentage, 81%, but was still categorized as very eligible. Despite meeting the criteria, the validators provided several suggestions to refine the e-module.

Media validation stage I was also conducted by three expert validators who assessed four aspects: initial display, readability and text design consistency, visuals, and navigation. The results of the media validation stage I are presented in Table 6.

Table 6. Stage I media validation scores by three validators.

Aspect	Percentage	Category
Initial Display	93%	Very Eligible
Readability and Text Design Consistency	83%	Very Eligible
Visuals	86%	Very Eligible
Navigation	87%	Very Eligible

Based on Table 6, all media aspects received very high ratings. The initial display aspect received the highest percentage, 93%, indicating that the e-module's cover, opening layout, and introductory design are visually appealing. The navigation aspect obtained 87%, suggesting that the navigation buttons, menus, and overall structure of the e-module facilitate user access throughout the content. The visual aspect received 86%, indicating that the images, graphics, and Earth Nullschool integration are already good. Meanwhile, readability and text design consistency obtained the lowest percentage, 83%, though still within the very eligible category. Validators provided suggestions such as adjusting text size and improving consistency of icons and navigation buttons, which were then used as the basis for revisions in stage II.

After revisions based on the validators' feedback in Stage I, Stage II material validation was conducted, involving two expert validators. The results are presented in Table 7.

Table 7. Stage II material validation scores by two validators.

Aspect	Percentage	Category
Suitability and Accuracy of Material	95.8%	Very Eligible
Language and Terminology	88.8%	Very Eligible
Presentation of Material and Media	93.7%	Very Eligible
Learning Evaluation	84%	Very Eligible

Based on Table 7, several aspects show an increase compared with stage I. The suitability and accuracy aspect increased from 91.6% to 95.8%, indicating that revisions were well-aligned with validators' recommendations. The presentation aspect also improved from 89.5% to 93.7%, indicating more systematic, better-integrated material presentation. The learning evaluation aspect increased from 81% to 84%, showing that the evaluation questions became more varied and aligned with competency indicators. Meanwhile, language and terminology remained consistent at 88.8%. All aspects fell under the very eligible category, indicating that the material met the eligibility standards for the trial stage.

Two expert validators conducted media validation stage II after revisions based on stage I feedback. The results of the media validation stage II are presented in Table 8 below.

Table 8. Stage II media validation scores by two validators.

Aspect	Percentage	Category
Initial; Display	97.9%	Very Eligible
Readability and Text Design Consistency	83.3%	Very Eligible
Visuals	87.5%	Very Eligible
Navigation	90.6%	Very Eligible

Based on Table 8, the percentage of respondents who scored highly on several media aspects increased. The initial display aspect rose from 93% to 97.9%, indicating that improvements to the initial layout were highly effective and visually appealing for users. The navigation aspect increased from 87% to 90.6%, suggesting that revisions to navigation buttons and menu structure made the e-module more user-friendly. The visual element rose from 86% to 87.5%, while readability and text design consistency slightly increased from 83% to 83.3%. Overall, all aspects fall under the "very eligible" category, indicating that the media are ready for the development trial stage.

3.3.2. Product Trial Result

After undergoing expert validation and revisions, the e-module was tested on students to determine its practicality and attractiveness from the user perspective. The product trial consisted of two stages: the Small Group Trial and the Large Group Trial.

The Small Group Trial was conducted with two groups of students: grade XI students who had already studied the climate change material, and grade X students who would study it. The distribution of questionnaires across these two groups aimed to obtain a more comprehensive overview regarding the practicality, readability, visual appeal, and usefulness of the e-module from students with different levels of prior understanding.

Table 9. Student response scores for small group trial – grade XI.

Aspect	Percentage	Average	Category
Material Suitability	87.5%		
Learning	75.7%	86%	Very Eligible
Display and Presentation	93%		
Navigation	88%		

Based on Table 9, the average student response in grade XI reached 86%, categorised as very eligible. The display and presentation aspect received the highest percentage (93%), indicating that students found the visual design and Earth Nullschool integration, which offer interactive climate data visualisation, highly appealing. The navigation aspect received 88%, showing that students found it easy to use and access various features. The material suitability aspect obtained 87.5%, indicating that the presented content is relevant and appropriate for learning needs. Meanwhile, the learning aspect received the lowest score, 75.7%, but was still categorised as eligible.

Table 10. Student response scores for small group trial – grade X.

Aspect	Percentage	Average	Category
Material Suitability	82%		
Learning	70%	81%	Very Eligible
Display and Presentation	88%		
Navigation	85%		

Based on Table 10, the average student response in grade X reached 81%, categorized as very eligible. The display and presentation aspect received the highest percentage (88%), indicating that, although grade X students had not yet studied climate change, they found the e-module visually

appealing. The navigation aspect received 85%, the material suitability aspect 82%, and the learning aspect 70%. The lower scores compared to grade XI are reasonable because grade X students lack prior knowledge of climate change and require more time to understand the concepts and follow the PBL learning flow within the e-module.

Following revisions based on UKK feedback, the Large Group Trial was conducted involving a larger number of grade X students. At this stage, a whole classroom simulation was conducted using the e-module for an entire lesson to observe how the product performs in a real instructional context. The UKB results provided broader insights into student acceptance and served as the basis for determining whether the product is truly feasible for classroom implementation.

Table 11. Student response scores for large group trial – grade X.

Aspect	Percentage	Average	Category
Material Suitability	79%		
Learning	80%	83%	Very Eligible
Display and Presentation	89%		
Navigation	85%		

Based on Table 11, the average response rate among students in the UKB was 83%, categorized as very eligible. The display and presentation aspect again obtained the highest percentage (89%), indicating consistent student perception that the e-module is visually appealing. The navigation aspect received 85%, the learning aspect increased to 80%, and the material suitability aspect scored 79%. The improvement in learning from 70% (UKK) to 80% (UKB) indicates that, after revision and in a more structured classroom setting, students better understood the PBL-based learning flow implemented in the e-module.

The use of the 4D model in this study proved effective in producing a high-quality e-module. The comprehensive define stage, which included five analysis (initial-final analysis, learner analysis, task analysis, concept analysis, and learning objective formulation), ensured that the developed product genuinely addressed real classroom needs and aligned with learner characteristics. These thorough analysis provided a strong foundation for the subsequent stages and minimized the risk of developing a product that did not meet user needs.

The systematic design stage resulted in a well-structured e-module with strong instructional design. The detailed storyboard created at this stage greatly supported the realization of the product in the next phase. The storyboard served as a blueprint for all design decisions, both visual and instructional, ensuring consistency across the e-module and facilitating communication among the developer, supervisors, and validators. The development stage, involving two rounds of expert validation and staged product trials (UKK and UKB), ensured that the product met feasibility and practicality standards before wider implementation. The iterative validation process produced an increasingly refined product. Each piece of validator and user feedback was followed up with measurable improvements, ensuring that the final product had undergone rigorous quality assurance.

This research was limited to the development stage in accordance with its objectives. The dissemination stage was not conducted because the study focused on product development and validation. The decision not to carry out the dissemination stage in this study was based on the research focus, which prioritized developing a product that is valid and practical. The dissemination stage requires extensive dissemination strategies involving multiple stakeholders (other schools, education authorities, teacher communities). It demands a longer time frame to assess the impact of its large-scale implementation. This stage may serve as a focus for future research that examines the effectiveness and long-term effects of using the e-module in physics learning across various schools.

An analysis of the Earth Nullschool-assisted e-module's position and characteristics shows that it offers several advantages compared to similar e-modules available online. Its main strength lies in the use of real-time atmospheric data through Earth Nullschool, whereas most other e-modules rely only on static images or graphs. The use of dynamic visualisation provides a more authentic and contextual learning experience, enabling students to observe climate change phenomena directly based on ongoing global atmospheric conditions.

The results of this study align with previous research demonstrating that physics e-modules and digital learning media can enhance student understanding, engagement, and competencies. For example, the development of an e-module integrated with Education for Sustainable Development (ESD) on climate change was found feasible and effective for fostering students' critical thinking in physics learning [15]. Similarly, a STEM education-based physics e-module integrated with climate change topics significantly improved student competence [16]. Other studies on interactive and contextual physics e-modules have reported positive effects on students' understanding of physics concepts and engagement [17]. A literature review also confirms that e-modules in physics learning generally enhance student learning outcomes, motivation, and higher-order thinking skills [18]. Compared with these studies, the present research advances prior work by integrating Earth Nullschool's real-time atmospheric data into an e-module, thereby providing a more authentic and contextual learning experience for senior high school physics students.

The development of a module on a similar theme was also carried out by Novita and Silvi in 2023, which can be accessed at <https://online.flipbuilder.com/ndyzv/debz/>. The differences observed between the developed module and the modules available online are listed in Table 12.

Table 12. Comparison of climate change e-modules.

Aspect	Earth Nullschool-assisted E-module	E-Modules Available Online
Model	Problem-Based Learning	Project-Based Learning
Technology	Earth Nullschool	-
Activity Structure	Each activity comprehensively and systematically follows PBL syntax	Activities do not fully follow PjBL syntax
Competency Test	Available in every learning activity	Structured formative and diagnostic assessments
Learning Approach	Data-driven and technology-based analysis	Experiments and projects

In addition, this e-module adopts a problem-based learning (PBL) approach, which systematically guides students to analyze real issues related to climate change. This approach distinguishes the developed e-module from most existing ones, which tend to be informative and not fully integrated with problem-solving-based learning models. The integration of physics concepts, such as the greenhouse effect, energy, radiation, and increased CO₂ concentration, also becomes a significant strength, rarely found in similar products that primarily focus on geographical or environmental aspects.

Despite its strengths, this e-module has several limitations. Its reliance on stable internet access is crucial, as Earth Nullschool visualisations cannot function optimally without adequate connectivity. Furthermore, the absence of an offline mode or a standalone application limits its flexibility compared to modern digital products accessible on mobile devices. Students' varying levels of data interpretation skills also present a challenge, as not all students are accustomed to reading three-dimensional atmospheric maps or understanding visual representations based on global atmospheric models. This requires more detailed guidance to help students explore the simulations effectively.

From an opportunities perspective, this e-module has excellent potential for further development. The growing global attention to climate change issues makes data-driven scientific learning media increasingly relevant in educational contexts. Earth Nullschool provides atmospheric data layers for wind, surface temperature, air pressure, and CO₂ concentration, which opens up opportunities to expand learning activities in the future. Moreover, the direction of the Merdeka Curriculum, which emphasises problem-based learning, supports the use of this e-module to enhance students' critical thinking skills. The rapid development of educational technology also offers opportunities to transform the e-module into a mobile application, an interactive video, or an integration with LMS platforms.

However, several challenges must be considered in long-term implementation. Changes in policies or system updates within Earth Nullschool may affect access to the data that form the core of the learning simulation. Additionally, digital literacy gaps and limited device availability in schools may hinder equitable access to e-modules. Digital simulation products from major institutions such as NASA, NOAA, and other international interactive platforms also pose competition that may reduce user interest

if this e-module is not continuously updated. These challenges require ongoing product development to ensure that the e-module remains relevant and competitive among various digital learning media. Although this study focuses on the feasibility and practicality of the e-module, the instructional design integrating PBL syntax with Earth Nullschool visualisation has significant potential to develop students' critical thinking skills. Critical thinking is one of the essential 21st-century skills that students need to navigate complex global issues.

Table 13. Relationship between PBL syntax and critical thinking skills.

No	PBL Syntax	Critical Thinking Skills
1	Orient students to the problem.	Problem Identification (Students identify and understand the problem).
2	Organizing students for investigation.	Analysis (Students plan and analyze factors related to the problem).
3	Guiding independent and group investigations.	Problem Solving (Students apply knowledge and strategies to solve the problem).
4	Developing and presenting the work.	Problem Solving & Drawing Conclusions (Students organize findings and draw evidence-based conclusions).
5	Analyzing and evaluating the problem-solving process [19].	Analysis & Drawing Conclusions (Students reflect, analyze, and draw conclusions on the process) [20].

The PBL syntax integrated into the e-module facilitates the development of critical thinking skills at each stage. In the problem-orientation stage, students are trained to identify and formulate problems through exposure to authentic climate-change scenarios. They are guided to determine the problem, its causes, and its impacts, which develops their analytical and interpretative skills. In the organizing for learning stage, students plan inquiry strategies by discussing research questions, identifying the data to be collected, and deciding how to analyze the data. This process enhances metacognitive abilities, awareness of one's own thinking processes, and the ability to design strategies to achieve learning goals. During the individual and group investigation stage, students collect and analyze data using Earth Nullschool to observe real-time climate conditions, identify patterns and trends, and establish cause-and-effect relationships. This activity fosters scientific literacy and data literacy, enabling students to distinguish between data and interpretation, recognize potential data biases, and draw conclusions based on empirical evidence. In the development and presentation of the work stage, students evaluate alternative solutions to climate change problems, consider the strengths and limitations of each option, and determine the most effective and feasible solutions. This stage develops evaluation and judgment skills as key components of critical thinking. Finally, in the analysis and evaluation stage, students engage in reflection by reviewing their learning process, assessing the strengths and limitations of their analysis, and identifying areas for improvement, which is essential for developing metacognitive awareness and lifelong learning skills.

Earth Nullschool, as a primary data source, requires students not merely to accept ready-made information but to observe, interpret, and analyze actual climate data [21]. Unlike conventional learning, where the teacher or textbook provides pre-processed information, Earth Nullschool-based learning requires students to transform raw data into meaningful information [22]. This process trains inquiry and scientific reasoning skills, which form the foundation of critical thinking in science [23]. Exploring global climate data also broadens students' understanding of the complexity of climate systems and the interconnectedness of natural phenomena. Students can observe how temperature changes in one region affect wind patterns in another, how ocean currents influence heat distribution, and how various factors interact in a complex climate system. Understanding complexity and interdependence is essential for developing systems thinking, the ability to view phenomena holistically and understand the interrelationships among components [24]. The integration of the "Critical Reasoning" dimension from the Profil Pelajar Pancasila in the learning objectives of this e-module is also essential within the national education context. This e-module develops critical thinking skills not only in academic contexts but also within the framework of Pancasila values. Students learn to process information objectively without

bias, appreciate different perspectives, make decisions based on data and humanistic values, and take responsibility for their choices [25].

4. Conclusion

Based on the development research conducted at SMAN 10 Kota Jambi, the Earth Nullschool–assisted e-module for climate change material meets the criteria of validity, practicality, and potential effectiveness as an innovative instructional resource in physics learning. Expert validation confirmed high material and media feasibility, indicating that the content aligns with the Merdeka Curriculum, is systematically organized using Problem-Based Learning syntax, and integrates interactive Earth Nullschool visualizations effectively. Student trials showed highly positive responses and improved learning outcomes, demonstrating that the e-module is engaging, easy to use, and supports better understanding of climate change concepts. Through PBL activities and real-time climate data exploration, the e-module guides students to identify problems, analyze information, and formulate solutions, thereby strengthening critical thinking skills in line with the Critical Reasoning dimension of the Profil Pelajar Pancasila. Therefore, this e-module is suitable as an alternative digital instructional material that provides contextual, meaningful, and 21st-century-oriented physics learning.

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