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Developing a Science Learning Model Integrating Inquiry and Citizen Science through an LMS to Enhance Students' Climate Literacy

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Abstract

This study aims to develop and evaluate a science learning model that integrates inquiry and citizen science through an LMS to enhance students' climate literacy (CLIM-BCS model). The study involved 168 pupils from six classes in Central Java, selected through purposive sampling. The evaluation comprised expert validation, assessment of the model's feasibility, improvements in climate change literacy as measured by pre- and post-tests, and pupil responses. The CLIM-BCS model developed comprises the following steps: problem orientation, formulation of questions, data collection via *citizen science*, LMS-based data analysis, scientific discussion, and reflection and climate action. The research results showed an expert validation score of 3.82, categorised as 'highly valid'. The model's feasibility ranged from 88.88% to 90.88%, whilst the *normalised gain* values ranged from 0.58 to 0.63, categorised as 'moderate'. The difference between pre-test and post-test scores was statistically significant across all classes. Student responses to the learning process ranged from 95.30% to 97.30%. These findings indicate that CLIM-BCS is a valid model, applicable in a research context, and has the potential to support climate change literacy

Keywords: citizen science; climate change literacy; science education; learning management system; the CLIM-BCS model.

1 Introduction

One of the most pressing global challenges today is climate change, which requires not only scientific solutions but also a public that is scientifically literate and capable of acting responsibly and making decisions based on accurate information. In this context, climate change literacy has become a key objective in science education. Climate change literacy encompasses an understanding of the climate system, an awareness of the interactions between humans and the environment, and a readiness to participate in efforts to mitigate and adapt to climate change [1]. However, a number of studies indicate that pupils' levels of climate change literacy remain relatively low, particularly in their ability to link scientific concepts to real-world problems and to translate that knowledge into actions based on accurate information [2, 3].

In climate change education, one of the main challenges lies in the limitations of conventional science teaching, which tends to emphasize conceptual aspects whilst providing limited opportunities for pupils to gain authentic and contextual learning experiences. Effective climate change education should engage pupils in scientific practices, the use of real data, and the investigation of environmental issues within local contexts [4, 5]. Integrated science learning can further contribute to sustainability education by connecting scientific concepts with broader environmental and societal contexts [6]. In this regard, citizen science emerges as a promising pedagogical approach because it engages pupils in collecting, analysing, and interpreting scientific information within authentic contexts. Pupils' involvement in citizen science can strengthen their ability to conduct scientific investigations, deepen their connection to environmental issues, and foster a stronger sense of responsibility and agency as agents of change [7-9].

At the same time, advances in digital technology have driven the adoption of Learning Management Systems (LMS). LMS platforms provide an organized learning environment to support assessment, communication, content delivery, and learning analytics, thereby enhancing the scalability and flexibility of learning [10, 11]. However, research indicates that,

in practice, the use of LMSs is still often limited to the distribution of materials and administrative functions and is therefore not yet fully optimized to support experience-based and inquiry-based learning [12, 13]. When using LMS, pupils find it difficult to understand scientific concepts due to the absence of hands-on experiments and reduced opportunities for group work [14]. This situation indicates that the potential of LMSs as transformative learning environments, particularly in climate change education, has yet to be fully realized.

Furthermore, although various studies have examined the role of citizen science in enhancing pupils' engagement with and understanding of science, as well as the use of LMSs in digital learning, the integration of these two components within a systematic pedagogical framework remains an important area for further investigation. Previous research has tended to treat citizen science as a supplementary activity separate from formal learning structures, whilst LMS use has often focused primarily on content delivery and learning management rather than on supporting authentic, inquiry-based scientific practices [12, 15]. Recent work has also addressed the development of pedagogical frameworks for integrating climate change into science teacher education in support of the Sustainable Development Goals [16]. Building on this direction, the present study focuses on integrating citizen science activities and LMS-supported data analysis within a structured learning model intended to develop students' climate literacy. Although inquiry-based and experiential learning approaches have demonstrated their relevance to science education, further research is needed to establish how citizen science, LMS-supported learning, and climate literacy development can be systematically connected within a coherent pedagogical framework [5, 17].

Based on this research gap, this study proposes the CLIM-BCS Model (Climate Literacy through Inquiry and Mobile-Based Citizen Science) as an innovative learning framework that integrates citizen science, inquiry-based learning, and an LMS-based learning environment to enhance students' climate change literacy. The CLIM-BCS model is grounded in learning theories, including inquiry-based learning, constructivism, and experiential learning, which emphasize the active construction of knowledge, engagement in authentic contexts, and reflection on learning experiences. Through this approach, pupils are positioned as active participants in scientific practice, enabling them not only to develop conceptual understanding but also to strengthen their environmental awareness and capacity to take action in addressing climate change issues.

In line with this, this study aims to develop and validate the CLIM-BCS Model as a learning framework for integrating citizen science into LMS-based science education, and test the model's effectiveness in enhancing students' climate change literacy. Consequently, this study is expected to make a theoretical and empirical contribution to the development of meaningful technology-enhanced learning and to strengthen the integration of authentic scientific practice within the digital learning environment.

2 Theoretical Framework

2.1 Citizen science as a pedagogical approach

The development of citizen science over the last two decades reflects a paradigm shift in research and education towards a more participatory, collaborative, and contextual approach. Citizen science enables members of the public, including pupils, to participate directly in the scientific process through observation, data collection, analysis, and the interpretation of research findings. In the context of science education, this approach is regarded as effective in bridging theoretical learning with authentic scientific practice that is relevant to pupils' everyday lives. Through engagement in real-world scientific activities, pupils gain the opportunity to develop conceptual understanding, scientific thinking skills, and an awareness of global and local environmental issues [7, 8]. Furthermore, citizen science supports experience-based learning by encouraging pupils to learn through direct interaction with natural and social phenomena in their immediate surroundings.

In educational practice, various studies indicate that the implementation of citizen science can enhance students' investigative skills, data interpretation abilities, scientific

literacy, and environmental awareness. Student involvement in activities monitoring air quality, biodiversity, climate change, and waste management provides meaningful opportunities to conduct investigations, formulate scientific questions, analyze evidence, and draw conclusions based on empirical data [9, 18]. Contextual science learning can be strengthened by connecting scientific explanations with local knowledge and experiences, helping learners relate formal concepts to phenomena in their surrounding environment [19]. Furthermore, citizen science strengthens the social dimension of learning by involving students in wider scientific communities through collaboration, discussion, and data sharing. Consequently, this approach can contribute not only to pupils' mastery of scientific concepts but also to the development of social responsibility and civic participation in addressing environmental issues.

Nevertheless, the implementation of citizen science in education still faces a number of challenges. Previous research indicates that citizen science activities in schools are often carried out as additional projects, temporary activities, or extracurricular programmes that have not yet been systematically integrated into the curriculum and formal learning processes [15, 20]. Consequently, the sustainability of these activities and their long-term impact on learning may be less than optimal. The CLIM-BCS model was developed to address these limitations by integrating citizen science into an inquiry-based learning structure supported by a LMS. In this model, citizen science activities are not treated as an additional component, but as an integral part of science education and the development of climate change literacy. The LMS is used to support data management, scientific collaboration and learning reflection, as well as to integrate field experiences with pupils' cognitive processes. Through this approach, the CLIM-BCS Model creates a more authentic, sustainable and relevant science learning environment in response to the environmental challenges of the 21st century.

2.2 LMS as a transformative learning environment

The development of LMSs in science education reflects a transformation from their original function as tools for distributing learning materials towards more comprehensive digital learning environments that support social interaction, scientific collaboration, and active knowledge construction. Modern LMS platforms can facilitate project-based learning, synchronous and asynchronous discussions, digital data analysis, and systematically documented learning reflections. Effective technology integration in science education requires alignment between technological resources, pedagogical strategies, and subject-matter knowledge rather than the mere adoption of digital tools [21]. Frameworks for technology integration, including the Substitution, Augmentation, Modification, and Redefinition (SAMR) model, can also provide a useful perspective for examining whether digital tools merely replace conventional teaching practices or enable more meaningful learning activities [22]. Nevertheless, the educational value of an LMS depends on how its features are aligned with learning objectives, instructional activities, and opportunities for meaningful student interaction [10, 11].

In previous research, an LMS integrated with citizen science has been designed. This LMS incorporates citizen science, which engages students in science projects and is vital for raising students' awareness of climate change [16]. Figure 1 shows the initial LMS interface after logging in; it features menus that support learning, namely learning materials, citizen science activities, discussion forums, quizzes, and the option to log out of the LMS. These menus can be accessed by clicking on the text. If a student wishes to undertake a citizen science project, they can select that menu. If a student wishes to participate in a discussion on the LMS, they can select the discussion menu. Similarly, for quizzes, students can select that menu to enhance their understanding of climate change.

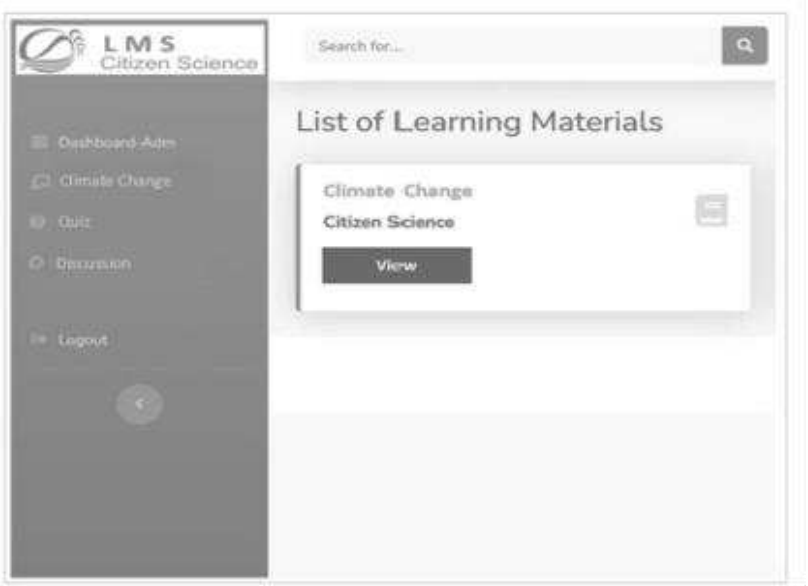


Figure 1. Menu view in the LMS that has been developed.
Adapted from Reference [16]

In the citizen science module, pupils will take part in projects and activities involving the collection of data on temperature, humidity, air pressure, and daily weather conditions. The data is recorded using appropriate measuring instruments, with support and guidance from the science teacher. The data is then entered into the LMS by the pupils, and the results are recorded within the LMS, as shown in Figure 2.

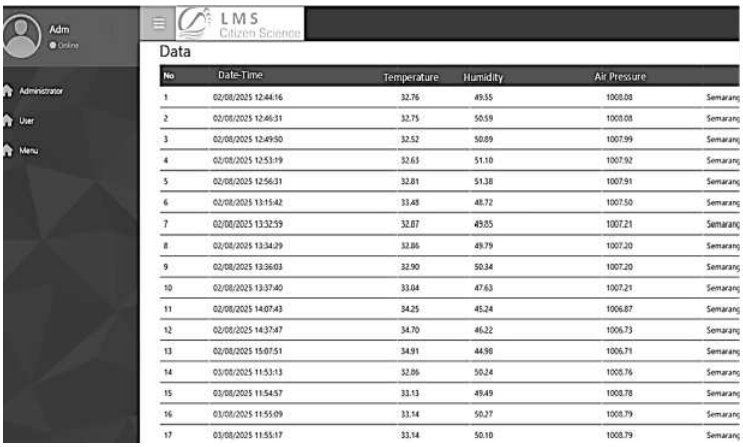


Figure 2. Display of data entered by students in the LMS.
Adapted from Reference [16]

Based on the data records that have been entered, as shown in Figure 2, pupils study the graphs and compare them with global data from the source www.windy.com. The graphs based on the data entered by pupils in the citizen science project and the global data are shown in Figure 3.

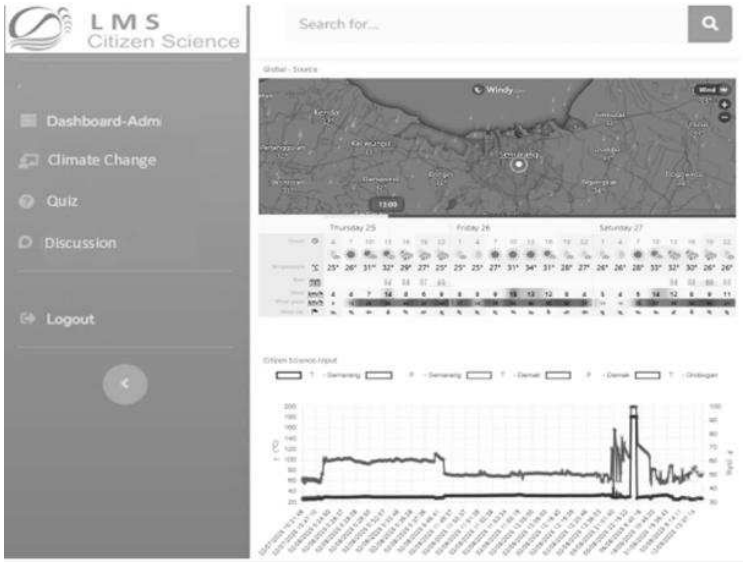


Figure 3. Graphical representation of the data entered by the pupils.
Adapted from Reference [16]

Based on Figure 3, pupils will learn to compare data obtained from citizen science activities with global data. Pupils learn by analyzing data to gain an understanding of climate change based on data, graphs, and discussions with fellow pupils and teachers.
In the CLIM-BCS Model, the LMS developed in previous research is utilized as a learning environment that integrates citizen science activities with the science learning process, aimed at developing climate change literacy. The LMS functions as a space for scientific collaboration, enabling students to share their observations, discuss climate change phenomena, and interpret data collectively. Furthermore, the LMS serves as a platform for analyzing citizen science data through features such as data uploading, information visualization, discussion forums, and the integration of various digital learning resources. Through these mechanisms, pupils are not merely passive recipients of information but are actively engaged in an authentic scientific process that requires critical thinking, data interpretation, and evidence-based reasoning [23, 24]. The integration of fieldwork with the LMS also enables continuity between empirical experience and conceptual learning, thereby making the learning process more contextual and meaningful.

2.3 Theories supporting the CLIM-BCS model

The CLIM-BCS model is underpinned by the integration of various learning theories that emphasize knowledge construction, direct experience, social interaction, and critical reflection. Constructivist theory posits that knowledge is constructed through the interaction between new experiences and an individual's prior knowledge [25]. This perspective is reinforced by the theory of social constructivism, which identifies social interaction, language, and the support provided by the learning environment as key elements in the development of understanding [26].

In the context of climate change education, these two perspectives provide a foundation for pupils to connect scientific concepts with the environmental phenomena they encounter in their daily lives. Authentic problems also play a vital role in establishing the relevance of learning, stimulating curiosity, and developing critical thinking and problem-solving skills. Problem-Based Learning enables pupils to develop knowledge and skills through active engagement in solving complex problems [27]. Thus, an understanding of climate change is not merely acquired through the reception of information but also through the process of constructing meaning, relating knowledge to real-world contexts, and developing an understanding of environmental issues.

In addition to constructivism, the CLIM-BCS model is grounded in the theories of inquiry-based learning and experiential learning, which emphasize the importance of investigation and direct experience in science learning. Inquiry-based learning regards questioning, investigation, the interpretation of evidence, and the drawing of conclusions as the primary processes in constructing scientific knowledge [28]. Meanwhile, experiential learning takes place through the interplay between concrete experience, reflective observation, abstract conceptualization, and active experimentation [29]. Both theories provide a foundation for student engagement in observing environmental conditions, collecting data, identifying patterns, and formulating explanations based on empirical evidence. The citizen science approach broadens learning opportunities by involving the public, including students, in data collection and authentic scientific practice. The potential of citizen science in supporting scientific understanding through public engagement in research activities [7]. In climate change education, such experiences can help pupils connect scientific concepts with environmental data in their immediate surroundings. This process also has the potential to develop scientific process skills, data literacy, and an awareness that understanding climate change requires systematic observation and the responsible interpretation of evidence.

The development of climate change literacy also requires a foundation in collaborative learning, social constructivism, and technology-enhanced learning. Collaborative learning emphasizes that knowledge can be developed through the exchange of ideas, discussion, and joint problem-solving. The importance of a learning environment that supports the construction of knowledge through meaningful activities and problem-solving, whilst emphasising the contribution of social interaction to cognitive development [30]. In the context of digital learning, a LMS can support this process by providing a space for sharing data, developing visual representations, engaging in discussion, and providing documented feedback. However, technology does not automatically result in meaningful learning; its benefits depend on how it is integrated with pedagogical objectives, activities, and interactions. Collaboration must also be accompanied by scientific reasoning skills so that pupils can distinguish between opinions and explanations supported by evidence. The importance of critical discourse and collaborative reasoning in science learning [31]. Therefore, data-driven exchanges of ideas can help students evaluate information, consider diverse perspectives, and construct stronger scientific explanations regarding the causes, impacts, and responses to climate change.

The next theoretical foundation is transformative learning and environmental education, which emphasize the importance of critical reflection and the application of knowledge in real-world action. Transformative learning occurs when individuals critically review their assumptions and frameworks of thought, thereby enabling the formation of new perspectives [32]. In the context of climate change, reflection helps pupils evaluate their understanding, consider the consequences of human activities, and re-examine habits that contribute to environmental problems. In line with this, education for sustainable development is not only oriented towards the acquisition of knowledge but also towards the development of competences, values, and the capacity to take responsible action [33]. Scientific understanding of climate change needs to be linked to the ability to make decisions and participate in mitigation and adaptation efforts that are relevant to the context of pupils' lives. By integrating reflection, evidence-based reasoning, and environmental action, CLIM-BCS provides a conceptual framework to support climate change literacy that encompasses the dimensions of knowledge, skills, and participation. Nevertheless, changes in environmental attitudes and behaviour cannot be assumed to arise automatically from increased knowledge; they therefore need to be empirically assessed through appropriate measurements and, where possible, long-term monitoring.

3 Methods

This study employs an Educational Design Research (EDR) approach to develop, validate, and test the effectiveness of the CLIM-BCS Model in improving students' climate change literacy. The EDR approach was chosen because this study aims not only to produce a learning model but also to establish a strong theoretical foundation, test the model's

feasibility for application in an authentic educational context, and generate design principles that can serve as a basis for the development of science education oriented towards climate change literacy [34, 35]. This study consists of two main phases. The first phase focuses on model development, comprising needs analysis, model design, expert validation, and model revision. The second phase focuses on testing the model's effectiveness through implementation in the classroom.

3.1 Development of the CLIM-BCS Model

Model development comprises several stages, namely needs analysis, model design, validation, and model revision [34]. During the needs analysis phase, a literature review was conducted on climate change literacy, citizen science, LMS-based science learning, inquiry-based learning, and environmental education. In addition, semi-structured interviews with science teachers and an analysis of curriculum documents were carried out to identify relevant learning needs. The results of the analysis showed that climate change education is still dominated by conceptual aspects, that student engagement in authentic scientific practice remains limited, and that the use of LMS is generally still restricted to the distribution of learning materials.

Based on these findings, the CLIM-BCS Model was developed by integrating inquiry-based learning, citizen science activities, and a digital learning environment supported by an LMS. Its development encompassed social systems, reaction principles, support systems, instructional impacts, and accompanying impacts, as recommended in learning model development [36].

Subsequently, the model was validated by experts in the field of science education. The validation focused on theoretical appropriateness, syntactic consistency, the model's feasibility, the integration of LMS and citizen science components, and the model's potential for developing pupils' climate change literacy. Feedback from the validators was used as the basis for revising the model before its implementation in classroom teaching.

3.2 Effectiveness testing of the CLIM-BCS model

The effectiveness trial involved lower secondary school pupils in Central Java, Indonesia, with relatively comparable academic characteristics. Schools were selected using purposive sampling, taking into account the readiness of learning infrastructure, previous experience in using an LMS, and specific geographical areas, such as schools located in coastal and mountainous regions.

The participants comprised six classes totalling 168 pupils aged 14–15 years. Prior to implementation, group equivalence was assessed based on science learning outcomes from the previous semester to ensure that all classes had relatively comparable baseline characteristics. Before teaching commenced, a pre-test was administered to all pupils in each class. Subsequently, each class received instruction using the CLIM-BCS model for six weeks, comprising twelve learning sessions, and concluded with a post-test.

Data collection was carried out using instruments designed to measure the validity, practicality, and effectiveness of the CLIM-BCS model developed. Validity data were obtained through a questionnaire administered to experts. Practicality data were obtained via lesson observation sheets to provide an overview of the implementation of the CLIM-BCS model within the learning process. Meanwhile, effectiveness data were obtained through pre-tests and post-tests on climate change literacy, which were developed based on the framework for climate change literacy and recent research on climate change literacy [1, 3, 37]. These instruments cover three main dimensions: knowledge of the climate, awareness of and attitudes towards the climate, and climate-related behaviour.

The collected data were subsequently analyzed. Data on validity and practicality were analyzed descriptively using percentage calculations. Meanwhile, climate change literacy data were analyzed based on mean scores and subsequently tested statistically at a significance level of $\alpha = 0.05$. The choice of statistical test was tailored to the characteristics and distribution of the data, utilizing either a paired-sample t-test or the non-parametric Wilcoxon signed-rank

test [38, 39, 40]. Furthermore, improvements in learning outcomes were analyzed using the normalized gain (n-gain) calculation, with the formula n-gain = (post-test score – pre-test score) / (ideal score − pre-test score). n-gain values were then categorized as high (≥ 0.70), moderate (0.30 ≤ n-gain < 0.70), and low (< 0.30) [41, 42].

4 Results

4.1 Development of the CLIM-BCS Model

The results of the needs analysis indicate that climate change education in schools is still dominated by content-oriented learning and has not yet provided adequate opportunities for pupils to engage in authentic scientific practice. Although teachers have been using Google Classroom in the learning process, its use remains largely limited to the distribution of materials, the collection of assignments, and the delivery of information; consequently, it does not yet fully support the processes of inquiry, scientific collaboration, and active knowledge construction. These findings are consistent with previous findings, namely that, in various educational contexts, LMSs are still primarily used as a repository for learning materials, rather than as a learning environment that fosters interaction and meaningful learning [11, 12]. Meanwhile, various studies indicate that student participation in citizen science activities can enhance scientific understanding, investigative skills, and environmental awareness as students interact directly with the phenomena under study [8, 18].

Based on the results of this needs analysis, the CLIM-BCS Model was developed to encompass six main stages of learning: problem orientation, question formulation, data collection through citizen science, LMS-based data analysis, scientific discussion, and reflection and climate action. The activities of teachers and pupils, as well as the supporting theory for each stage of the model, are outlined as follows.

1. Problem orientation
   During the problem orientation stage, the teacher presents climate change phenomena relevant to the pupils' lives through environmental data, news reports, videos, and authentic phenomena in the surrounding environment. The presentation of contextual problems aims to activate pupils' prior knowledge, build awareness of climate change issues, and foster a desire to learn. Pupils observe the phenomena, identify the problems, and relate them to their existing experiences and knowledge. This stage is based on constructivist theory and inquiry-based learning, which hold that learning begins with pupils' engagement in understanding meaningful phenomena or problems. Position orientation as the initial phase in the inquiry learning cycle [28]. In the context of climate change education, learning that utilizes climate change issues and contextual problems can support the development of students' climate literacy [43].

2. Question formulation
   During the question formulation stage, the teacher facilitates pupils in developing investigative questions based on the phenomena they have observed. The teacher provides prompt questions and helps pupils determine the focus of their investigation, as well as the variables that can be observed through environmental data collection. Pupils, either individually or in groups, formulate questions that can be answered through empirical evidence. This stage is based on inquiry-based learning and social constructivism, as pupils construct the focus of their inquiry through a process of thinking and interaction with group members. Problem conceptualization, including the formulation of questions, is a crucial component of the inquiry cycle, as it determines the direction of subsequent investigation [28].

3. Data collection through citizen science
   During the data collection phase through citizen science, the teacher provided guidance on observation procedures, the use of measuring instruments, the location

and timing of measurements, and data recording techniques. Pupils were directly involved in collecting environmental data, such as air temperature, humidity, and rainfall. The data obtained is systematically recorded and documented as empirical evidence to answer the research questions. This stage integrates the principles of experiential learning and inquiry-based learning, as pupils gain learning experiences through direct involvement in the process of observation and evidence gathering. Furthermore, the citizen science approach provides pupils with the opportunity to participate in environmental data collection activities that are relevant to real-world issues. Environmental citizen science initiatives have the potential to develop students' knowledge, skills, and environmental citizenship competencies [44].

4. LMS-based data analysis
   This stage integrates constructivism with technology-enhanced learning, as technology provides an environment in which pupils can construct knowledge through the analysis of empirical data. The integration of technology into inquiry-based learning can support the organisation, interpretation, and communication of scientific data [28, 45]. Digital learning applications can also support the assessment of higher-order thinking skills in science education, extending technology use beyond content delivery to the evaluation of students' cognitive performance [46]. Thus, the LMS in CLIM-BCS functions not only as a data storage medium but also as a learning space for developing pupils' abilities to analyse and interpret evidence.

5. Scientific discussion
   During the scientific discussion stage, the teacher facilitates pupils in presenting the results of their analysis, comparing findings across groups, and evaluating arguments based on the available evidence. The teacher encourages pupils to ask questions, offer responses, and provide feedback on the results of other groups. Pupils put forward claims based on the results of their data analysis, provide evidence and reasons to support these claims, and evaluate the arguments presented by other groups. This stage is underpinned by the theory of social constructivism and the scientific argumentation approach, which regard interaction, the exchange of ideas, evidence, and reasoning as vital components in the construction of scientific knowledge. A meta-analysis indicates that argumentation-based learning makes a positive contribution to learning outcomes, scientific process skills, conceptual understanding, and pupils' attitudes [47]. Consequently, scientific discussions within CLIM-BCS serve to transform observational data into scientifically accountable knowledge.

6. Reflection and climate action
   In the final stage—reflection and climate action—teachers guide pupils to reflect on the learning process and outcomes and to link their findings from the investigation to climate change issues in their local environment. Teachers then facilitate pupils in identifying realistic mitigation and adaptation measures that are appropriate to their environmental context. Pupils reflect on the changes in their understanding gained during the learning process, evaluate their experience of citizen science, and draw up simple action plans that can be carried out individually or in groups. This stage is based on experiential learning, which places reflection as a key part of knowledge formation through experience, as well as an action-oriented approach to environmental education. Contextually designed climate change learning can support the development of climate literacy, including aspects relating to perceptions and actions [43]. The integration of reflection and action in the final stage thus links the scientific knowledge acquired by pupils with their readiness to participate in climate change mitigation and adaptation actions within their local communities.

The CLIM-BCS model that was developed was subsequently validated. The validation results are presented in Table 1.

Table 1 Expert Validation of the CLIM-BCS Model

No.	Aspect	Average	Category
1	Theoretical foundation (constructivism, inquiry-based learning, experiential learning, situated learning, socio-scientific and sustainability education)	3.82	Highly Valid
2	Learning syntax (problem orientation, question formulation, data collection through citizen science, LMS-based data analysis, scientific discussion, and reflection and climate action)	3.88	Highly Valid
3	Social system (teacher as facilitator; students as investigators and collaborators)	3.80	Highly Valid
4	Principles of reaction (scaffolding, questioning, and evidence-based feedback)	3.80	Highly Valid
5	Support system (LMS, citizen science activities, social environment, and climate action environment)	3.82	Highly Valid
6	Instructional effects (climate literacy)	3.82	Highly Valid
7	Nurturant effects (collaboration and digital literacy)	3.80	Highly Valid
	Average	3.82	Highly Valid

Table 1 shows that all components of the CLIM-BCS model fall into the 'highly valid' category, with average scores ranging from 3.80 to 3.88. The learning syntax component received the highest score, namely 3.88, indicating that the sequence of learning stages—comprising problem orientation, question formulation, data collection through citizen science, LMS-based data analysis, scientific discussion, and reflection and climate action—was deemed to be logically structured and consistent with the model's objectives. The theoretical foundation and support system each received a score of 3.82. Meanwhile, the social system, reaction principles, and accompanying impacts each received a score of 3.80. The instructional impact, which focuses on the development of climate literacy, received a score of 3.82. Overall, the CLIM-BCS model achieved an average score of 3.82 and falls within the 'highly valid' category. These results indicate that the CLIM-BCS Model fulfills the characteristics of a comprehensive learning model as outlined as it is supported by a strong theoretical foundation, a systematic syntax, a clearly defined social system, reaction principles that support active learning, an adequate support system, and explicitly formulated learning outcomes [36]. Overall, the validation results confirm that the CLIM-BCS Model is suitable for use as an LMS-based science learning model that integrates citizen science to facilitate the development of pupils' climate change literacy.

4.2 The Effectiveness of the CLIM-BCS Model

Testing the effectiveness of the CLIM-BCS model through its implementation in the classroom. The implementation of the model was observed during the learning process using an observation sheet developed on the basis of the six syntactic stages of the CLIM-BCS model. The results of the observations showed that all six stages of the CLIM-BCS model could be implemented with a high degree of success.

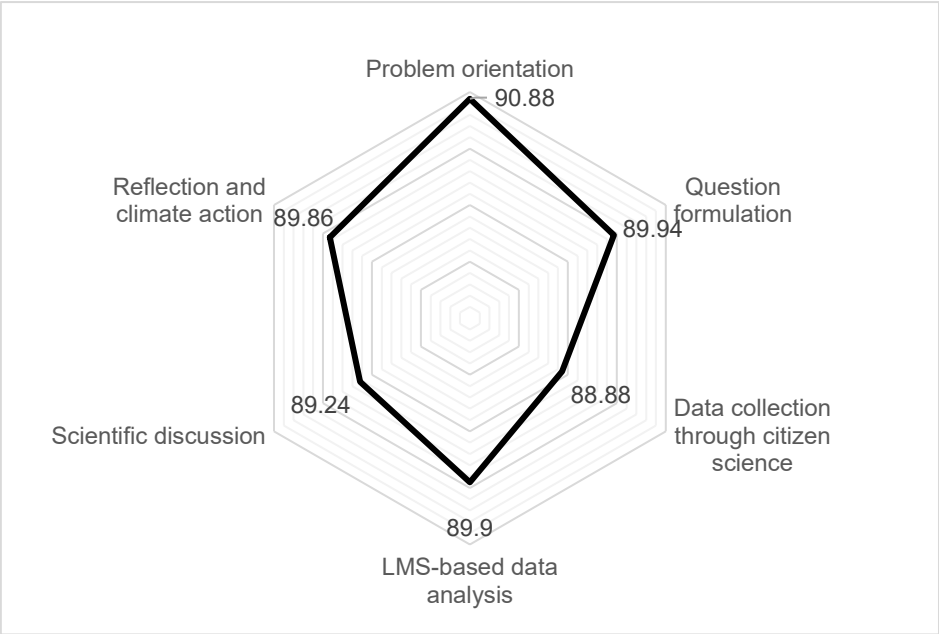


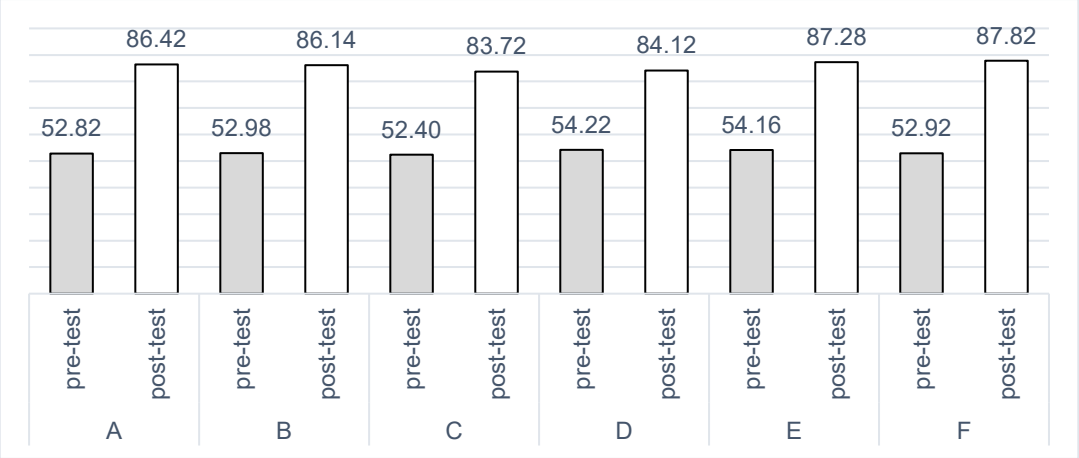
Figure 1 Graph of the Implementation of the CLIM-BCS Model Syntax

The results of the observations showed that all stages of the CLIM-BCS Model were implemented very effectively during the learning process (Figure 1). The average implementation scores for each stage ranged from 88.88 to 90.88, with 'problem orientation' achieving the highest score (90.88), followed by 'question formulation' (89.94), 'LMS-based data analysis' (89.90), reflection and climate action (89.86), scientific discussion (89.24), and data collection through citizen science (88.88). Overall, these findings indicate that the CLIM-BCS Model syntax has a very high level of implementation and can be consistently applied in the context of science education.

The high feasibility scores at the problem orientation stage indicate that the climate change issues presented were able to capture pupils' attention and encourage their initial engagement in learning. Meanwhile, the high feasibility scores at the LMS-based data analysis and scientific discussion stages indicate that the integration of the LMS successfully supported collaboration, data interpretation, and evidence-based scientific argumentation. Furthermore, strong implementation at the 'reflection and climate action' stage indicates that pupils were able to link the results of their investigations to critical reflection and the planning of environmental actions.

These findings suggest that the CLIM-BCS Model possesses a high degree of practicality and is supported by a clear and manageable learning syntax, enabling it to be applied by teachers and pupils in climate change education. These findings are consistent with previous research, which indicates that the success of implementing a learning model is greatly influenced by the clarity of the learning stages, the availability of learning resources, and the suitability of the model to the learning context [48]

The effectiveness of the CLIM-BCS model is also demonstrated by a significant improvement ($\alpha = 5\%$) in pupils' climate change literacy. The average pre-test and post-test scores for pupils' climate change literacy are presented in Figure 2, whilst the results of the analysis are presented in Table 2.



Notes: A = SMP 1 Bangsri Jepara; B = SMP 1 Kembang Jepara; C = SMP 2 Bandungan; D = SMP Islam Sultan Agung 1 Semarang; E = SMP 1 Bringin; F = SMP 10 Semarang.

Figure 2 Pre-test and Post-test Scores of Students' Climate Literacy

As shown in Figure 2, there is a difference between the average pre-test and post-test scores for pupils' climate change literacy. It can be seen that the post-test scores are higher than the pre-test scores. All schools showed an increase in scores from the pre-test to the post-test. Pre-test scores ranged from 52.40 to 54.22, whilst post-test scores increased to between 83.72 and 87.82. The highest increase was recorded at SMP 10 Semarang (F), amounting to 34.90 points, followed by SMP 1 Bringin (E) with 33.12 points, whilst the lowest increase was recorded at SMP 2 Bandungan (C), amounting to 31.32 points. These results indicate that the learning activities or interventions carried out have the potential to improve pupils' achievement across all six schools consistently.

Table 2 Results of the Normality, Homogeneity, and Paired-Samples t-Test/Wilcoxon Test of Students' Climate Literacy Scores

Class	Test	∑	Min	Max	Ave.	Std. Dev.	Normality p(α = 0.05)	Homog. p(α = 0.05)	Paired t-test/ *Wilcoxon* (α = 0.05)
A	Pre-test	28	43.24	61.28	54.22	3.25	0.202	0.126	t = -38.82
	Post-test	28	78.86	90.22	88.42	2.84	0.088		p< 0.001
B	Pre-test	28	42.12	60.18	54.88	3.18	0.066	0.221	t = -45.41
	Post-test	28	79.92	91.02	87.22	2.22	0.122		p< 0.001
C	Pre-test	28	44.14	60.84	51.98	3.48	0.136	0.044	z = -10.72
	Post-test	28	78.28	88.92	84.88	2.86	0.082		p < 0.001
D	Pre-test	28	44.44	61.22	53.64	3.67	0.062	0.121	t = -39.72
	Post-test	28	78.86	89.66	86.32	3.88	0.092		p< 0.001
E	Pre-test	28	46.88	62.12	54.28	3.46	0.064	0.067	t = -40.44
	Post-test	28	77.92	90.22	86.28	3.64	0.121		p< 0.001
F	Pre-test	28	43.84	58.52	51.98	3.42	0.160	0.0086	z = -39.78
	Post-test	28	74.38	90.88	88.89	3.94	0.069		p < 0.001

Notes: A = SMP 1 Bangsri Jepara; B = SMP 1 Kembang Jepara; C = SMP 2 Bandungan; D = SMP Islam Sultan Agung 1 Semarang; E = SMP 1 Bringin; F = SMP 10 Semarang.

Table 2 shows that the pre-test and post-test climate change literacy scores of pupils were normally distributed and homogeneous in Classes A, B, D, E and F. Meanwhile, the data for Class C were normally distributed but not homogeneous. The results of the paired-samples t-test for Classes A, B, D, E and F, and the Wilcoxon test for Class C, indicate a significant difference between students' pre-test and post-test climate change literacy scores (p-value < 0.001). These findings suggest that students'

climate change literacy improved after participating in lessons using the CLIM-BCS model. Furthermore, an analysis of the improvement in each climate change literacy indicator was carried out to examine the effectiveness of the intervention in greater depth. The results of this analysis are presented in Table 3

Table 3 n-gain Results for Each Indicator of Students' Climate Literacy

Class	Score	Indicator				n-gain	
		Knowledge of the Causes and Impacts of Climate Change	Attitudes Toward the Importance of Environmental Protection	Concern for Adopting Environmentally Friendly Behaviors	Participation in Climate Change Mitigation and Adaptation Actions	Score	Category
A	pre-test	2.46	2.11	2.18	2.98	0.62	Moderate
	post-test	4.11	3.98	3.98	4.12		
	n-gain	0.65	0.65	0.64	0.56		
B	pre-test	2.56	2.32	2.22	2.88	0.63	Moderate
	post-test	4.22	4.02	4.02	4.04		
	n-gain	0.68	0.63	0.65	0.55		
C	pre-test	2.42	2.12	2.14	2.88	0.62	Moderate
	post-test	4.12	3.82	3.82	4.22		
	n-gain	0.66	0.59	0.59	0.63		
D	pre-test	2.36	2.22	2.18	2.82	0.63	Moderate
	post-test	4.08	4.02	3.88	4.16		
	n-gain	0.65	0.65	0.60	0.61		
E	pre-test	2.24	2.34	2.32	2.86	0.59	Moderate
	post-test	3.98	3.98	3.88	4.02		
	n-gain	0.63	0.62	0.58	0.54		
F	pre-test	2.22	2.11	2.24	2.98	0.58	Moderate
	post-test	3.88	3.86	3.92	4.02		
	n-gain	0.60	0.61	0.61	0.51		

Notes: A = SMP 1 Bangsri Jepara; B = SMP 1 Kembang Jepara; C = SMP 2 Bandungan; D = SMP Islam Sultan Agung 1 Semarang; E = SMP 1 Bringin; F = SMP 10 Semarang.

Table 3 presents the n-gain results for the average scores of each climate change literacy indicator. The n-gain analysis indicates a moderate improvement across all indicators. Pupils' climate change literacy improved across all classes (A–F) and for all indicators measured. For the indicator of knowledge regarding the causes and impacts of climate change, the n-gain values ranged from 0.60 to 0.68, with the highest value found in Class B (0.68) and the lowest in Class F (0.60). The indicator for attitudes towards the importance of environmental conservation showed n-gain values ranging from 0.59 to 0.65, whilst the indicator for concern regarding environmentally friendly behaviour ranged from 0.58 to 0.65. Meanwhile, the indicator for participation in climate change mitigation and adaptation actions yielded n-gain values ranging from 0.51 to 0.63. This pattern indicates that improvements occurred consistently across all dimensions of climate change literacy, although the magnitude of the improvements varied between classes and between indicators.

Overall, the average n-gain score for climate change literacy across the six classes ranged from 0.58 to 0.63, all of which fell within the 'moderate' category. Class B recorded the highest average n-gain score (0.63), followed by Classes C and D (0.62

each), Class A (0.62), Class E (0.59), and Class F (0.58). This pattern indicates that relatively greater improvements occurred in pupils' knowledge of the causes and impacts of climate change, whilst the lowest improvements tended to occur in participation in climate change mitigation and adaptation actions. These findings suggest that the implementation of the learning model resulted in relatively consistent improvements in pupils' climate change literacy across the dimensions of knowledge, attitudes, environmental concern, and participation. However, pupils' ability to translate their understanding into concrete actions relating to climate change remains at a relatively moderate level of improvement.

Improvements in pupils' climate change literacy are also linked to their active and meaningful engagement during the learning process using the CLIM-BCS model. Pupils' activities were observed during lessons to assess the extent to which they were actively engaged in the learning process. The results of these observations are presented in Table 4.

Table 4 Student Activities during Learning Using the Citizen Science-Integrated Mobile Learning Application

No.	Activity	A		B		C		D		E		F	
		f	%	f	%	f	%	f	%	f	%	f	%
1	Involvement in the citizen science project	25.00	75.19	24.60	72.82	24.63	72.82	24.63	72.82	25.00	75.19	23.13	72.22
2	Involvement in data collection	24.13	78.52	24.12	75.39	24.13	75.39	24.13	72.39	24.13	78.52	23.13	75.36
3	Involvement in discussions through LMS	23.85	72.22	23.82	72.82	23.73	72.82	23.73	71.82	23.85	70.42	22.78	70.28
4	Involvement in classroom discussions	24.13	78.52	21.86	71.09	22.85	71.09	22.85	70.09	24.13	78.52	25.16	78.58

Notes: f = frequency; A = SMP 1 Bangsri Jepara; B = SMP 1 Kembang Jepara; C = SMP 2 Bandungan; D = SMP Islam Sultan Agung 1 Semarang; E = SMP 1 Bringin; F = SMP 10 Semarang.

Based on Table 4, student activities during the learning process were generally consistent with the application of the CLIM-BCS model. The learning process engaged students in learning about climate change through citizen science projects, environmental data collection, discussions via the LMS, and classroom discussions. Student activity levels increased throughout the learning process, and students appeared enthusiastic and actively engaged in various learning activities. Such active engagement in learning can have a significant impact on the quality of learning outcomes.

After taking part in the learning intervention, pupils completed a questionnaire regarding their responses to the use of a mobile learning application integrated with citizen science. The questionnaire covered the novelty of the learning process using the CLIM-BCS model, the benefits of the model for pupils, and pupils' interest in the model. The results of the pupils' responses are presented in Table 5.

Table 5 Student response to the CLIM-BCS model

No.	Aspec	Studens respons					
		A Yes (%)	B Yes (%)	C Yes (%)	D Yes (%)	E Yes (%)	F Yes (%)
1	The novelty of the learning process lies in the use of the Climate	100.00	100.00	98.88	100.00	100.00	96.67

No.	Aspec	Studens respons					
		A Yes (%)	B Yes (%)	C Yes (%)	D Yes (%)	E Yes (%)	F Yes (%)
	Literacy through CLIM-BCS model.						
2	Novelty of science learning models and aids	94.88	96.88	96.00	96.82	96.78	94.00
3	The novelty of citizen science activities	100.00	100.00	97.77	100.00	100.00	96.82
4	Benefits of LMS within the "Climate Literacy through CLIM-BCS model.	96.67	93.75	96.67	96.67	96.67	93.45
5	The benefits of LMS in enhancing climate literacy	96.88	96.67	93.33	96.88	96.67	93.33
6	Interest in the next learning topic	96.88	100.00	100.00	96.88	100.00	100.00
7	Interest in other subjects	96.88	93.33	96.88	96.88	95.62	96.88
	Average	95.62	95.62	95.30	97.30	95.62	95.30

Notes: A = SMP 1 Bangsri Jepara; B = SMP 1 Kembang Jepara; C = SMP 2 Bandungan; D = SMP Islam Sultan Agung 1 Semarang; E = SMP 1 Bringin; F = SMP 10 Semarang.

The results presented in Table 5 indicate that students responded very positively to the implementation of the CLIM-BCS model, with average positive response percentages across the six groups (A–F) ranging from 95.30% to 97.30%. Group D recorded the highest average response (97.30%), followed by Groups A, B, and E (95.62%), while Groups C and F obtained averages of 95.30%. Regarding individual aspects, the novelty of the learning process through the CLIM-BCS model and citizen science activities received particularly high responses, reaching 100% in several groups. Students also expressed strong appreciation for the novelty of the science learning model and its supporting tools, the benefits of the LMS for learning and enhancing climate literacy, and their interest in exploring subsequent learning topics and other subjects. Although the responses regarding aspects relating to the LMS were slightly lower in some groups, all the percentages fell within the high category. Overall, these findings suggest that the CLIM-BCS model was well received by students, particularly in terms of learning innovation, citizen science engagement, digital learning support, and sustained interest in learning.

5 Discussion

The research findings indicate that the CLIM-BCS Model achieved an average expert validation score of 3.82, falling within the ‘highly valid’ category. These results suggest that the model possesses a theoretical foundation and pedagogical design deemed suitable for integrating citizen science into science education delivered via a Learning Management System (LMS). The learning syntax aspect received the highest score, namely 3.88, indicating that the sequence of the six learning stages has been logically designed to link the identification of climate change issues with empirical investigation, data analysis, scientific discussion, and reflection and climate action. These findings are consistent with research indicating that discovery-based learning fosters a deeper understanding by linking climate change issues to scientific inquiry and environmental contexts relevant to the pupils [49]. The main contribution of CLIM-BCS lies in the integration of scientific inquiry, student participation in environmental data collection, and digital technology support within a single learning sequence explicitly aimed at developing climate change literacy.

The implementation rates of the six stages of CLIM-BCS ranged from 88.88 per cent to 90.88 per cent, indicating that the model can be implemented in the classroom context under study. The 'problem orientation' stage achieved the highest percentage at 90.88 percent, whilst the 'data collection through citizen science' stage achieved the lowest percentage at 88.88 percent. The high level of implementation of the problem orientation stage can be attributed to the use of environmental phenomena relevant to the pupils' daily lives, such as changes in temperature and local weather conditions, as a starting point for learning. These phenomena help pupils connect global climate change issues with their everyday environmental experiences. The importance of regional context in inquiry-based climate change learning [49]. Meanwhile, environmental data collection requires consistent measurement procedures, accurate record-keeping, the availability of equipment, and teacher guidance. Therefore, the implementation of CLIM-BCS needs to be supported by standardized observation guidelines and data quality checks so that the evidence generated by pupils can be used appropriately in the scientific reasoning process.

The integration of citizen science into CLIM-BCS provides students with the opportunity to be directly involved in generating and interpreting environmental evidence, rather than merely receiving information from textbooks or teachers' explanations. Observation data are used to identify patterns, compare findings, and formulate explanations based on empirical evidence. Community and citizen science activities are associated with various environmental education outcomes, including improved scientific knowledge, inquiry skills, attitudes towards the environment, and a range of behavioral aspects and environmental concerns, as demonstrated by a systematic review of 100 studies [50]. Nevertheless, student involvement in data collection alone does not necessarily result in deep learning. More comprehensive empirical evidence is needed regarding the educational outcomes of citizen science, while the importance of pedagogical aspects and forms of participation in environmental citizen science initiatives also needs to be considered [51, 44]. Thus, the strength of CLIM-BCS lies in positioning data collection as part of an inquiry process that continues through analysis, discussion, interpretation, and the formulation of scientific explanations.

The LMS serves to link environmental observation activities with subsequent learning activities, such as data documentation, analysis, discussion, and reflection. In CLIM-BCS, the LMS functions not only as a repository for materials or a collection point for assignments, but also as a means of maintaining continuity between field investigations and the construction of knowledge in the classroom. Pupils can revisit their observation results, compare findings, and communicate interpretations based on the available evidence. This role is particularly relevant in climate change education, as pupils need to understand the distinction between daily weather observations and evidence of long-term climate change. For example, daily temperature measurements can be used to study local environmental conditions but are insufficient to prove the existence of climate change trends. Pupils need to be guided to understand the scope, limitations, and context of the data before drawing conclusions. Although the research findings support the feasibility of integrating LMS and citizen science, the contribution of each component to improving climate literacy cannot yet be disentangled based on the design of this study.

An improvement in climate change literacy was observed across all classes following the implementation of CLIM-BCS. Normalized gain scores ranged from 0.58 to 0.63, falling within the 'moderate' category according to the study's criteria, while pre-test–post-test results indicated statistically significant differences across all classes. These findings are consistent with previous studies examining the impact of the SSI-STEAM program on climate literacy among lower secondary school pupils and demonstrating the relevance of inquiry-based approaches in climate change education [43, 49]. This is improvement can be understood through the interconnections between the stages of the CLIM-BCS model. Problem orientation helps to activate pupils' prior knowledge; question formulation guides the investigation; data collection provides empirical evidence; and analysis via the LMS helps pupils to organize and interpret this evidence. Subsequent scientific discussion provides a space to test explanations, whilst reflection and climate action link learning outcomes to

environmental issues. However, as the study employed a single-group design with pre- and post-tests and no control group, this improvement cannot yet be fully attributed to CLIM-BCS. These results are more appropriately interpreted as promising preliminary evidence of improved climate literacy within the context of this study.

Analysis by indicator shows that improvements in knowledge of the causes and impacts of climate change tended to be higher than improvements in participation in mitigation and adaptation actions. Normalized gain values for the knowledge indicators ranged from 0.60 to 0.68, whilst those for participation in mitigation and adaptation ranged from 0.51 to 0.63. This pattern suggests that strengthening conceptual knowledge is relatively easier to achieve during interventions than fostering participation in climate action. Knowledge and action are two interrelated, yet distinct, learning outcomes. Pupils can understand the causes and impacts of climate change through observation and discussion, but the implementation of climate actions is also influenced by opportunities, environmental support, resource availability, habits, and beliefs about the benefits of those actions. The outcomes of environmental education through citizen science are associated with the forms of participation and pedagogical designs employed [44, 50, 52]. Therefore, the 'reflection and climate action' stage needs to be strengthened through practical and measurable activities, such as monitoring the school environment, assessing energy use, or conducting environmental campaigns based on observational data. Further research should distinguish between students' reported intentions to act and the actions they actually implement and sustain over the long term.

Pupils' responses to the mobile learning application integrated with citizen science ranged from 95.30 per cent to 97.30 per cent. These results indicate a very positive reception of the learning experience, which combines direct observation activities with digital technology support. This positive reception can be attributed to pupils' opportunities to document their observations, access data, and continue the investigative process via the LMS. This experience makes technology an integral part of pedagogical activities, rather than merely a means of delivering content. Nevertheless, students' positive responses must be distinguished from evidence of learning effectiveness. Perceptions regarding the ease of use, benefits, and novelty of the application do not directly prove an improvement in understanding, skills, or behavioral change. Therefore, the results of student responses in this study are more appropriately positioned as supporting evidence regarding the acceptance of the model, whilst improvements in climate literacy need to be interpreted based on pre-test–post-test results and the analysis of learning indicators. Further research could identify the LMS features that best support student engagement and test the application of the model in schools with varying digital infrastructure conditions.

Theoretically, CLIM-BCS offers an integration of inquiry-based learning, citizen science, LMS, and the development of climate change literacy within a single systematic pedagogical framework. Its contribution lies in positioning citizen science as an integral part of science education, rather than as an additional environmental project separate from the learning process. This approach aligns with the direction of climate change education, which emphasizes science-based understanding, learner engagement, and an action-oriented focus, as highlighted in the UNESCO climate education guidelines. In practical terms, CLIM-BCS can serve as a guide for science teachers to link local environmental observations with broader scientific concepts, while training pupils to interpret data and present evidence-based explanations. Its implementation requires teacher readiness, adequate measurement tools, clear data collection protocols, and guidance on interpreting observation results. Such support is necessary to ensure that data collection activities genuinely contribute to scientific understanding, rather than merely serving as a practical exercise detached from learning objectives.

Several limitations should be considered when interpreting the results of this study. The research involved 168 pupils from six classes in Central Java who were selected purposively; therefore, generalising the findings to a wider population and school context must be done with caution. The absence of a control group also limits the strength of causal conclusions regarding the effectiveness of CLIM-BCS. Furthermore, the limited

implementation period has not provided information on knowledge retention and the sustainability of climate actions after the learning programme ended. This study also did not isolate the contributions of each component, namely inquiry, citizen science and LMS support. Future research is recommended to use a quasi-experimental design with a comparison group, conduct follow-up measurements, and evaluate the quality of data produced by pupils and evidence of climate actions that have actually been implemented. Overall, the research findings indicate that CLIM-BCS is a valid model that can be applied in a research context and has the potential to support the development of climate change literacy. However, testing in more diverse educational contexts is still required to ensure its comparative effectiveness and the sustainability of its impact.

6 Conclusion

The CLIM-BCS model has been shown to be highly valid, highly feasible, and capable of enhancing pupils' climate change literacy, with average n-gain scores of 0.58–0.63 and pupil response rates of 95.30%–97.30%. This model offers theoretical and practical implications for the development of science education that integrates inquiry, citizen science, and LMS to link conceptual understanding with empirical evidence and environmental concern. However, improvements in knowledge still tend to be higher than participation in mitigation and adaptation. Therefore, teachers are advised to strengthen concrete and measurable climate action activities, accompanied by guidance on data collection and analysis. Future research should involve a comparison group, a more diverse range of school contexts, and long-term measurements to test the effectiveness and sustainability of the model's impact. Given that this study did not utilize a control group, the results should be viewed as promising preliminary evidence for the development of science education oriented towards literacy and climate action.

Authors' contributions
JS: Selection of studies, model development, data coding and analysis, and drafting of the manuscript. HN and CH: development of validation and data collection instruments, and drafting of the manuscript. NLDMS: design of the LMS, data collection, and editing. All authors have thoroughly reviewed and approved the final manuscript.

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Data availability
The data will be provided on request.

Declarations

Ethics approval and consent to participate
The study protocol was reviewed and approved by the ethics committee of the Institute of Research and Community Service at Universitas PGRI Semarang, Indonesia (25.B/LPPM UPGRIS/I/2026, 14 January 2026). The study was conducted in accordance with the applicable institutional ethical guidelines and regulations. Permission to conduct the study was also obtained from the participating school. Written informed consent was obtained from the parents or legal guardians of all student participants, who were under 16 years of age, before data collection. Student assent was also obtained where required by the approved ethics protocol. Participation was voluntary, and students were informed about the purpose and procedures of the study and their right to withdraw without penalty. Confidentiality was maintained by using identification codes instead of students' names in the research dataset.

Consent to publish
Not applicable. This manuscript does not contain any identifiable individual data, images, or other personal information requiring consent for public

Competing interests
The authors declare no competing interests.

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