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Discovery Learning and Scientific Literacy: Integrating PISA Indicators in High School Science

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ABSTRACT

Purpose of the study: The aim of this study is to analyze the level of scientific literacy among Grade X students, identify problems during the learning process, and explore factors influencing the effectiveness of Discovery Learning in teaching environmental change topics within the Merdeka Belajar curriculum framework.

Methodology: This study used a mixed methods approach with a sequential explanatory design. Data were collected using multiple-choice science literacy tests, interviews with a biology teacher, and documentation. Analysis was conducted with qualitative descriptive methods. Tools included printed tests, interview guides, and documentation logs. Data validation employed triangulation of methods and sources.

Main Findings: This study found that the scientific literacy of tenth-grade students at State Senior High School 1 Kota Agung was relatively low, with an average achievement of only 48%. The weakest indicator was the use of scientific evidence (15%), followed by the identification of scientific problems (17%), and the explanation of scientific phenomena (31%). Low literacy was caused by limited learning time, lack of student focus, and a suboptimal learning approach. The Discovery Learning model has the potential to increase students' active participation, conceptual understanding, and critical thinking skills.

Novelty/Originality of this study: This study offers a new perspective by integrating the Discovery Learning model with PISA-based scientific literacy indicators in the context of the Merdeka Belajar curriculum. It provides empirical evidence on students' low scientific literacy in senior high school and identifies key instructional and contextual factors, contributing to more targeted strategies for improving science education in Indonesia.

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1. INTRODUCTION

Education is a conscious process aimed at shaping students' personalities and developing their overall competencies. In the 21st century, education faces significant challenges due to the rapid development of Science and Technology. The Industrial Revolution 4.0 era demands that the younger generation possess a combination of hard and soft skills to compete and adapt quickly to global dynamics [1], [2]. One crucial competency students must possess in this era is scientific literacy.

Scientific literacy extends beyond the ability to understand scientific concepts; it also encompasses the ability to think critically, solve problems, evaluate information, and make evidence-based decisions in everyday life. According to the Program for International Student Assessment (PISA), scientific literacy encompasses an understanding of scientific phenomena, the ability to design and evaluate scientific investigations, and the interpretation of scientific data and evidence [3], [4]. These competencies are relevant to 21st-century skills, such as communication, collaboration, creativity, and innovation.

Unfortunately, based on PISA studies conducted from 2000 to 2018, Indonesian students' scientific literacy remains relatively low [5], [6]. Indonesia's average score consistently falls below the international average (500), with its ranking consistently declining year after year. This indicates that Indonesian students are not yet fully able to grasp scientific concepts and processes in depth and are unable to integrate scientific knowledge into real-life contexts [7], [8]. Several factors contributing to low scientific literacy include inadequate educational infrastructure, suboptimal learning methods and models, and low levels of active interaction in the teaching and learning process [9], [10].

Curriculum reform through the Independent Learning Curriculum (Curriculum Merdeka Belajar) is expected to be a solution to improve the quality of learning and student literacy [11], [12]. This curriculum provides more space for students to deepen their understanding of concepts and improve their competencies through meaningful learning [13], [14]. In this context, learning models that encourage active student involvement, such as Discovery Learning, are highly relevant [15], [16]. Discovery Learning is a constructivist learning model that emphasizes students' independent exploration and discovery of concepts through structured activities [17], [18].

The Discovery Learning model is considered effective in improving scientific literacy because it provides exploratory learning experiences [19], [20]. In this model, students are involved in the process of identifying problems, searching for and processing information, and drawing conclusions based on evidence they discover themselves. This way, students not only understand the material theoretically but are also able to apply it in real-world contexts. Furthermore, this model can foster curiosity, critical thinking, and independent problem-solving, all of which are essential components of scientific literacy.

Several previous studies have demonstrated the effectiveness of environmental-based learning in improving students' scientific literacy. For example, Baptista et al. [21] found that an Inquiry-Based Science Education approach to local mining issues can improve students' scientific argumentation and decision-making skills. Another study by Paz and Vasconcelos [22], Through role-play simulations on deep-sea mining issues, research has also shown improvements in scientific literacy and systemic thinking skills. However, these studies have generally been conducted at the junior high school level and have not specifically examined the effectiveness of the Discovery Learning model within the context of the Merdeka Belajar curriculum in Indonesia.

Furthermore, research by Winarni et al. [23] demonstrated that ICT-based Discovery Learning can improve scientific literacy at the elementary school level, but has not yet tested this model on high school students with complex topics such as environmental change. Several other studies, such as Chanapimuk et al. [24] and Pramuda et al. [25] also highlight the importance of context and teacher support, but have not yet comprehensively utilized the PISA scientific literacy framework, which encompasses conceptual understanding, investigation design, data interpretation, and evidence-based decision-making. Therefore, this study aims to fill this gap by applying the Discovery Learning model to the topic of environmental change for 10th-grade high school students, and integrating the PISA-based scientific literacy approach within the Merdeka Belajar curriculum framework. This approach is expected to provide an empirical contribution to the development of science learning strategies relevant to 21st-century challenges in Indonesia.

Based on this background, more in-depth research on students' scientific literacy skills is essential, particularly in the application of the Discovery Learning model. This study will analyze the level of scientific literacy skills of 10th-grade students, identify problems that arise during learning, and explore factors that influence the effectiveness of Discovery Learning on environmental change. Therefore, the research findings are expected to contribute to improving learning strategies and curriculum development to enhance the quality of scientific literacy at the secondary school level.

2. RESEARCH METHOD

This research uses a mixed methods approach, a combination of quantitative and qualitative methods, to obtain more comprehensive, balanced, and informative results. The research approach is sequential explanatory, beginning with the collection and analysis of quantitative data, followed by the collection and analysis of qualitative data to further explain the quantitative results. The approach used was a quantitative explanatory sequential approach. In the first stage, quantitative data was collected through tests to measure students' scientific literacy skills. Next, the qualitative phase was conducted through interviews and documentation to deepen the quantitative results obtained previously.

2.1. Population and Sample

The population in this study was all 10th-grade students at State Senior High School 1 Kota Agung, consisting of four classes. The research sample was selected using purposive sampling based on the results of the pre-research, namely class X.A, which had the lowest scores compared to the other classes. This sample consisted of 29 students.

2.2. Data Collection Techniques

The data sources in this study consisted of primary and secondary data. Data collection techniques used three main methods: interviews, tests, and documentation. The researcher conducted interviews with the 10th-grade biology teacher, Mrs. NNW to obtain in-depth information regarding the learning process, the approaches used in the classroom, and the teacher's perceptions of students' scientific literacy skills. The test was used to measure the scientific literacy skills of 10th-grade students on environmental change. This test consisted of 15 multiple-choice questions developed based on scientific literacy indicators. Furthermore, documentation was used to supplement the learning outcome data and support other collected data, such as student grades, learning activity notes, and teaching materials used by the teacher. Table 1 below presents the outline of the teacher interview.

Table 1. Teacher interview grid

Scientific Literacy Indicator	Scientific Literacy Sub-Indicator	Question Number
Identifying Scientific Issues	Identifying valid scientific opinions	1, 2
Explaining Scientific Phenomena	Analyzing effective literature review	3
	Understanding research design elements and their impact on findings/conclusions	7, 8
	Analyzing data and graphs accurately	10
	Solving problems using quantitative skills, including basic statistics	4
	Understanding and interpreting basic statistics	5
Using Scientific Evidence	Considering inferences, predictions, and drawing conclusions based on data	6, 9

Then in Table 2 below is the grid for students' scientific literacy questions, namely as follows:

Table 2. Grid of student science literacy question instruments

Scientific Literacy Indicator	Sub-Indicator of Scientific Literacy	Question Indicator
Identifying Scientific Issues	Identifying valid scientific claims	Identifying causes of environmental damage (e.g., SO_2 and acid rain)
	Recognizing ecological imbalance	Explaining the process of biomagnification and its impact
	Identifying non-recyclable waste materials	Selecting non-recyclable items from a given list
Explaining Scientific Phenomena	Analyzing literature from various media sources	Determining the type of information source from disaster and air pollution excerpts
	Understanding research design elements	Determining lowest pollution concentration locations; understanding the concept of 3R waste management
	Understanding solutions to reduce pollution and manage household waste	Identifying proper household waste disposal solutions
Analyzing Data	Analyzing data through graphical representation	Determining decomposition time of inorganic waste based on provided graph
	Applying quantitative reasoning	Calculating the most effective fertilizer dosage from experimental data
	Interpreting basic statistical data	Explaining the purpose of using statistics to draw conclusions from data
Using Scientific Evidence	Drawing inferences, predictions, and conclusions based on data	Explaining the impact of water hyacinth on ecosystems; interpreting experimental outcomes on plant growth
	Using data to identify accumulation of toxic substances in food chains	Identifying which organism has the highest DDT accumulation in a food chain

2.3. Data Analysis Techniques

Data analysis in this study was conducted using descriptive qualitative methods through three main stages: data reduction, data presentation, and drawing conclusions or verification. The data reduction stage involved simplifying and summarizing important data and identifying emerging themes and patterns. The data was then presented in descriptive narrative form to facilitate understanding and conclusion-drawing. In the final stage, the researcher drew conclusions by analyzing the meaning of the data obtained and examining cause-and-effect relationships based on field findings. To ensure data validity, this study employed method triangulation and source triangulation techniques. Method triangulation was conducted by comparing results from tests, interviews, and documentation, while source triangulation was conducted by comparing information obtained from students, teachers, and related documents. This technique aims to ensure that the data obtained is valid, credible, and consistent with actual conditions in the field.

3. RESULTS AND DISCUSSION

Research conducted on students of State Senior High School 1 Kota Agung obtained data on scientific literacy from Class X.A students of State Senior High School 1 Kota Agung. The percentage of scientific literacy achievement is explained descriptively based on the test score criteria set by Arikunto [26] in Table 3 below:

Table 3. Results of descriptive statistical analysis of students' scientific literacy abilities

No	Criteria	Interval	Number of Students	Percentage (%)
1	Very High	80–100	0	0%
2	High	66–79	7	24%
3	Medium	56–65	4	14%
4	Low	40–55	12	41%
5	Very Low	≤39	6	21%
	Total		29	100%

Descriptive analysis was conducted to assess students' scientific literacy skills. Seven students (24%) had high literacy skills, while four students (14%) had moderate literacy skills. Meanwhile, 12 students (41%) had low literacy skills, and six students (21%) had very low literacy skills. These scores are considered low based on the scientific literacy criteria established by Arikunto [26].

The overall scientific literacy ability of students in grade 10A at State Senior High School 1 Kota Agung was obtained by calculating the average score of the scientific literacy ability test results. Based on the results of this study, students' scientific literacy ability is included in the low criteria with an average level of understanding achieved of 48%.

3.1. Data Analysis

3.1.1. Indicators for Identifying Scientific Problems

The discovery learning model emphasizes the discovery of concepts or principles that students do not yet possess. The discovery learning model aims to transform passive learning into active and creative learning. The discovery learning model consists of the following steps: (1) problem identification, (2) developing possible solutions, (3) data collection, (4) data analysis and interpretation, and (5) testing conclusions. The discovery learning model begins when educators pose thought-provoking questions and encourage students to read books and participate in other learning activities.

Furthermore, educators provide students with the opportunity to identify problems related to the subject and formulate them in the form of hypotheses. Next, educators provide students with the opportunity to gather relevant information to verify the validity of these hypotheses. They then process the data obtained through interviews, observations, and other data sources. Furthermore, educators conduct careful testing to verify whether the hypotheses are based on the results and data processing. The next step, educators and students draw conclusions that serve as general principles applicable to all similar problems.

Scientific literacy skills are also influenced by the ability to read information. This ability significantly influences the ability to identify problems. One learning model that can improve students' scientific attitudes is discovery learning. Identifying problems provides students with the opportunity to identify as many facts as possible and formulate hypotheses.

The indicator categorized as effective by the syntax of the discovery learning model is problem identification, as it enables students to identify observations or phenomena, formulate objectives, and generate hypotheses. Based on the results of students' scientific literacy scores for the scientific problem identification indicator, the overall average score was 17%.

3.1.2. Indicators Explain Phenomena Scientifically

The competencies measured in scientific literacy are not always explained in specific material. Instead, students are asked to identify a concept that applies their knowledge, explain scientific phenomena that occur, and use scientific evidence to discover a concept within a given material. A learning model that can help develop scientific literacy is the discovery learning model. Therefore, students are required to experience, feel, and understand facts and concepts related to scientific phenomena in order to develop scientific attitudes and scientific process skills.

The discovery learning model effectively improves students' scientific literacy. The aspect of explaining scientific phenomena requires students to recall content information relevant to a specific situation and use it to interpret and explain the proposed phenomenon. Indirect observation indicators measure students' general scientific literacy skills. Due to the limitations of human senses, facts and natural phenomena cannot be observed directly. Therefore, a tool is needed to establish or demonstrate facts and/or symptoms that demonstrate the behavior of the material being studied. In this case, implicit perception indicators are developed within the stimulus syntax of the discovery learning model. Students observe by looking at pictures and reading stories provided so they can visualize the information presented.

Scientific literacy-oriented learning is essential for developing scientific literacy in line with everyday life processes. This learning addresses social issues that require scientific concepts in problem-solving decision-making and helps students solve problems. Global problems are addressed by reading texts about phenomena, causes, impacts on ecosystems, and efforts to mitigate global warming, thereby fostering students' interest in reading. The discovery learning model is combined with reading texts about global issues, enabling students to put their scientific literacy into practice.60 Based on the results of students' scientific literacy skills on the indicator of explaining phenomena scientifically, it can be seen that the overall average score was 31%.

3.1.3. Indicators Using Scientific Evidence

The discovery learning model considers three aspects of scientific literacy: (1) content, (2) process, and (3) context. Previous research focused more on aspects of scientific phenomena, using scientific evidence, and identifying scientific questions [27], [28]. The discovery learning model is highly suitable for active student participation in the learning process. The discovery learning model guides students to understand concepts, meanings, and relationships through an intuitive process until they finally reach a conclusion [29].

The syntax of the discovery learning model includes stimulation, problem solving, data collection, data processing, verification, and generalization, which can train and strengthen students to be more focused [30]. In addition, the use of the discovery learning model is very helpful for students in understanding the context of science because the discovery learning model is syntax-based, which provides opportunities for students to identify as many problems as possible related to dynamic flow material through various learning resources. The scientific literacy process aspect has 3 assessment items, namely identifying scientific problems, explaining phenomena scientifically, and using scientific evidence [4]. With this model, it is expected to improve and encourage the development of students' scientific attitudes [31], [32]. Based on the results of students' scientific literacy ability scores on the indicator using scientific evidence, it can be seen that the overall average score obtained is 15%.

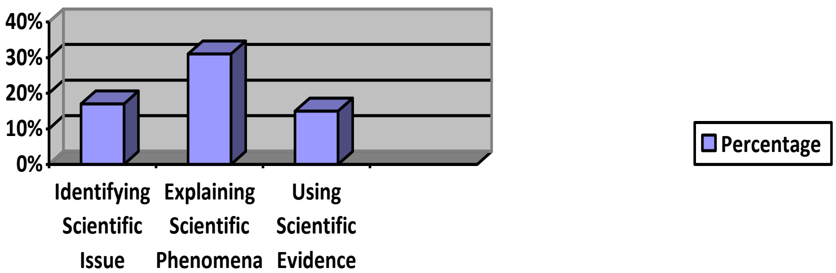

Figure 1. Percentage of students' cognitive dimensions of scientific literacy

Based on the analysis of the scientific literacy skills of Grade XA students at State Senior High School 1 Kota Agung, solving problems in the cognitive dimension is still considered low. This is evidenced by the overall score of 48%. This is evident in the low ability to identify scientific problems, explain scientific phenomena, and use scientific evidence. In the cognitive dimension, the lowest percentage was in the aspect of using scientific evidence. This is due to the large amount of material required, which leads educators to only introduce and explain the material directly due to time constraints. However, students must not simply memorize but also be able to understand the material explained.

Students' scientific literacy skills in the context of earthquake disasters are categorized as very low. Therefore, hard work is needed to improve them through various methods, one of which is optimizing the use of discovery learning models in learning. Discovery learning is effective in helping students construct knowledge that is used to understand information and integrate that information into solutions [33]. The latest survey in 2018 ranked Indonesian students' scientific literacy 70th out of 78 countries.

These results indicate that scientific literacy skills are relatively low compared to other countries. This is because Indonesian students have not yet applied science concepts in their daily lives. Based on these results, research is needed to improve scientific literacy skills. One solution is to implement the discovery learning model, which essentially empowers students to ask questions, observe, gather information, and draw conclusions [34]. The use of the discovery learning model can have a positive impact by improving students' scientific literacy skills [35].

Scientific literacy can be improved through learning that actively engages students and allows them to discover the concepts they are learning, making learning more meaningful. Students' scientific literacy skills need to be enhanced by exploring their potential according to their needs and characteristics, based on the curriculum, using the discovery learning model. This finding aligns with previous research, which concluded that utilizing the discovery learning model can improve students' thinking skills. Improving students' scientific literacy skills can be used to meet the demands of learning activities in the current industrial revolution.

Furthermore, other research has shown that implementing the discovery learning model can improve conceptual understanding and science learning outcomes [36], [37]. In today's era, students are required to be able to think at a higher level. One of the critical thinking skills is scientific literacy. The discovery learning model can improve scientific thinking skills because it involves a series of processes [38], [39]. Discovery learning encourages students to develop scientific skills through investigation and discovery activities regarding scientific concepts. Because the educator acts solely as a facilitator, the skills acquired are not the result of memorizing concepts.

Discovery learning outlines ways to facilitate students' learning processes, leading to targeted achievement goals [40]. The discovery learning model has a suitable syntax for classroom implementation, thereby enhancing scientific literacy [41]. Improvement in students' scientific literacy skills is influenced by several factors, one of which is the discovery learning model, which trains students according to the demands of scientific literacy, encompassing content/knowledge and competency/process, and motivates students to develop concepts based on their own discoveries.

The discovery learning model has a significant impact on scientific literacy skills, and overall, students' scientific literacy abilities improve. Previous research has shown that the discovery learning model significantly impacts students' scientific literacy abilities. The content aspect accounts for 22.22%, the skills aspect for 29.63%, and the context aspect for 25.93%. The relationship between the discovery learning model and scientific literacy is that the discovery learning model emphasizes direct experience in the field, thus eliminating reliance on textbook theories. Field experience can lead students to discover concepts that can then be directly applied in the field. Thus, students can solve the problems they face. Previous research has shown the influence of the discovery learning model and scientific literacy on student skills with a value of $0.001 < 0.05$.

3.2. Research Findings

In the research data analysis results, the researcher will present the research findings to answer the problem formulation and research objectives based on field findings and theoretical foundations. The results of this study consist of a description of data obtained during field data collection through interviews, test questions, and documentation. The analysis of students' scientific literacy skills at State Senior High School 1 Kota Agung is included in the low category based on the percentage of multiple-choice test results, namely 48%. The low scientific literacy abilities of students are caused by students who lack focus and do not pay attention when the teacher explains so that the material presented is not understood. There are problems with students' scientific literacy abilities due to several factors, namely (1) The learning process is too fast because they are chasing predetermined material. (2) Calculation of learning time allocation is less than optimal. (3) Conditions for educators that allow for face-to-face attendance. (4) Students who lack focus and do not pay attention when the teacher explains so that the material presented is not understood. Based on these findings, efforts are needed to build student motivation and participation. Efforts made are: (1) Carrying out careful planning so that students are able to understand the material. (2) Implementing learning methods and media that have not been used. (3) Creating perfect worksheets that contain complete competencies.

Factors contributing to low scientific literacy include (1) a lack of interest in reading and unfamiliarity with argumentative, graphical, and pictorial questions. (2) Scientific literacy questions are lengthy and require critical thinking, requiring sufficient time to interpret the text. Furthermore, other research indicates that low scientific literacy is caused by students' inability to solve scientific questions that require understanding and analysis. Several factors contribute to low scientific literacy, including (1) the topic has never been studied before, making it difficult for students to answer questions on the scientific literacy questions given. (2) Students are not accustomed to working on questions that use arguments. (3) Educators are not accustomed to supporting students' learning process and helping them develop scientific literacy skills. Other factors contributing to low scientific literacy include educational programs and systems, inefficient choices of learning methods and models, inadequate learning facilities and media, and teaching materials and resources.

Previous research in this area indicates that students experience problems in the discovery learning process. The discovery learning model can be challenging for students due to the failure of the learning process. The causes are students' lack of understanding of the material, insufficient knowledge about the hypotheses or experiments to be conducted, and inefficient time constraints. These factors can be interpreted as obstacles to the learning process. In this case, learning fails to encourage students' understanding of the material because, during experiments, students are unable to draw conclusions from the results.

Problems in previous research include students' inability to solve problems that require in-depth analysis. Students are unable to complete certain questions that require more in-depth analysis. Students review the answers but are unable to correct their mistakes. Consequently, none of the questions achieved the maximum score for all questions and the discovery learning model achieved the maximum score for achieving completion. Previous research has shown that students' scientific literacy skills in South Sulawesi are relatively low. The learning process in high schools throughout South Sulawesi has not been effective in improving students' scientific literacy skills. Data shows that most students failed to complete questions in the low category, and none were included in the good or excellent categories. The current learning process still emphasizes mastery of theory and memorization, resulting in underdevelopment of students' learning abilities. Learning models that are too teacher-centered tend to neglect the rights, needs, and development of students. Therefore, it is essential to consistently implement student-centered learning processes that are fun, intelligent, and joyful, and encourage students' thinking skills.

Students' scientific literacy skills in biology lessons in South Sulawesi are still relatively low. Therefore, educators need to apply constructivist learning principles as required by the school curriculum to achieve more effective learning. Furthermore, monitoring and evaluation of how schools implement the curriculum in the classroom are necessary. However, not all discovery learning models are ineffective in improving student knowledge. Other research suggests that discovery learning can significantly improve student academic achievement because it allows students to be more active in discovering knowledge.

Other researchers also state that this learning approach allows students to collect and classify information, formulate hypotheses, make predictions, interpret results, and draw conclusions, thereby improving student academic achievement. This positively impacts students' thinking skills and understanding, ultimately contributing to their scientific literacy [9], [42]. Problem-based learning seeks to help students become independent learners while also improving their scientific literacy. Furthermore, low student scientific literacy can be improved through effective learning. Implementing an ethnoscience approach is possible if educators are able to integrate local wisdom. However, most educators lack this capability. As educators, we are limited in using the concepts, processes, and contexts of science and scientific knowledge, so science learning in schools pays less attention to the local culture that is developing in society. An educator is required to master skills and abilities, adapt to the current era of new technology, use media, choose learning models appropriate to the 21st century, and develop instruments that will be used during the learning process. The focus of science educators should be to improve students' ability to think critically, rationally, and creatively, which can only be possible when educators are ready to actively engage students in constructive scientific discussions.

This study presents a novelty by specifically examining students' scientific literacy skills based on three main indicators—identifying scientific problems, explaining scientific phenomena, and using scientific evidence—through the application of the discovery learning model in the context of an earthquake disaster. The focus on scientific literacy in the local context and the use of a constructivist learning model make this study unique because it combines an active student approach with relevant contextual issues, which are still rarely studied in depth in secondary schools in Indonesia.

The results of this study have important implications for education, particularly in developing more effective learning strategies to improve students' scientific literacy. The discovery learning model has been shown to encourage active student participation, improve critical thinking skills, and help students understand scientific concepts in real-life contexts. Therefore, teachers and educational policymakers are advised to integrate this model into the curriculum, particularly for topics that require analytical and applied understanding.

This study has limitations in terms of scope and generalizability, as it involved only one class in one school with a limited sample size. Furthermore, implementing the discovery learning model requires sufficient time and teacher preparedness to design effective learning scenarios, which in practice is often hampered by limited learning time and limited learning resources.

4. CONCLUSION

Based on the results of the research that has been conducted, it can be concluded that the scientific literacy ability of students at State Senior High School 1 Kota Agung is relatively low, with an average percentage of 48% based on the results of a multiple-choice test of 15 items. This low achievement is caused by a lack of student focus during the learning process, which results in minimal understanding of the material. In addition, there are several other contributing factors such as the learning process that occurs too quickly due to chasing material targets, less than optimal time allocation, and the absence of face-to-face teacher attendance. Based on these findings, it is recommended that future researchers conduct further analysis using a mixed method approach and more in-depth data processing in a determinant manner to obtain a more comprehensive picture of the factors that influence students' scientific literacy.

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AUTHOR CONTRIBUTIONS

Conceptualization, W. and M.G.V.; Methodology, W.; Software, W.; Validation, W. and M.G.V.; Formal Analysis, W.; Investigation, W.; Resources, M.G.V.; Data Curation, W.; Writing – Original Draft Preparation, W.; Writing – Review & Editing, W. and M.G.V.; Visualization, W.; Supervision, M.G.V.; Project Administration, M.G.V.; Funding Acquisition, M.G.V.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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