



Prototype of Greenhouse Effect for Improving Problem-Solving Skills in Science, Technology, Engineering, and Mathematics (STEM)-Education for Sustainable Development (ESD): Literature Review, Bibliometric, and Experiment

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ABSTRACT

This research aims to improve problem-solving abilities regarding the greenhouse effect using project-based learning methods supported by Science, Technology, Engineering, and Mathematics (STEM)-Education for Sustainable Development (ESD)-based teaching materials. The study was conducted in multiple phases: (i) utilizing a pretest to gauge students' prior knowledge, (ii) employing the project-based learning approach to teach the greenhouse effect, and (iii) assessing students' final knowledge (with a posttest). The research was completed with the observation of temperature variations in a greenhouse prototype. Students monitored and recorded temperature changes over time. Students' problem-solving abilities increased significantly after being treated using project learning assisted by STEM-ESD teaching materials, imparting more information through the media by stimulating students' curiosity and interest in science subjects.

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1. INTRODUCTION

A greenhouse is a controlled natural system that protects plants from extreme climatic conditions and provides the ability to change internal climatic conditions to form a suitable climatic environment for good plant growth, both in terms of quality and quantity (Queen, 2021). The greenhouse effect is an important subject in junior high school (Lopresto, 2018; Kara et al., 2011; Flanders et al., 2020). The most important reason why science subjects on the greenhouse effect are very important is that this subject is related to phenomena that often occur in nature (Willits Smith et al., 2023), especially the temperature of earth that is neither too hot nor too cold.

Based on this explanation, analysts believe that utilizing a learning-based learning project can empower students to be more dynamic in learning (Mayasari et al., 2016; Sinaga et al., 2017). Involving a Science, Technology, Engineering, and Mathematics (STEM) approach – Education for Sustainable Development (ESD) with project-based learning can encourage students to make progress in their capacity to deal with problems (Ridwan et al., 2021). Lots study about STEM and ESD have been carried out to improve 21st-century capabilities (Timpontiane and Williams, 2022; Lagcao et al., 2023; Ekamilasari and Pursitasari, 2021; Suryani and Hamdu, 2021). Several researchers have shared their thoughts and ways to enhance problem-solving skills related to the greenhouse effect. To elucidate the greenhouse effect, certain scientists employ empirical observations in natural settings, with the development of specialized apparatus and software (Kurniawan et al., 2017) to explain temperature, warmth, and heat exchange to junior high school students. The technique is easy and allows it to be executed. The teaching model is very important to improve solving ability student problems (Asril et al., 2023).

The primary challenge, particularly in developing nations such as Indonesia, lies in identifying effective tactics and media for educating about the greenhouse effect. Investigating the greenhouse effect necessitates the use of advanced apparatus, which is severely restricted in availability. Teaching children about natural or everyday objects can effectively cultivate their scientific understanding of the natural world, making them adept problem solvers. Thus, individuals can utilize and execute their knowledge within the societal context (Mariyam et al., 2017). Regrettably, the current availability of guidance on implementing pedagogical approaches utilizing domestic apparatus remains insufficient, despite its significance, particularly in the context of educating rural communities in Indonesia about the greenhouse effect phenomena.

This research aims to improve students' problem-solving abilities regarding the greenhouse effect using a project-based learning model supported by STEM-ESD teaching materials. The project was carried out using simple household equipment. This research shows new information regarding the need to use project learning (even using household equipment) for students' problem-solving abilities. Also, to complete this study, we added bibliometric analysis. We hereby give a comprehensive collection of bibliometric articles, as indicated in **Table 1**, with references to earlier bibliometric studies and our investigations into earlier bibliometric analysis.

Table 1. Previous studies on bibliometric.

Author	Title	Result
Shidiq et al., (2021)	The use of simple spectrophotometer in STEM education: A bibliometric analysis	The study, which made use of the VOSviewer program, found that modified spectrophotometers are frequently used in chemistry and STEM teaching, providing prospects for future research.

Table 1 (Continue). Previous studies on bibliometric.

Author	Title	Result
Nordin, (2022)	Correlation between process engineering and special needs from bibliometric analysis perspectives.	VOSviewer, a process engineering tool for mapping analysis, experienced a decrease in publications on "process engineering special demands" between 2017 and 2021.
Bilad, (2022)	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	An analysis of articles on chemistry and special education using VOSviewer and Publish or Perish showed a decline in publications in 2017 and a rise in 2021.
Riandi <i>et al.</i> , (2022)	Implementation of Biotechnology in Education towards Green Chemistry Teaching: A Bibliometrics Study and Research Trends	With journals being the most prevalent source, the study bibliometric analysis of research trends on biotechnology in education revealed four study concept potentials, underscoring the significance of teaching green chemistry in schools.
Nordin, (2022)	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	A study that examined teaching, science, and engineering research using the VOSviewer and Perish applications found a significant drop because of pandemic conditions.
Wirzal & Putra, (2022)	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	Utilizing the VOSviewer software, a research study on the relationship between chemical engineering and special needs examined 800 pertinent papers between 2018 and 2022.
Nandiyanto & Al Husaeni, (2021)	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	A bibliometric assessment of research on Indonesian materials was conducted using VOSviewer, and the results showed that "acid" received the most attention from 2016 to 2021, with 43 publications and 8 foreign linkages.
Maryanti <i>et al.</i> , (2022)	Sustainable development goals (SDGs) in science education: Definition, literature review, and bibliometric analysis.	The bibliometric analysis, a vital instrument in science education, offers a thorough grasp of the subject, underscoring the important role it plays in facilitating research on the SDGs.
Nandiyanto & Al Husaeni, (2021)	A bibliometric analysis of chemical engineering research using VOSviewer and its correlation with covid-19 pandemic condition.	Despite a decline in research since 2019, chemical engineering uses VOSviewer software for bibliometric analysis, which provides useful information on research trends and themes.
Al Husaeni, (2022)	Computational bibliometric analysis of research on science and Islam with VOSviewer: Scopus database in 2012 to 2022.	In a study on science and Islamic research, VOSviewer was used for bibliometric analysis, which revealed a drop in research, particularly in Indonesia and Malaysia. This study also provided excellent reference materials for future research.
Al Husaeni, (2022)	Bibliometric analysis of briquette research trends during the Covid-19 pandemic.	A review of 973 pertinent papers on briquettes was analyzed using VOSviewer, bibliometric analysis, and data mapping; the results showed a decline in research over the previous three years as a result of the COVID-19 pandemic.

Table 1 (Continue). Previous studies on bibliometric.

Author	Title	Result
Ragadhita & Nandiyanto, (2022)	Computational bibliometric analysis on publication of techno-economic education.	A study on science and Islamic research that employed data from the Scopus database from 2012 to 2022 and VOSviewer for bibliometric analysis found a reduction in research, mainly in Indonesia and Malaysia.
Al Husaeni & Nandiyanto, (2022)	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSviewer	A study that used VOSviewer to chart the development of nano propolis research over the last ten years found a spike in research on nanoparticles and propolis.
Febriandi et al., (2023)	Research on algebraic thinking in elementary school is reduced: a bibliometric analysis	VOSviewer, a bibliometric approach, was used to analyze 996 articles from 2012–2021, revealing a decline in research on algebraic thinking skills and providing valuable insights for future research.
Supriyadi et al., (2023)	Global trend of ethnoscience research: a bibliometric analysis using Scopus database	An analysis of the Scopus database showed that ethnoscience research has significantly increased over the past 50 years, suggesting prospective directions for future study. This bibliometric study identified potential directions for ethnoscience research in the future.
Supriyadi et al., (2023)	Didactical design research: a bibliometric analysis	By identifying research topics, authors, sources, countries, affiliations, and most-cited papers in DDR publications, Scopus offers bibliometric analysis. This analysis showed a large growth in DDR initiatives from 2015 to 2022.
Nandiyanto et al., (2023)	Particulate matter emission from combustion and non-combustion automotive engine process: review and computational bibliometric analysis on its source, sizes, and health and lung impact	This study discusses the growth trend of scientific publications on the topic of particulate matter identified based on several categories such as the most cited, publisher, author, country, and affiliation.
Kolakoti et al., (2023)	Enhancing heat transfer performance of automotive car radiator using camphor nanoparticles: experimental study with bibliometric analysis	In this study, an attempt was made to investigate the heat transfer performance of a four-wheeler automotive radiator using a novel coolant system.
Nandiyanto et al., (2023)	Particulate Matter Emission from Combustion and Non-Combustion Automotive Engine Process: Review and Computational Bibliometric Analysis on Its Source, Sizes, and Health and Lung Impact	This study aimed to comprehensively analyze particulate matter (PM) emissions from vehicles, focusing on their sources based on combustion and non-combustion process, classification (PM10, PM2.5, PM0.1), and health implications (including PM transportation into lungs).
Nandiyanto et al., (2023)	Involving Particle Technology in Computational Fluid Dynamics Research: A Bibliometric Analysis	This research was conducted to determine (i) the growth in the number of scientific publications in the field of particle technology in computational fluid dynamics (CFD), (ii) top citations based on the number of citations, publisher, and country, (iii) visualization of the most productive author, and (iv) publication development map based on keywords.

Table 1 (Continue). Previous studies on bibliometric.

Author	Title	Result
Ramdhani et al., (2023)	A comprehensive study on biochar production, bibliometric analysis, and collaborative teaching practicum for sustainable development goals (SDGs) in Islamic schools	This research endeavors to assess the impact of additional practicum sessions and experimental demonstrations through video presentations on students' comprehension in an Islamic boarding school. The study focuses on enhancing students' understanding of the biochar concept, particularly its role as an adsorbent, aligning with contemporary issues related to the Sustainable Development Goals (SDGs) and environmental problem-solving.
Suherman et al., (2023)	How to Improve Student Understanding in Learning Science by Regulating Strategy in Language Education? Definition, Factors for Enhancing Students Comprehension, and Computational Bibliometric Review Analysis	This study aims to explain language education development research for improving student comprehension in learning science. This study also reviews the definition of these strategies, identifies factors that contribute to improving students' comprehension, and conducts a computational bibliometric review analysis.
Al Husaeni et al., (2022)	How Language and Technology Can Improve Student Learning Quality in Engineering? Definition, Factors for Enhancing Students Comprehension, and Computational Bibliometric Analysis	The research aims to review developments in language and technology research that can improve the quality of teaching and learning in engineering. Several factors that can influence the teaching and learning process are explained, supported by a bibliometric analysis (with keywords "Language" AND "Engineering Learning" from Google Scholar from 2020 to 2022).
Fauziah et al., (2022)	Strategies in Language Education to Improve Science Student Understanding during Practicum in Laboratory: Review and Computational Bibliometric Analysis	This study aims to explain the development of language research in science learning which can improve students' understanding during practicums in the laboratory. This research also explores the factors that contribute to increasing student understanding and bibliometric analysis using the keywords "language", "practicum", "laboratory" and "science" from 2015 to 2021.
Nandiyanto et al., (2023)	Bibliometric data analysis of research on resin-based brakepads from 2012 to 2021 using VOSviewer mapping analysis computations	This study aims to analyze and demonstrate step-by-step bibliometric data analysis using VOSviewer completely and systematically. The analysis was carried out with the number of publications obtained, relating to the predetermined topics totaling 88 documents in 2017-2021.
Ruzmetov & Ibragimov, (2023)	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021	Theoretical and practical interest in salicylic acid and its derivatives has increased over the last two decades, and with it, academic study in the field has been burgeoning. Most scientometric studies have only focused on a specific property of the topic compounds. None, however, are discussed in the origination progress and prospects of SA and its derivatives. The present study makes a bibliometric review of 2010 papers published during 2000-2021 which were indexed by Scopus in the sub-discipline of salicylic and salicylates.

2. LITERATURE REVIEW

2.1. Greenhouse Effect

The greenhouse effect refers to the phenomenon where certain atmospheric conditions on Earth resemble the warming effect observed in a greenhouse. The earth's atmosphere acts as a barrier that prevents the sun's heat from escaping into space. Atmospheric gases, such as carbon dioxide (CO₂), can retain the sun's heat, leading to the entrapment of heat within the Earth's atmosphere (Riza et al., 2018). The term greenhouse effect was first used by European and American farmers, citing similarities between the mechanisms on the earth's surface and the mechanisms in the gardening process in their countries (Meziane et al., 2024; Quartey et al., 2015; Shigetomi et al., 2014). Farmers usually use greenhouses in winter because the sun's heat during the day will be trapped and reflected by the glass, preventing the heat from escaping. This way, at night the plants will not be affected by cold temperatures (Cohen, 2010; Mandler et al., 2012; Yunas et al., 2021).

Chloro Fluoro Carbon (CFC) molecules were considered highly reactive and detrimental to O₃ due to their low molecular weight, which allows them to rapidly ascend to the stratosphere. Additionally, the reaction between chlorine (Cl) and O₃ exhibits an endless oscillation. The significance of CFC emissions has diminished since the global emission of CFCs has ceased. Nevertheless, additional greenhouse gases also undergo reactions with O₃ in certain conditions. N₂O, also known as nitrous oxide, is produced through microbial processes in soils and aquatic environments. It is a result of the oxidation (nitrification) and reduction (denitrification) of fixed nitrogen (Sibanda & Manik, 2023). The global source emits a total of approximately 107 tons per year of nitrogen (N), with a maximum allowable increase of 30%. Nitrous oxide (N₂O) undergoes a chemical reaction as represented by Eq. (1-3):



The existence of O₃ in the equation is indicated by the arrowheads. If N₂O is not dissolved by sunlight, causing the O₃ to break into O₂, the reaction can oscillate for a significant duration. In addition to serving as a chlorine sink, methane (CH₄) plays a significant function in stratospheric chemistry. Sibanda and Manik (2023) described Eq. (4-6):



but HCl is unstable in the presence of the H₂O group and the reactions are shown in Equations (5) and (6):



Here, we aimed to illustrate, using an arrowhead, the repetitive nature of Cl's attack on methane in the presence of ozone and moisture. Nevertheless, the quantity of water present in the stratosphere is quite limited, particularly in tropical regions where the tropopause lacks the necessary cold temperatures to retain water and transport it upwards to the stratosphere. While the majority of CH₄ is released from tropical marshy areas and rice fields, it can frequently have positive effects on the ecosystem. Moreover, the presence of CO₂ in the stratosphere can potentially have a cooling effect, leading to modifications in the speeds of crucial reactions. This, in turn, partially counteracts the depletion of the O₃ layer, resulting in

increased shielding against UV radiation for green plants (Yin & Xu, 2022). However, due to its high density, CO₂ is likely to be found in limited quantities in the stratosphere. The oxidation of CO, CH₄, and other hydrocarbons can serve as a significant source of hydrogen-bearing radicals in the atmosphere. This process can either result in the generation or destruction of O₃. Radicals containing hydrogen undergo a reaction with NO, resulting in the production of NO₂. This NO₂ compound can easily dissociate into NO and [O] atoms when exposed to light. The oxygen atoms undergo a chemical reaction with oxygen molecules (O₂) to produce ozone (O₃). The reaction can be shown in equations (7-13):



The aforementioned responses demonstrate the influence of the presence of moisture or precipitation in the atmosphere. Additionally, it demonstrates the correlation between the atmospheric generation of O₃ and the presence of NO. If the concentration of NO is high, specifically exceeding 70 ppt (parts per trillion), as observed in urban areas and extensive landmasses, the oxidation of CO and hydrocarbons will result in a net generation of O₃. Conversely, if the natural oxidation process removes CO and hydrocarbons, it will lead to a depletion of O₃ (Tan & Shin, 2023). However, our observation of the reaction indicates that NO acts as a catalyst for the decomposition of O₃. The potential existence of CH₄ might potentially reverse the process, which can be summarized as the concept that "nature can correct itself" (Petroni *et al.*, 2017). However, the risks arise from the possibility that this creation of O₃ could occur in the surrounding environment and have the potential to cause cancer in humans.

Figure 1 often causes misunderstandings regarding the meaning of the cause of the greenhouse effect because many houses or buildings have glass walls (Lueddecke *et al.*, 2001; Abasto *et al.*, 2023; Ahmedi, 2022). **Figure 1(a)**, greenhouse gas (GHG) emissions are pollutants that are a factor in environmental damage due to increasing earth temperature or global warming (Mitrovich, 2006; Savino, 2009). If this gas increases in the atmosphere and continues continuously, it will result in the warming of the earth or what is usually called global warming (Cheng & Leong, 2023; Nandiyanto *et al.*, 2018). Human life is not unrelated to air (Shearer & Kniel, 2021), it is a crucial necessity in life. However, in the present age characterized by rapid global advancements in urban construction (Poirier & De Loë, 2011; Rahmat & Mutolib, 2016; Ziva *et al.*, 2021), industrialization, and transportation, the global scenario is transforming due to the consequential air pollution (Wang & Tassinari, 2019; Zulhijah *et al.*, 2015). Over time, this pollution will erode the pristine state of the Earth

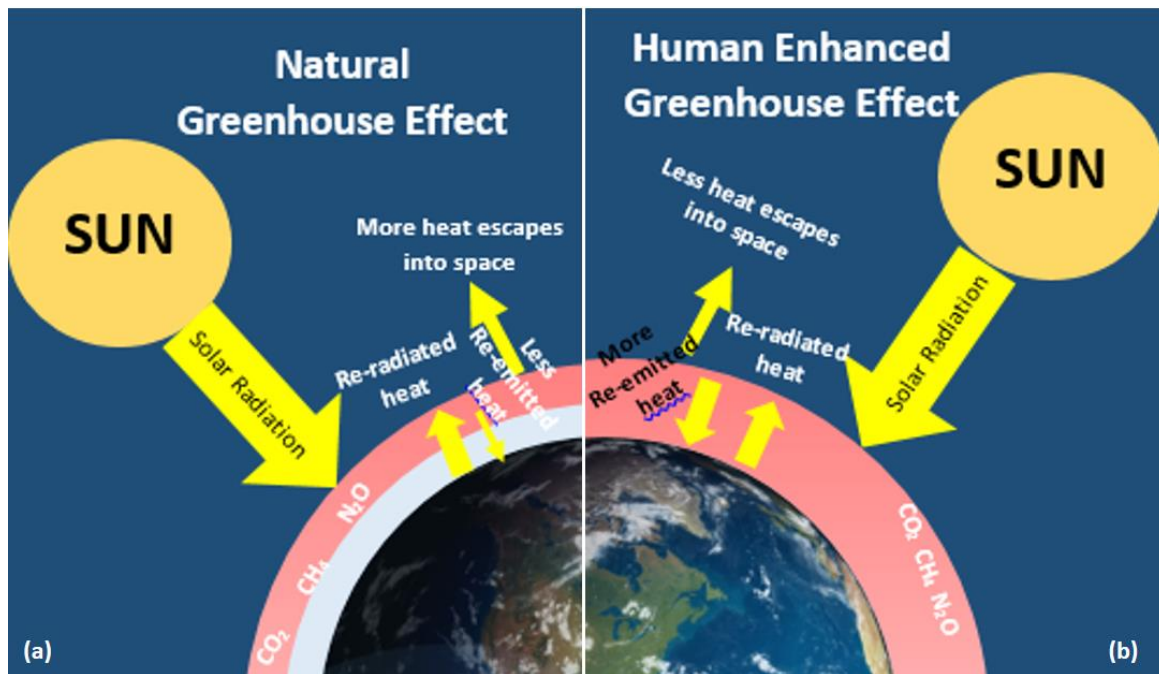


Figure 1. The greenhouse effect: (a) natural greenhouse effect; (b) human enhanced greenhouse effect.

Figure 1(b), air pollution refers to the alteration of the air's composition from its original normal state to a highly concerning condition caused by the introduction of pollutants into the air (Torgerson *et al.*, 2020; Winarno *et al.*, 2020; Suhandi & Samsudin, 2019). These compounds occur naturally in the atmosphere, but excessive or persistent increases in their levels can result in many adverse effects on the Earth, including global warming (Ulum *et al.*, 2020; Hamzah *et al.*, 2019). According to the IPCC, states that there are several categories of greenhouse gases, and among these gases, the total content reaches 70% (Shepardson *et al.*, 2011; Kulshreshtha *et al.*, 2022). Apart from this, various other sectors dominate, namely energy, transportation, and industry. The gas that plays a significant role is carbon dioxide (CO₂) which triggers global warming with a contribution of around 9–26% of the total which circulates for approximately 75 years because this gas is one of the gases that has the longest resistance in the atmosphere (Ocal *et al.*, 2011). Most people think that pollutant gas can only be produced from exhaust emissions, even though rice fields also have an important role in the process of producing microorganisms to create nitrous oxide gas. This gas acts as a parasite for the surrounding environment and the ozone layer (Ürey *et al.*, 2020; Zakaria *et al.*, 2018). Apart from this gas, methane gas also plays a role and has 21 times greater potential than others in the global warming process compared to CO₂ (Lee *et al.*, 2018).

The greenhouse effect is typically manifested by alterations in the Earth's temperature (Kidman & Casinader, 2019; Husamah *et al.*, 2022). The greenhouse effect phenomenon has been effectively utilized in different applications and sectors. One of the 21st-century skills is a problem-solving ability (Shatunova *et al.*, 2018; R. Zhang *et al.*, 2018; Nasir *et al.*, 2022). Solving problems can be defined as an action in resolving daily problems and making decisions carefully, precisely, harmoniously, rationally and considering them from various points of view (Shin *et al.*, 2017; Ndiokubwayo *et al.*, 2020; Turşucu *et al.*, 2018).

According to the Partnership for 21st Century Skills, problem-solving skills function in providing innovative solutions or resolutions in dealing with global problems (Maashi *et al.*, 2022; Malone *et al.*, 2021). Thus, problem-solving skills are one of the benchmarks that 21st-century students should have so they can compete optimally. This was also stated by

(Mikhaylovsky *et al.*, 2021) where the ability to solve problems is one of the educational skills in the 21st century. However, observations in the field are different from expectations. It is still rare for schools to support students in developing problem-solving abilities.

Previous research (Salinas & Pulido, 2017) stated that the problem-solving ability test results obtained by students who were given treatment were 48.11 and the results of students in conventional classes were 36.17. The average of both is still low when compared to the ideal maximum score, namely 100. The average obtained by the two groups of students shows that the students' problem-solving abilities are still far from expectations (Yang *et al.*, 2017). This was also confirmed by the physics teacher at the school that STEM-based learning is very difficult to do. Apart from students' limited interest in making projects and technology, it is also because teachers focus more on practicing questions which are considered to prepare them to get used to solving exam questions (da Silva *et al.*, 2022; Zabala-Vargas *et al.*, 2022). Apart from that, teachers also think that physics class hours are very insufficient if they have to apply STEM in the learning process. However, the teacher stated that he had carried out project-based learning on the concept of the greenhouse effect.

Apart from that, only 19% of students stated that the teacher had given problem-solving skills questions and only 38% of children were interested in solving the problems given. This shows that science learning at the school does not support students' problem-solving abilities (Wakhata *et al.*, 2023). Problems that occur in the field can be overcome by implementing a supportive teaching system using appropriate learning activity models. Thus, they can improve their ability to solve problems (Akgunduz, 2016; Hsieh & Chan, 2016). Therefore, an approach is needed that integrates science with other fields, namely the STEM approach. STEM education is seen as effective in equipping students with the necessary skills to navigate the challenges of the 21st century, as it necessitates pupils to actively recreate knowledge (Lüsse *et al.*, 2022), collaborate (X. Zhang *et al.*, 2016), solve problems, learn through designing, carry out construction, and use technology. STEM education aims to create students who are STEM literate by developing 21st-century skills (Eliyawati *et al.*, 2023; Kaniawati *et al.*, 2019; Samsudin *et al.*, 2016). Several research results have shown that STEM learning is successful in practicing 21 skills (Purwanto *et al.*, 2018; Solihah *et al.*, 2023; Nurzakiyah *et al.*, 2023). Introducing a STEM approach in experimental classrooms has been shown to enhance students' problem-solving skills in comparison to control classes that do not use a STEM approach (Kaniawati *et al.*, 2016; Kaniawati & Feranie, 2018). Implementing STEM in education can enhance problem-solving skills and facilitate students' engagement with real-world issues.

2.2. Project-Based Learning

Project-based learning is an innovative learning model, which brings theory closer to application in everyday life. Much research regarding project-based learning is available (Purwianingsih *et al.*, 2023; Nurani *et al.*, 2024; Putra & Sakti, 2022; Fatmala, 2023; Darojah, 2024; Wahyuningsih, 2024; Lestari, 2019) Thus, it places more emphasis on contextual learning through complex activities that can be carried out across scientific disciplines (Untari *et al.*, 2019; Subroto, 2015; Meng, 2023). The following presents the characteristics of project-based learning according to the understanding of project-based learning compared to learning. The stages of project-based learning are divided into three stages, namely planning (Deejring, 2017), creating-implementing, and processing (Ismail *et al.*, 2018). The essential questions raised in project-based learning must be open questions that do not have one right answer or one problem solution. The questions or problems raised must be related to students' daily lives (Kartini *et al.*, 2021). Furthermore, the active involvement of students in

preparing project plans is very necessary. Thus, students have a sense of ownership and are fully involved in the projects that have been prepared. In the third step, student activities at this stage include (1) creating a timeline for project work, (2) creating a deadline for project completion, (3) allowing students to create new goals in the plans they have made, (4) guiding students if the new goal they create is not related to the project they are working on, (5) helps students to continue carrying out the project by the initial processing focus, but does not limit students' environmental literacy skills (Meng, 2023). The fourth step is to monitor students and the progress of projects carried out by students. The teacher acts as a facilitator in the project implementation process provides motivation and teaches students how to work together in groups. The fifth step is to assess to provide feedback and assistance to students. Thus, they can achieve their goals. The final step is evaluation which aims to reflect on the project implementation process.

The project-based learning paradigm is capable of developing 21st-century skills in the context of globalization (Marzal & Asyhar, 2020). Project-based learning can enhance higher-order cognitive abilities such as analysis, synthesis, and evaluation (Untari et al., 2019). This is corroborated by the findings which indicate that over 70 schools that implemented project-based learning experienced a rise in 21st-century abilities, as well as an improvement in students' self-perception and their ability to engage in advanced cognitive processes. Project-based learning enables students to utilize communication skills, transmit ideas effectively, demonstrate organization and time management abilities, engage in inquiry-based learning, develop self-assessment and reflection skills, actively participate in group work, and cultivate leadership qualities.

3. METHODS

3.1. Bibliometric Analysis Method

The methodology employed in this study is a bibliometric analysis technique combined with computational mapping analysis. Detailed information for the use of bibliometric is explained elsewhere (Husaeni & Nandiyanto, 2022; Azizah et al., 2021). Utilizing the fundamental principles of bibliometrics, every analysis employs statistical and mathematical methods to statistically examine, elucidate, and visually represent the pertinent research domain. Assessing the status and major aspects might aid in identifying and predicting future research trends and areas of high interest. The research was carried out in five distinct stages, specifically keyword identification, data gathering, data processing and analysis, result analysis, and conclusion.

The research focuses on the keyword "Greenhouse effect and problem-solving". Keywords are utilized to designate articles that are deemed pertinent. The Abstract and Title serve as criteria for picking articles based on pre-established keywords. The study period included in the evaluation process spanned from 2013 to 2023. On January 15, 2024, a data search was performed using the VosViewer application, which resulted in the discovery of 200 articles that were indexed by Scopus. Scopus is an open-source article search platform that indexes article data. It allows users to access articles and citations from diverse sources without any restrictions based on the reputation of the article or its publisher. Once the process of collecting data is finished, the data is stored in two specific file formats, namely *.ris and *.csv. The *.ris format serves as the data mapping format in the VOSviewer application, whilst the *.csv format is utilized for data analysis in Ms. Excel. Microsoft Excel is utilized annually to examine development data and arrange articles according to their highest citation count. The study concept and methodology of this paper are illustrated in **Figure 2**.

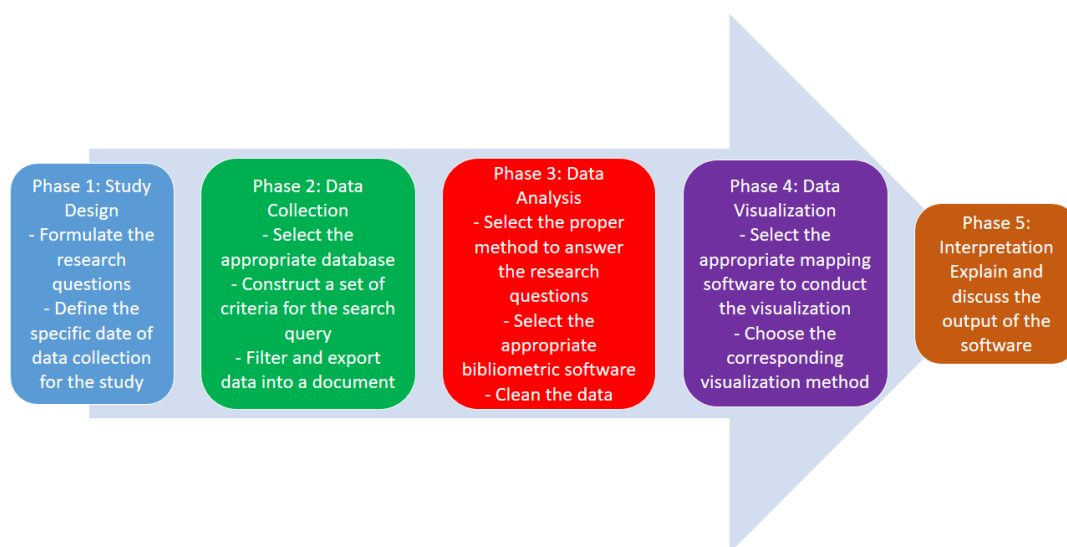


Figure 2. Science mapping workflow using bibliometric analysis.

VOSviewer is a program that aids in the visualization and analysis of search result data. VOSviewer is used to conduct two types of analyses: co-authorship analysis and Co-Occurrence analysis. The analysis yields a visualization map as the outcome. We employed two distinct forms of visualization, specifically network and overlay. Co-authorship analysis is a method of examining the connection between articles by considering the frequency of joint authorship. As the proximity of points between authors increases, their collaborative writing also increases. Co-occurrence analysis is a method used to examine the frequency of a word or term, which is then represented in a graphic map showing its existence. The binary approach is employed in this analysis to determine the word count.

3.2. Research Design

Research design is a scientific way to obtain research data with a specific purpose. The design used in this research is "one group pre-test and post-test design", namely a quantitative research design which is included in the category of error one pre-experimental method. This pre-experimental research method with a one-group pre-test and post-test design type is research used to examine the influence of independent variables on dependent variables. This pre-experimental research uses one group pre-test and post-test one group of subjects without a control class was applied, because research testing was seen from a comparison of the results of the pre-test and post-test research. The pre-test is an observation carried out before the experiment, while the post-test is an observation carried out after the experiment.

3.3. Teaching Methods

The research was carried out in ten steps, and each step was carefully evaluated through direct observation.

- (i) Students are assessed through a pretest to understand the knowledge students have acquired so far.
- (ii) Students are given teaching material about the greenhouse effect using the project-based learning method. Students listen to what the teacher says. Students determine basic questions: The teacher presents the topic and asks questions about how to solve the problem.

- (iii) Students ask basic questions about what students should do regarding problem-solving topics.
- (iv) Project activity planning: Develop project activity planning.
- (v) Project implementation schedule: Develop a project implementation schedule.
- (vi) Deepening the problem: Deepening the problem.
- (vii) Product quality improvement: Improve product quality.
- (viii) Product creation: Create a product.
- (ix) Product display: Display the product to others.
- (x) At the end after product exposure, students are given a posttest.

The project was carried out by observing the phenomenon of increasing temperature in a greenhouse prototype with varying wall materials measuring 50 × 40 × 40 cm. This greenhouse prototype is designed. Thus, the walls can be replaced with different materials but with the same thickness and area. Solar heat is used to produce heat in the greenhouse prototype by storing it outdoors. Thus, it is exposed to direct sunlight.

To observe the greenhouse effect phenomenon, the thermometer was placed in one position, and the temperature was measured every 5 minutes. Inside the cube is placed one thermometer (T1). To evaluate students' problem-solving abilities, several tests were carried out, including pretest-posttest techniques at each teaching step, questionnaires, surveys, and interviews for qualitative analysis.

4. RESULTS AND DISCUSSION

4.1. Bibliometric Analysis Results

Bibliometrics has been employed to facilitate study analysis across several research domains (Nandiyanto et al., 2022). This study employed bibliometric analysis to gain insight into the contemporary research trends related to the Greenhouse effect and its problem-solving approaches.

4.1.1. Development of Crystal Structure Education Research

A total of 200 publications, spanning from 2013 to 2023, have been published on the topic of the greenhouse effect and its mitigation strategies. The titles, abstracts, and article data were screened to ensure their relevance to the specified study issues. The evolution of research on the Greenhouse effect and problem-solving is depicted in **Figure 3**. In general, fewer studies were conducted between 2013 and 2023. There were 6 articles published in 2013, 14 articles in 2014, 11 articles in 2015, 14 articles in 2016, 16 articles in 2017, 11 articles in 2018, 20 articles in 2019, 19 articles in 2020, 25 articles in 2021 and 2022, and 38 articles in 2023.

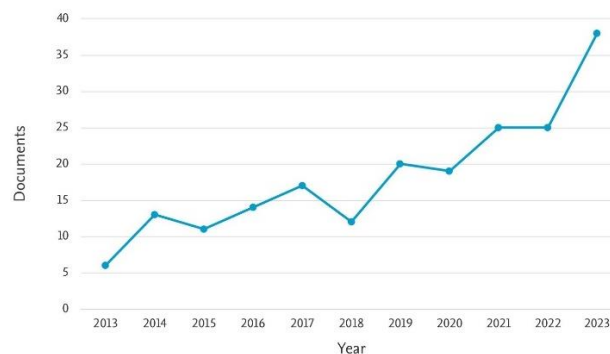


Figure 3. Development of published articles per year related to the greenhouse effect and problem-solving (2013 – 2023).

4.2. Students' Demographics

Table 2 displays the kids' level of interest in subjects that hold significant importance in junior schools. Five overarching topics are examined to measure students' preparedness in the study of heat transfer. Every pupil exhibits distinct interests and qualities. This outcome validates that students' preferences for subjects are rooted in curiosity and student contentment. These data were additionally utilized as a foundation for assessing intelligence and appraising the most effective learning methodologies (Hidayat *et al.*, 2020; Nandiyanto *et al.*, 2018).

Table 2. Students' demographic data for subjects.

No	Subject	Score (%)	Remark
1	Religion	79.00	Discipline
2	Mathematics	53.33	Students' curiosity in science
3	Science	43.33	Society-related
4	Social Science	50.00	Science-related curiosity
5	Indonesian Language	76.70	Communication skills

4.3. Experimental Equipment

The experimental equipment used in this research is presented in **Figure 4**. The experiment was carried out by observing changes in temperature as a function of time. The main heat source is solar heat which enters the prototype house with varying wall materials measuring $50 \times 40 \times 40$ cm (**Figure 4**). This house prototype is designed. Thus, the walls can be replaced with different materials but with the same thickness and area. Illustrative examples of greenhouse prototypes without trees and with trees are presented in **Figure 4**.

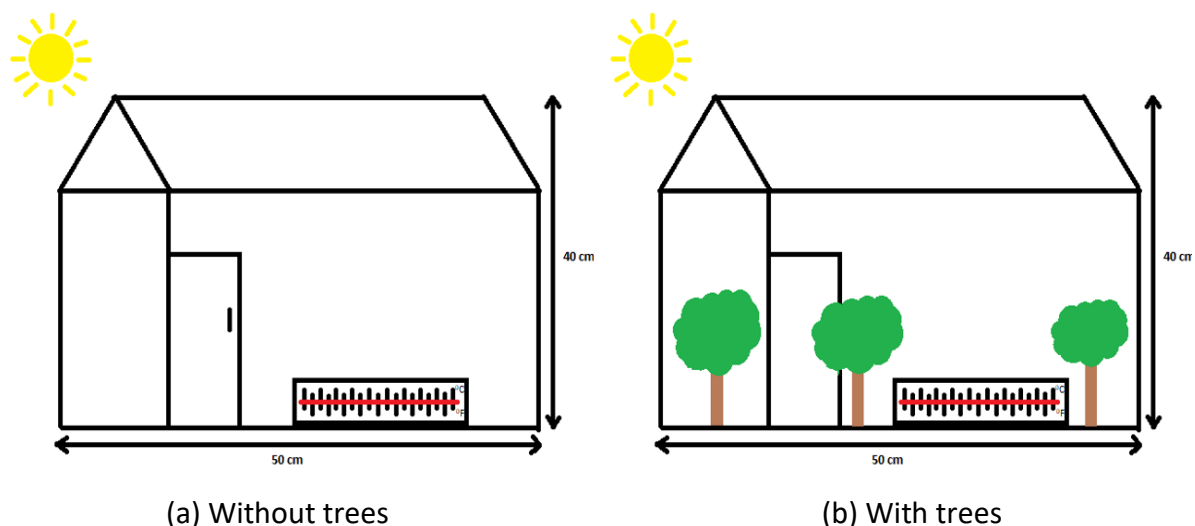


Figure 4. Illustration of a greenhouse prototype without trees and with trees.

To evaluate the greenhouse effect phenomenon, several thermometers were placed in several positions, and the temperature was measured every 5 minutes. Inside the cube is placed one thermometer (T1). The position of the thermometer is explained in detail in the method section above and an illustration is in **Figure 4**. Following are the results of temperature measurements in the greenhouse prototype in **Figure 5**.

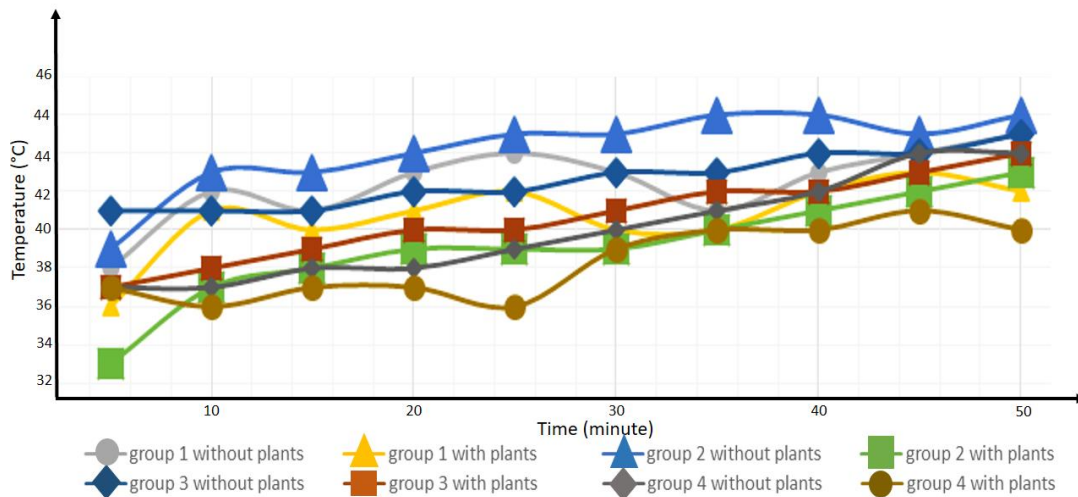


Figure 5. Temperature profile as a function of time in each group.

Figure 5 shows the relationship between temperature and heating time in different groups. Group 1, the initial temperature of the thermometer in the greenhouse prototype with plants is 36°C while for those without plants, it is 38°C. After the 5-minute process, there was a successive increase in temperature from T1 with plants and T1 without plants, namely 41 and 42°C. The highest temperature increase occurs at T1 without plants, this is because there are no plants that carry out the photosynthesis process (Aksoy & Erten, 2022). The longer the heating process takes, the hotter the temperature inside the greenhouse prototype will be (thermal diffusivity).

Figure 5 in group 2 shows that the initial temperature of the thermometer in the greenhouse prototype with and without plants is 37°C. After a 30-minute process, there was a successive increase in temperature from T1 with plants and T1 without plants, namely 39 and 40°C. The lowest temperature increase occurs at T1 with plants, this is because plants not only carry out photosynthesis but also carry out transpiration, namely the process of evaporating water from their leaves (Besson et al., 2010; Riandi et al., 2022). This process requires energy, and most of this energy is taken from around the plant, including heat. Therefore, transpiration can help reduce the temperature around the plant. The longer the heating process takes, the hotter the temperature inside the greenhouse prototype will be, but still not as hot as in the greenhouse prototype without plants.

Figure 5 in group 3 shows that the initial temperature of the thermometer in the greenhouse prototype with plants is 37°C while without plants it is 41°C. After the 40-minute process, there was a successive increase in temperature from T1 with plants and T1 without plants, namely 42 and 44°C. The lowest temperature increase occurs at T1 with plants, this is because plants besides carrying out photosynthesis and transpiration, plants also function as insulators of solar radiation, the leaves and twigs of plants act as insulators of solar radiation (Putri et al., 2016; Saragih & Solihat, 2021). They can absorb, reflect, and scatter sunlight, which helps reduce the amount of heat that reaches the Earth's surface. The longer the heating process takes, the hotter the temperature inside the greenhouse prototype will be, but still not as hot as in the greenhouse prototype without plants.

Figure 5 in group 4 shows that the initial temperature of the thermometer in the greenhouse prototype with and without plants is 37°C. After a 50-minute process, there was a successive increase in temperature from T1 with plants and T1 without plants, namely 40 and 44°C. The lowest temperature increase occurred at T1 with plants, this is because plants besides carrying out photosynthesis, transpiration, and blocking solar radiation, plants also

function as humidity enhancers, namely the transpiration process of plants increases the humidity around them (Roviati *et al.*, 2019; Erwinsyah & Nurjhani, 2017). Humidity can help reduce air temperature because water vapor has a high heat capacity, meaning that changing the temperature of water vapor requires quite a lot of energy. This is different from other substances such as dry air which has a lower heat capacity. Humidity produced by water vapor originating from plant transpiration has a cooling effect on the surrounding air temperature. When water vapor evaporates, heat energy from the environment around the plant is used to convert the water into steam. Due to the high heat capacity of water vapor, this transpiration process helps reduce the temperature of the air around the plant (Sukardi & Sopandi, 2021; Abdullah *et al.*, 2018). This can create more comfortable conditions for the plant itself and perhaps also for other organisms around it.

Based on this data, it can be seen that the longer the time measured, the higher the heat obtained. Apart from that, it is clear that the temperature in the greenhouse prototype with plants is lower compared to the one without plants. These results are used as learning material that must be analyzed by students.

4.4. Learning Outcomes

Based on demographic data **Table 3** shows the dataset of pretest and posttest scores obtained by students. These questions are given to ensure the level of students' problem-solving abilities during the learning process. These questions consist of topics about the greenhouse effect contextually. The results showed that in general students' grades increased significantly. Only a few points experienced a decline, which will be explained in detail in the qualitative analysis.

In the posttest session, it was found that almost all students were able to answer the questions correctly, thereby increasing students' problem-solving abilities regarding the greenhouse effect. Apart from that, students looked more enthusiastic than during the initial pretest. This was caused by increased student interest after carrying out a project to make a greenhouse prototype to help students more easily understand the lesson material provided. The increase in students' problem-solving abilities due to the implementation of the project for making a greenhouse prototype is in line with our previous research (Dani Nandiyanto, 2020; Nandiyanto, 2019).

Table 3. Score (%) obtained by students using the project-based learning method.

No	Problems	Score			Category
		Pretest	Posttest	Gain	
1	Explain the problem of the greenhouse effect in global warming using your language	1.89	3.89	0.95	High
2	Explain the process of the greenhouse effect based on pictures	1.71	3.58	0.82	High
3	Propose several ideas for efforts to reduce the impact of global warming	2.17	3.50	0.73	High
4	Evaluate data regarding global warming	1.18	2.84	0.59	Medium*
5	Providing solutions to overcome global warming	2.44	3.53	0.70	High

4.5. Qualitative Analysis

Before presenting the project for making a greenhouse prototype to students, we conducted a pretest. The pretest results show that not all students understand the greenhouse effect. Some students cannot answer the questions given. Then students are taught about the greenhouse effect using conventional teaching methods such as the chalk-

and-talk method. To improve students' problem-solving abilities, the learning method was changed to project-based learning because it can provide visual and kinesthetic stimuli (Nandiyanto et al., 2018). Therefore, we present project learning. To guide students, they are also equipped with STEM-ESD teaching materials which are a stimulus in carrying out projects.

To analyze the results, we interviewed students and compared the results (as shown in **Table 3**). In the pretest session, some students were unable to answer the questions given. This is caused by the lack of students' problem-solving abilities regarding the learning provided. During the learning process using project-based learning, the teacher asks the students "Is there anything you want to ask...?". Then, it has no one answer. Thus, it is assumed that all students understand the material presented. Then, students are given project assignments in the STEM-ESD teaching materials. The students became more interested in working on the project. Even though there is still no response from students when the teacher asks the students again after reading the project instructions in the teaching materials "Is there anyone who doesn't understand?", we cannot guarantee that students understand the material. Posttest analysis shows an increase in students' problem-solving abilities. However, to ensure the results, an analysis of each question was carried out compared to the interview process.

The posttest can measure each student's problem-solving abilities. When asking the question "(presented as a table) Based on the data in the table above, explain the problems currently facing our earth.", Student A answered "*The problem facing the earth is the increase in CO gas-gas and CH₄ which is very high*", student B answered, "*increasing levels of greenhouse gases is a problem facing our earth*". Student B's answer was not like Student A, because Student B's interests are not like Student A's. Then the teacher again asked the question "Explain the process and causes of the greenhouse effect", student A "*It reflects sunlight into the atmosphere.*", while student B answered "*When sunlight enters the atmosphere, some of it is absorbed by the earth is partly reflected.*" The answers given by students have their characteristics. The reason depends on students' interest in the greenhouse effect material. The results in **Table 3** show that some improvement was found in students' scores on most questions. However, the main important parameters are the questions for which students scored medium (see **Table 3** with Asterix (*)). The analysis obtained from increasing the medium score is as follows:

- (i) Students do not understand the relationship between variables. They do not think about the causes of the temperature increase. (Rojas et al., 2023).
- (ii) In the data evaluation section (question number 4) the student experienced difficulties so we can conclude that the student does not really like science. However, this can be overcome by additional learning about data evaluation in the greenhouse effect prototype which will be carried out in our next work. (Vacharith et al., 2022).
- (iii) Some students do not understand the consequences of decreasing the amount of ice at the north or south poles. This inspires teachers to provide more examples and teach about the negative consequences of the greenhouse effect. We found that students understand the greenhouse effect but they do not understand the definition of the type of greenhouse effect (Seguido & Cantos, 2020).
- (iv) We found that students only memorized the definition of the relationship between variables without understanding in depth the substance of the relationship between these variables. This can be compared with the greenhouse effect classification as explained above (Uelmen et al., 2020).

5. CONCLUSION

A learning model to improve students' problem-solving abilities regarding the greenhouse effect has been demonstrated. Different from other teaching methods, we combine conventional teaching and project-based learning. The results of the analysis show that students' problem-solving abilities increased significantly after being given treatment using project-based learning. The use of teaching materials also improves students' problem-solving abilities and imparts more information through teaching materials by stimulating students' curiosity and interest in the subject. Additionally, the project data involved only four groups of students, which informs the need for further study, which will be undertaken in our future work. This research produces new information about the need for project learning and STEM-ESD teaching materials to improve students' problem-solving abilities.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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