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From Molecules to Minds: Ontological and Epistemological Perspective of Global Warming and The Implementation in Science Education

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Abstract

The study was a qualitative research, employing ontological and epistemological approaches to explore the philosophy of global warming. Questionnaires and interviews were conducted with students and teachers, which examined whether the current implementation of global warming education aligns with ontological and epistemological perspective and propose recommendations to improve global warming education in science lesson. The ontological perspective begins with literature review that examines the unique of greenhouse gasses characterized as heat traps, focusing on microscopic view of vibrational modes of molecules and their impact on global warming. Furthermore, the epistemological perspective explored how researchers validate the scientific understanding of global warming and its impact on the environment. In addition, the questionnaire result showed that various teaching method, such as experiment, video, PhET simulation, teacher explanation, and internet exploration, were used. But most of students never see the microscopic view of vibrational greenhouse gas molecules that trap the heat. Students also did not evaluate and validate the influence of greenhouse gas concentration on increasing system temperature as epistemological approach. Therefore, the lesson of global warming especially the concept of greenhouse effect, needs an approach that integrates ontological and epistemological perspective, such integrating modeling or simulation in microscopic scale into experimental activities (bifocal modeling).

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INTRODUCTION

Global warming has become one of the primaries focuses in global discussions, particularly within the framework of the United Nations' Sustainable Development Goals (SDGs), which aims to achieved by 2030. One of these goals is climate action, which aims to reduce greenhouse gas emissions, the main driver of global warming, and achieve net-zero emissions by 2050, thereby impacting climate change (Oughton et al., 2023). Experts predict that if global warming continues unchecked, it will lead to major disasters with an impact on humanity (Affan Kamal, 2022).

Global warming is more than increasing Earth' surface temperatures, but also includes changes in extreme weather patterns, increased frequency and intensity of natural disasters, tropical cyclones, and serious impacts on ecosystems and biodiversity (van Aalst, 2006). A temperature increase of 1.5 degrees above the average of pre-industry period has a significant negative impact on the environment and human life (Hoegh-Guldberg et al., 2019). Therefore, action to achieve sustainable development goals (SDGs) is crucial and requires the involvement of all stakeholders, not only policymakers but also society, including high school students.

However, it is urgent to increase global warming literacy in areas of knowledge, attitudes and behavior to increase the society participation in action for SDGs achievement, especially reducing carbon dioxide emissions. A literate generation can improve the quality of decision-making and actions (Kurup et al., 2021). In contrast, an illiterate generation will create non-environment-friendly policies that worsen global warming conditions.

A curriculum of global warming education should be designed properly to give students experiences for learning to create a literate generation in global warming. Therefore, this paper explores global warming from both ontological and epistemological perspective, explore the condition of global warming education in some secondary schools in West Java, Indonesia and propose effective lessons to foster its advancement.

The ontological study explores the greenhouse effect phenomenon, describing a microscopic view of greenhouse gas molecules, such as carbon dioxide and methane in trapping heat. While the epistemic study, on the other hand, explores how scientists derive and validate knowledge of global warming. Furthermore, another result of this research comes from a survey about global warming lesson implementation in the classroom, providing a brief overview of the real condition, the challenges, and problems.

Based on this finding, the paper describes some recommendations to improve global warming literacy of the students.

The research questions are:

1. What is global warming from ontological and epistemological perspectives?
2. What teaching strategies for global warming are commonly used in secondary schools?
3. How do students perceive global warming?
4. How can the teaching of global warming in secondary schools be improved based on ontological and epistemological perspectives?

RESEARCH METHOD

The particular study employed a qualitative approach (Creswell, 2018), including a literature review of scientific journal, questionnaires, observations, and interviews to see the learning implementation of global warming education in the secondary school level. The questions item of the questionnaire, including teaching learning method on global warming, teaching learning material and how the students understand greenhouse effect caused by anthropogenic greenhouse gases.

The participants involved in the questionnaire were 124 students, aged 17-19 years from two schools in West Java who had studied the topic of global warming, and 2 science teachers who taught the topic of global warming. The questionnaire of teaching method and interviews with teachers were conducted to figure out the answer of research questions. The item questions of a questionnaire are created to obtain the students' perspective on global warming, are shown in Table 1.

Table 1. Items of Questionnaire

No	Item	Code
1	I believe that global warming is currently happening.	P1
2	I believe that global warming is also caused by human activities.	P2
3	I understand that the greenhouse effect is caused by greenhouse gases.	P3
4	I understand the process of the greenhouse effect.	P4
5	I have seen a visualization of how the vibration of greenhouse gases can trap infrared waves.	P5
6	I have conducted an experiment using a carbon dioxide sensor to observe the greenhouse effect.	P6
7	I have conducted an experiment measuring the electric current produced by a solar cell.	P7
8	I have seen a visualization of the electrons' flow in a solar cell when given a light intensity.	P8
9	I understand that the process of electric current occurs due to the flow of electrons in solar cells when given light intensity.	P9
10	I believe that global warming is the cause of climate change.	P10
11	I believe I can be part of the solution to the climate crisis.	P11
12	Small action, the climate action that I have taken has an impact on the climate crisis, especially due to global warming.	P12
13	Climate action undertaken by schools has an impact on the climate crisis, especially due to global warming.	P13
14	I am ready to take actual action that can reduce greenhouse gas emissions.	P14

The demographics of the teacher participants are shown in Table 2.

Table 2. Teachers Profile as Research Participants

Profile	Teacher	
	First School	**Second School**
Teaching science experiences	31 years	18 years
Degree	Bachelor's degree in Chemistry Ed.	Master's degree in Physics Ed.
Professional Certificate	Teaching chemistry for secondary schools	Teaching physics for secondary schools
Age	57 years old	42 years old

The interviews with teachers were conducted using a semi-structured method based on the questions of the students' questionnaire. Data analysis employed a descriptive qualitative and quantitative approach. A qualitative approach was conducted to analyze the interview results, while quantitative approach was conducted using statistical tools such as the Winstep application to determine the validity and reliability of questionnaire items. Then, good validity and reliability items are analyzed for their averages. Meanwhile, criteria for students' perception are determined for each item. Finally, the particular research gives recommendations to improve teaching strategies and enhance students' perception of global warming based on ontological and epistemological perspectives.

RESULT AND DISCUSSION

1. Ontology and Epistemology of Global Warming

1.1 Ontology of Global Warming

Ontology is a branch of philosophy that studies the structure of objects, types, nature, events, processes, and relationships in every reality (Smith, 2012). The study of ontology provides a definitive and comprehensive classification of entities in all areas of existence (Smith, 2012). A definitive classification becomes a comprehensive answer to the question of a complete description and explanation of all events in the universe. Some philosophers offer different approaches to provide a definitive classification, one of them is the substantialist, which considers ontology as a substance-based discipline or object-centered on events or processes (Smith, 2012). Ontological questions for analyzing the system, such as the form or nature of the system (Aliyu et al., 2015). Thus, in this study, it will be discussed in substance regarding global warming starting from the definition of experts regarding global warming, both the microscopic view and due to human activities, which is the Anthropocene understanding.

Global warming has become one of the primaries focuses in global discussions, particularly within the framework of the United Nations' Sustainable Development Goals (SDGs), which aims to achieved by 2030 (Pelton, 2020). Experts predict - if global warming continues- there will be many major disasters that will impact humanity (Singh & Singh, 2012). For example, global warming has an impact on changes in extreme weather patterns (Moore et al., 2015), increased frequency and intensity of natural disasters (Singh & Singh. (2012), and serious impacts on terrestrial ecosystems (Ostberg et al., 2013). Changes in temperature and rainfall can disrupt the life cycles of certain species, cause local extinctions, destroy vital habitats, and spread various diseases. In addition, the agricultural sector and food security are threatened, considering that climate change can reduce crop yields, biodiversity, and increase plant vulnerability to pests and diseases (Muluneh, 2021). In general, global warming is defined as an average temperature increase of 1.5 ºC or more above the pre-industrial average (between 1861–1890 or 1881–1910 (Nikulin et al., 2018). Over the past 50 years, the Earth's climate has changed rapidly compared to climate variability observed over the past 5000 years (Kirk-Davidoff, 2018). Global average surface air temperature has increased by about 0.8 ºC, sea level has risen by about 12 cm, and precipitation patterns have shifted (Kirk-Davidoff, 2018).

Solar activity remained relatively constant from 1920 to 2020, while carbon dioxide (CO_2) concentrations continued to increase, and global temperatures continued to rise (Moore, et.al., 2021). Global surface temperature variations over the past four decades have experienced significant warming, especially in high continental latitudes (Hansen et al., 2010). The highest warming occurred in the first decade of the 21st century, with global average temperatures increasing by 0.51 °C relative to 1951–1980 (Hansen et al., 2010). Thus, it concluded that there is a strong relationship between carbon dioxide concentrations and global temperatures.

The IPCC, consisting of more than 1,300 scientists from around the world, estimates that due to greenhouse gases (GHG) produced by human

activities (anthropogenic), global temperatures will continue to rise for the next decades (IPCC 2007; IPCC, 2013; Moore, et.al., 2021). The IPCC reports that around 41 billion tons of carbon dioxide are released annually, contributing to the increase in the Earth's temperature (Vaz Jr., et al., 2022). Empirical facts presented by researchers in various articles also show an increase in greenhouse gas concentrations of more than 25% since the Industrial Revolution in the early 19th century (Ramanathan, 2006; Cohen, 1990). GHG is the cause of the greenhouse effect and results in an increase in temperature, including daily average temperatures, maximum temperatures, and minimum temperatures globally throughout the year in every season. The greenhouse effect plays an important role in keeping the Earth warm by trapping heat energy that would otherwise escape into space (Singh, 2024). The natural process helps stabilize the planet's temperature, making life possible (Kweku et al, 2019). Without the greenhouse effect, the Earth's global average temperature would be much cooler, making life impossible. Greenhouse gases such as water vapor (H2O), carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) act like a blanket, absorbing infrared radiation and preventing it from escaping into space (Singh, 2024). The phenomenon contributes to the consistent warming of the Earth's surface and atmosphere. But when its concentration is excessive will lead to global warming. Greenhouse gases can absorb and re-radiate infrared waves to the Earth's surface, causing the increasing of the Earth's surface temperature. It is related to the vibrational mode of the atoms of the molecule. All particles with a temperature above zero Kelvin will move either translationally, rotationally, or vibrationally. The vibrational mode and the number of modes is influenced by the number of constituent particles and the structure of the molecule. The vibrational energy of each mode is different and determines its absorption energy. According to quantum theory, molecules can only absorb certain energies that correspond to discrete differences in vibrational energy levels.

In general, molecular vibration modes are divided into two modes; stretching and bending.

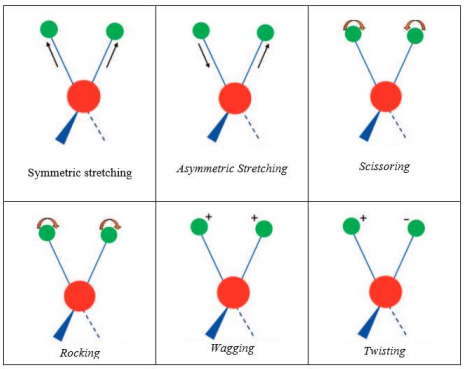
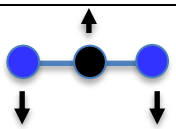


Figure 1. Molecules' Vibration Mode (El Azazy, 2018)

Stretching mode is divided into symmetric and asymmetric, while bending mode is divided into Scissoring, Rocking, Wagging, and Twisting, as seen in Figure 1 (El Azazy, 2018).

To describe the motion of molecules in space, at least three coordinates are needed; therefore, the degrees of freedom of molecular motion can be expressed as 3N, with N being the number of particles. For diatomic particles such as oxygen and nitrogen, there will be 6 degrees of freedom with 3 degrees of freedom to move translationally, 2 to move rotationally, and only one vibration mode, symmetric stretching. This vibration mode does not cause a dipole moment in the molecule, so oxygen and nitrogen, as the main gases that make up the atmosphere, cannot absorb infrared (IR) wave energy. This is different from greenhouse gas molecules such as carbon dioxide and methane. Carbon dioxide (CO_2) has a linear molecular structure; it needs three degrees of freedom to move translationally, two degrees of freedom to move rotationally, and 4 degrees of freedom to vibrate. Thus, the vibration modes are symmetric stretching, asymmetric stretching, and two bending modes, as presented in Table 3.

Table 3. Mode of vibration CO2 (Oreborn, 2018)

Mode	**Figure**	**IR active**
Symmetric stretching		No
Asymmetric stretching		Yes
Bending		Yes
Bending		Yes

Based on active interaction with infrared waves, carbon dioxide, methane, and water vapor are categorized as greenhouse gases. An illustration of carbon dioxide interaction with infrared waves is shown in Table 2. When infrared waves touch carbon dioxide particles in asymmetric or bending mode, infrared energy will be absorbed. As the impact, carbon dioxide energy is excited to a higher level. Then, this energy will be released back in all directions, including back to the Earth's surface. Thus, infrared waves emitted from the Earth's surface do not go into space but are trapped on the Earth's surface. The greater the concentration of carbon dioxide gas or other greenhouse gases in the atmosphere, the greater the intensity of infrared waves radiated back to the Earth's surface. So, the Earth's surface temperature increases significantly.

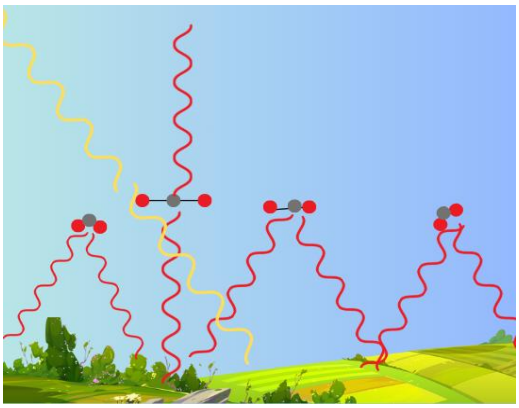


Figure 2. Trapped Infrared

1.2 Epistemology of Global Warming

Discussion on global warming is still controversial between the Intergovernmental Panel on Climate Change (IPCC) and Non-IPCC regarding the cause or reasons. IPCC reported that the increase in global temperature began to be observed since the mid-20th century, pre-industrial revolution. So, it has high possibility to be occurred due to the concentration of anthropogenic greenhouse gases (GHG) in the atmosphere or human activities (Mahmoud & Gan, 2018). IPCC reports that around 41 billion tons of carbon dioxide are released annually, which contributes to increasing the Earth's temperature (Vaz Jr., et al., 2022). There is a strong relationship between the concentration of carbon dioxide in the atmosphere and the average temperature of the Earth (Alana & Moreno, 2020). This fact can be interpreted from the graph of global temperature and carbon dioxide concentration in the atmosphere, as presented in Figure 3.

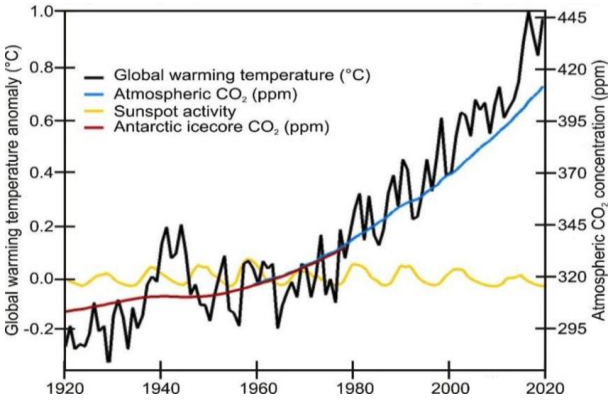


Figure 3. Carbon dioxide concentration and global temperature anomalies from 1920 - 2020 (Moore, et.al., 2021)

Based on the graph in Figure 1, solar activity has remained relatively constant during the period from 1920 to 2020, while carbon dioxide (CO2) concentrations and global temperatures have continued to increase (Moore, et.al., 2021). The IPCC, which consists of more than 1,300 scientists from around the world, estimates that due to greenhouse gases produced by human activities, global temperatures will continue to rise for the next decades (IPCC 2007; IPCC, 2013; Moore, et.al., 2021). Although most people believe in global warming, many people do not believe that global warming occurs due to the production of greenhouse gases from human activities. Therefore, global warming and temperature increases due to increased concentrations of greenhouse gases, as the result from human activities are still controversial (Keller, 2008; Ramanathan, 2006; Botkin, 1990).

However, over the past decade, much research has strengthened the IPCC report that global warming is caused by anthropogenic GHG. GHG that causes the greenhouse effect has caused an increase in temperature, including daily average temperature, maximum temperature, and minimum temperature, globally throughout the year in every season. Empirical facts presented by researchers in various articles show an increase in greenhouse gas concentrations of more than 25% since the Industrial Revolution in the early 19th century (Ramanathan, 2006; Cohen, 1990).

Over the past four decades, global surface temperature variations, as shown in Figure 3, have been characterized by significant warming, especially in the high latitudes of continents. The greatest warming occurred in the first decade of the 21st century, with the global mean temperature increasing by 0.51°C relative to 1951–1980. Seasonal surface temperature trends are comparable in each season, with a significant upward trend ranging from 0.60 to 0.65°C over the past 60 years.

The increase in boreal winter temperatures is most pronounced over the Eurasian continent and northern North America. While in the austral winter (June-July-August), a typical warming occurs in coastal areas of Antarctica. In general, various researchers define global warming as a rate of increase in average temperature of 1.5 degrees or more above the pre-industrial average (between 1861–1890 or 1881–1910) (Nikulin et al., 2018).

Over the past 50 years, the Earth's climate has changed rapidly compared to the climate variability observed over the past 5000 years. The global average surface air temperature has increased by 0.8 °C, sea level has risen by about 12 cm, and precipitation patterns have shifted. Global warming and associated climate change have been driven by increasing concentrations of gases that absorb and emit infrared radiation in the atmosphere, primarily carbon dioxide and methane (Kirk-Davidoff, 2018).

2. Commonly Used Teaching Strategy

Before proposing the recommendation on global warming lessons in secondary schools, aiming to figure out the implementation of global warming actually, a questionnaire was conducted with students, interviews with teachers, and classroom observations. Based on the questionnaire about how the teachers conduct the global warming education and greenhouse effect, the percentage of students' answers in various mode is presented in Figure 3.

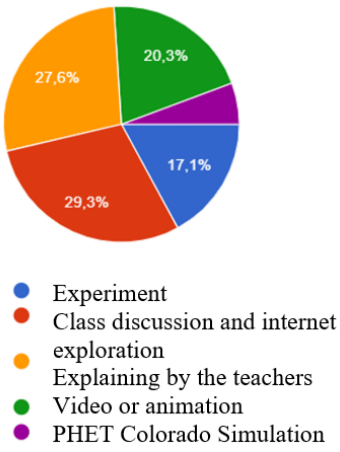


Figure 4. Teaching strategy on global warming

Based on Figure 4, the teaching strategies for global warming and the greenhouse effect vary, including experiments, internet exploration, videos or animations, and PhET simulations. However, no single teaching strategy is entirely sufficient. 29,3% students stated that the teacher used class discussion and internet exploration to teach global warming and greenhouse effect, 27,6% explained by the teachers, 20,3% used video or animation, 17,1% used experiment, while the rest used PHET simulation. To gain more in-depth data on the teaching strategy of global warming, interviews with the teachers were conducted. And, the result is presented in Table 4.

Based on Table 4, teachers commonly use internet exploration to teach global warming, especially by finding facts about global warming. But to construct a global warming, there are two investigation methods. First, actual hands-on activities using simple apparatus such as a Beker glass. In this investigation, students can have the abstraction that a system covered by plastic will have a higher temperature than an open system. But students could not have the abstraction that in the actual greenhouse effect, increasing temperature is caused by greenhouse gas. Second, virtual exploration, such as a PHET simulation. In these activities, students can understand that a higher concentration of greenhouse gases leads to more infrared radiation and higher temperatures. However, they still struggle to grasp the concept of greenhouse gas vibrations that cause infrared radiation to be redirected back to the Earth's surface.

Table 4. Interviews Result with The Teachers

Questions	**Teacher**	
	First School	**Second School**
Teaching method of global warming	Students work in groups and are asked to explore the internet to find out the causes of global warming, how the process occurs and the impact on the environment. Then, students are asked to make posters to campaign for action to reduce carbon dioxide emissions.	In the beginning, the teacher presents the facts that global warming is occurring. Then, students explore the causes and processes. They also discuss to decide simple

Questions	**Teacher**	
	First School	**Second School**
		actions to reduce global warming.
Teaching materials or media.	Slide Power Point and Canva.	Video from the internet, animation of the Earth' increasing temperature.
Experimental activities in teaching the greenhouse effect caused by greenhouse gases.	Using two beakers glasses, one covered with plastic and the other left open. After that, all the beakers were placed under the hot sun. Their temperatures were measured every 5 minutes.	For experimental activities using virtual with the PHET simulation
How students evaluate and validate their knowledge of global warming	Students explore data on the internet that explains that global warming is occurring based on existing facts.	Students evaluate data on the Earth's increasing temperature and the concentration of carbon dioxide in the atmosphere to discover the fact that global warming occurs due to carbon dioxide gas produced by humans.

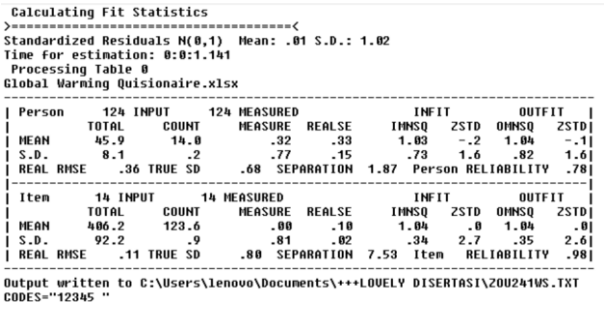
3. Students' perception on global warming

Before analyzing students' perception of global warming, the questionnaire items were analyzed by the Winstep application. The validity and reliability results are presented in Table 5.

Table 5. Validity of Questionnaire Items

Item	Outfit			
	MNSQ	ZSTD	Corr	Validity
P1	1,21	1,3	0,42	Valid
P2	1,30	1,6	0,36	Valid
P3	1,72	4,8	0,37	Not Valid
P4	0,60	-3,7	0,62	Valid
P5	1,01	0,1	0,50	Valid
P6	1,59	3,5	0,35	Not Valid
P7	1,41	3,2	0,56	Valid
P8	1,12	1,0	0,52	Valid
P9	0,66	-3,3	0,60	Valid
P10	0,91	-0,7	0,48	Valid
P11	0,80	-1,8	0,51	Valid
P12	0,76	-2,1	0,56	Valid
P13	0,73	-2,3	0,53	Valid
P14	0,73	-2,2	0,52	Valid

Based on the validity result in Table 5, the third and fifth items are not valid. These two items will be excluded from the analysis process. The reliability analysis result of the instruments is presented in Figure 5.



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 Calculating Fit Statistics
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Standardized Residuals N(0,1)  Mean: .01 S.D.: 1.02
Time for estimation: 0:0:1.141
 Processing Table 0
Global Warming Quisionaire.xlsx
-------------------------------------------------------------------------------
| Person     124 INPUT     124 MEASURED                INFIT        OUTFIT   |
|          TOTAL     COUNT     MEASURE  REALSE     IMNSQ   ZSTD  OMNSQ   ZSTD|
| MEAN      45.9      14.0         .32     .33      1.03    -.2  1.04    -.1|
| S.D.       8.1         .2         .77     .15       .73    1.6   .82    1.6|
| REAL RMSE    .36 TRUE SD     .68  SEPARATION  1.87  Person RELIABILITY  .78|
|-----------------------------------------------------------------------------|
| Item      14 INPUT      14 MEASURED                INFIT        OUTFIT   |
|          TOTAL     COUNT     MEASURE  REALSE     IMNSQ   ZSTD  OMNSQ   ZSTD|
| MEAN     406.2     123.6         .00     .10      1.04     .0  1.04     .0|
| S.D.      92.2         .9         .81     .02       .34    2.7   .35    2.6|
| REAL RMSE    .11 TRUE SD     .80  SEPARATION  7.53  Item   RELIABILITY  .98|
-------------------------------------------------------------------------------
Output written to C:\Users\lenovo\Documents\+++LOVELY DISERTASI\ZOU241WS.TXT
CODES="12345 "
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Figure 5. Person and item reliability

Based on the validity and reliability, there are 12 items that fit to be analyzed, including P1, P2, P4, P5, P7, P8, P9, P10, P11, P12, P13, and P14. Table 6 shows the logit measure for each item.

Table 6. Logit measure items

Item	Logit (Measure)	Standard Error (S.E.)	Average Score
P6	1.51	0.10	1,88
P8	15	0.09	2,27
P5	1.02	0.09	2,30
P7	0.76	0.09	2,56
P9	0.36	0.09	2,96
P11	-0.02	0.09	3,31
P12	-0.13	0.09	3,41
P4	-0.27	0.09	3,58
P13	-0.32	0.09	3,54
P3	-0.43	0.10	3,73
P14	-0.54	0.10	3,83

P10	-0.56	0.10	3,85
P1	-1.08	0.11	4,24
P2	-1.33	0.12	4,40

Item P6 was the most difficult (logit = 1.51) for respondents to agree. This means that most respondents disagreed about having conducted experiments using carbon dioxide sensors during global warming learning. Item P2 is the easiest (logit = -1.33) to answer with agreement. It means that respondents tend to agree that global warming is occurring. Although most respondents agree that global warming is occurring, some respondents disagree and are hesitant. In addition, from the results of the logit measure and the average score, the learning about global warming is not in accordance with the ontology and epistemology of global warming. Learning has not provided direct experience of how greenhouse gases cause global warming.

4. Enhancing global warming lesson

Based on the students' questionnaire result and teacher' answers, the global warming learning and the concept of the greenhouse effect still need to be improved based on ontological and epistemological views. Based on ontological views, the greenhouse effect as a result of greenhouse gases can be explained microscopically. But learning is the literature on exploring the causes and effects of global warming, which does not explore in depth the process of global warming in a microscopic view. In fact, high school students should have been introduced to abstract concepts and started thinking formally by reviewing the process of the greenhouse effect microscopically. Also, it is an urgent for students to find their data based on experiments with increasing carbon dioxide concentration; the temperature of the system will increase. With this microscopic visual and direct experience, student learning will be more meaningful since they observe and experience it directly. According to Dewey's meaningful learning theory (1997, 2001), experience in learning is very important for a meaningful learning process (Widodo, 2021). Students experience a meaningful learning process if they gain experience through observation activities, then compare and make connection to their prior knowledge. Thus, it is very important for students to have experiences directly through their observations of how greenhouse gases can increase global temperatures. This activity gives students the opportunity to understand the concept more contextually. Contextual learning can enhance students' interest and become more meaningful (Sarah et al., 2024).

An effective approach to bridge the observation of micro-scale concepts and hands-on experimentation is bifocal modeling. This method enables students to conduct observations at both macroscopic and microscopic levels (Blikstein, 2012; Fuhrmann et al., 2013; Chen et al., 2023). The bifocal modeling serves as an alternative to support inquiry-based activities, offering students direct experiential learning as epistemological while simultaneously providing visualizations of microscopic phenomena as an ontological perspective. This dual approach facilitates the development of conceptual thinking among students.

CONCLUSION

Global warming refers to a rise in the Earth's average surface temperature, exceeding 1.5 degrees Celsius above pre-industrial levels. This phenomenon is driven by increased concentrations of anthropogenic greenhouse gases, such as carbon dioxide, methane, and water vapor. From an ontological perspective, the greenhouse effect can be understood microscopically, explained by vibrational characteristics of greenhouse gas molecules that absorb and re-emit infrared radiation back toward the Earth's surface. From an Epistemological perspective, scientists validate global warming through empirical data, such as rising global average temperatures and elevated greenhouse gas concentrations in the atmosphere. The qualitative research employed a questionnaire and interviews showed that global warming education in science learning still needs improvement based on ontological and epistemological perspectives. The learning needs to integrate micro-scale observation activities for deep conceptual understanding and hands-on experiments into science education. One effective approach is the implementation of bifocal modeling, which bridges conceptual understanding with practical experimentation.

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