Identifying Students' Misconceptions of Greenhouse Effect Through Inductive Analysis

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ABSTRACT

Limited studies have been conducted to identify students' misconceptions about concepts in biology such as in the topic of greenhouse effect. One of the contributing factors is due to lack of convenient and valid instrument developed to measure these misconceptions. The present study explores students' conceptions on an environmental phenomenon i.e. the greenhouse effect (GHE). The sample of the study consisted of 58 Grade 9 students from two classes; Class A and Class B in a secondary school in Malaysia. The data were collected through students' mental models and followed by an open-structured interview in order to elicit students' conceptions in GHE. Mental models are a technique that allow students to explain the phenomenon under study based on their prior knowledge, existing ideas or conceptions, and past experiences. Findings show that inductive data analysis is able to detect the common misconceptions among students and helpful in providing teachers with information both on students' prior knowledge and on their misconceptions in GHE. Inductive analysis of the mental model revealed the common misconceptions on GHE and 18 misconceptions codes were discovered. To promote effective and meaningful learning, teachers need to find ways to rectify the misconceptions. Based on the results of this study, teachers can design appropriate lessons that will enhance students' understanding in learning GHE. The findings may contribute towards enriching research on science education and in designing curriculum instruction and pedagogy.

Keywords: Greenhouse effect; Misconception; Mental model; Inductive analysis

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INTRODUCTION

Many studies have explored students' abilities in understanding scientific concepts at different educational levels. The results have revealed that students have different conceptions or ideas of scientific concepts, and most of the concepts differ from those that are generally accepted by the scientific community (Saat et al., 2016). Misconceptions in biological concepts have been recognized as major barriers affecting students' understanding of accurate scientific explanations (Duda, 2020; Jafer, 2020; Saat et al., 2016). Misconceptions in biology can range from minor alternative interpretations of a concept to a complete rejection of a theory. In this study, misconceptions refer to students' conceptions that conflict with scientific information.

Research on students' understanding of greenhouse effect (GHE) was initiated in 1993 by Boyes and Stanisstreet (Hillman, Stanisstreet, & Boyes, 1996), and the effort was continued by other researchers (Arslan, Cigdemoglu, & Moseley, 2012; Chang et al., 2010; Ekborg & Areskoug, 2012; Osterlind, 2005; Ratinen, 2011; Shepardson et al., 2011). These studies revealed an array of misconceptions about GHE and students' inaccurate conceptualizations of atmospheric environmental phenomena, not only among students (Boyes & Stanisstreet, 1998; Porter et al., 2012; Robelia, Greenhow, & Burton, 2011; Shepardson et al., 2009) but also among preservice

science teachers (Arslan et al., 2012; Ekborg & Areskoug, 2012; Hillman, Stanisstreet, & Boyes, 1996; Jafer, 2020; Kalipci et al., 2009; Khalid, 2003). GHE related phenomena include global warming (Arslan et al., 2012; Boyes et al., 1998; Shepardson et al., 2011), air pollution (Boyes & Stanisstreet, 1997), and thinning of the ozone layer (Arslan et al., 2012; Boyes et al., 1998; Kalipci et al., 2009).

Students believe that GHE is solely caused by human activities and poses harmful effects to humans; therefore, students believe humans do not need GHE for survival (Arslan et al., 2012). Studies have found that students tend to assume that they have already understood the scientific concept of GHE, as it is studied in the lower secondary science curriculum (Teng, 2012). On the other hand, teachers believe that students have prior knowledge about GHE, and so teachers often consider this topic as a "self-study" topic when finishing the syllabus at the end of the school term (Daniel, 2011).

In addition, living in a tropical country located near the equator with mostly sunny, hot weather throughout the year, Malaysian students have limited experience with the negative impacts of GHE such as an increase in global temperature, melting polar ice caps, or rising sea levels (Teng, 2012). The students were only exposed to these concepts through printed or electronic resources such as books, magazines, posters, television, and the Internet. They are, however, unable to experience the intense heat compared to people living in cold countries near the North Pole and South Pole. As a result, some students especially at the primary level are not much aware that excessive GHE has become a critical issue that is not only threatening humans' life at the poles but in every part of the Earth (Headman, 2020; Teng, 2012). Clearing misconceptions rooted in students' minds is of utmost importance, in order to cause reconceptualization of learning (Hillman, Stanisstreet, & Boyes, 1996; Saat et al., 2016). According to Lazarowitz and Lieb (2006), the misconceptions students hold could obstruct the acquisition of new knowledge. Thus, it is important for teachers to identify the students' misconceptions and institute relevant measures to eliminate those misconceptions.

Different types of assessments are used in science education in order to identify students' misconceptions. These would include interviews (Montfort, Brown, & Findley, 2007; Thompson & Logue, 2006), open-ended questions (Tsai & Chou, 2002; Tsaparlis & Papaphotis, 2002), concept maps (Kharatmal, 2009; Kinchin, 2000), mental models (Reinfried et al., 2012; Shepardson et al., 2011), and diagnostic assessment (Tan, Lim & Kor, 2017; Uzuntiryaki & Geban, 2005) such as three-tier multiple-choice questions (Eryılmaz, 2010; Gurel, Eryılmaz & McDermott, 2015; Saat et al., 2016), which have both advantages and disadvantages in practical usage (Tsai & Chou, 2002). The purpose of the study is to explore the use of inductive analysis to identify Grade 9 students' conceptions of GHE. By identifying the student's conceptions of GHE, students' misconceptions will also be identified based on the assessment techniques employed in this study. This research focuses on the following research question i.e. what are the misconceptions of Grade 9 students on GHE?

METHOD

A qualitative research paradigm has been chosen due to its distinctive features and suitability to answer the research question posed in this study. The researchers are interested in understanding how participant constructs the meaning of the phenomenon under study, through interpreting their experiences in uncovering the meaning of a phenomenon for those students (Merriam, 2009; Saat & Fadzil, 2019). The data collection process for this study took 8 months. This study was conducted to determine students' conceptions and misconceptions of GHE. Data collection involved the construction of mental models and open-ended interviews. Based on the analysis of the mental models and interview transcripts collected, inductive analysis was conducted to elicit any misconceptions among the students.

Participants and Site of the Study

The study took place in a high school located in one of the urban areas in Malaysia that implemented the Cambridge IGCSE® syllabuses. Two Grade 9 science classes with students aged 16 years were selected for the study using a purposeful sampling technique (Creswell, 2008). The participants were taking biology and computer studies during this research. These two classes (Class A and Class B) remained intact throughout the study. Class A comprised thirty-three (33) students, (21 male, 12 female) and Class B comprised twenty-five (25) students (9 male, 16 female). These students also took computer studies as a compulsory subject at school and were trained to use EDMODO. The participants have gone through the same syllabus for Biology subject thus, assuring that they have been introduced to the topic and have prior knowledge regarding GHE. Students were involved in the construction of mental models and open-ended interviews (inductive analysis) in this study.

Ethical Consideration

The participants of the study gave their oral affirmative agreement to participate in the study. Students and parents were informed about the purpose, methods, and intended possible uses of the research, and that students' participation was voluntary. Furthermore, the research did not involve any sensitive issues. The consent forms were distributed to the students who agreed to participate in the study, and only students whose parent(s) signed the consent form were selected as participants. The participants were assured that the researcher would protect their privacy and confidentiality.

Research Procedures

Figure 1 shows a schematic diagram that summarises the procedure of the study. The following sections will elaborate on the procedure of data collection and how the researchers analyse the qualitative data.

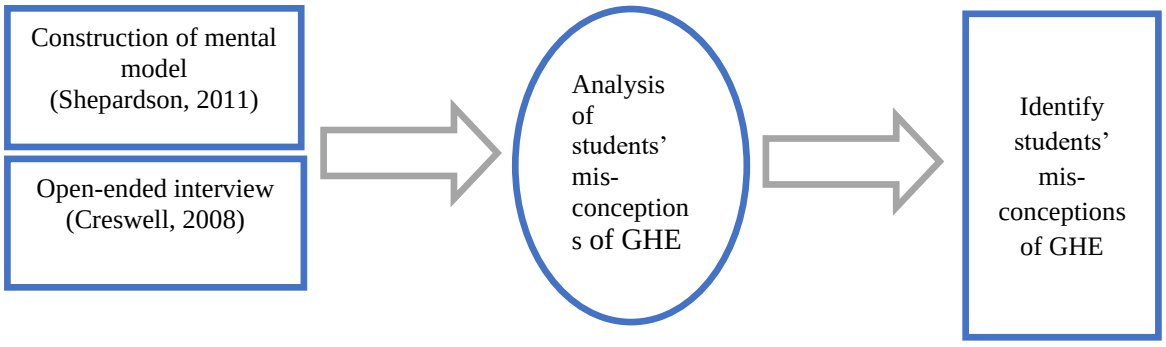


Figure 1: Procedure of the study.

Identifying Students' Conception of GHE

The first step involved two techniques to identify students' conceptions of GHE. First, the students constructed their mental model (Shepardson et al., 2011) of GHE. Next, they participated in open-ended interviews to further elicit students' misconceptions of GHE based on the mental models they have constructed.

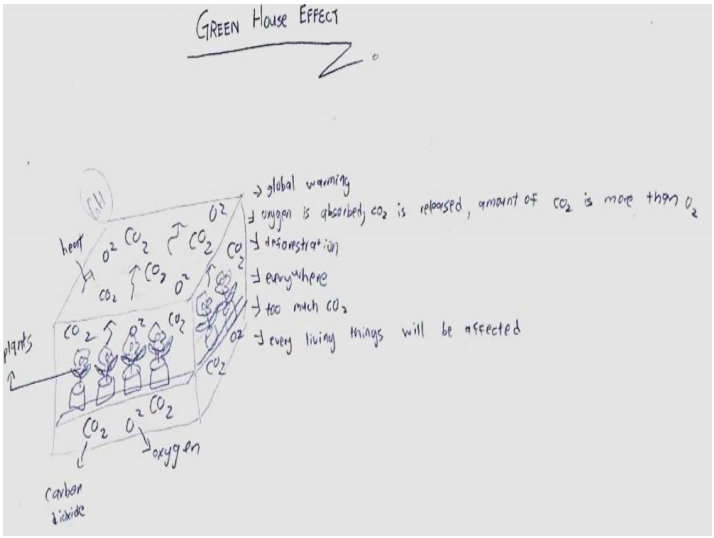
Construction of Mental Model

Students from Class A (n = 33) were given a blank white paper and pencil to construct drawings that represented their mental model of GHE. Students were informed that they needed to represent their main ideas about GHE in the forms of images, symbols, labels, text, or any combination of these forms (Thomas & Hairstone, 2003). Mental models are a technique that allows students to make predictions or explain the phenomenon under study based on their prior knowledge, existing ideas or conceptions, and past experiences (Greca & Moreira, 2000). The mental model is a representation of the level of understanding of concepts possessed by students. By eliciting students' mental models, educators can reveal the multiplicity of learning processes and turn science instruction into a more inclusive endeavour (Shepardson et al., 2011; Varela, Sesto, & García-Rodeja, 2020).

Some studies (Greca & Moreira, 2000; Shepardson et al., 2011), however, have indicated that mental models are personal and often unstable. They involve a dynamic process that is always restructuring, as it is dependent on students' new knowledge, ideas, conceptions, and experiences. Therefore, open-ended interviews followed the mental models to clarify the ambiguities in the models and students' conceptions (Tuysuz, 2009) of GHE. The main aim of the interview is to highlight students' conceptual understanding of the greenhouse effect and make claims about their mental representations of the processes involved.

Inductive analysis of the mental model and open-ended interview of Student #32 will be used as an example in this paper as the participant gave typical feedback during the study. Students' mental models (see Figure 2) were analysed together with the interview transcripts, using an inductive analysis technique to analyse and determine students' misconceptions of GHE. The purpose of this step was to include clarification on the ambiguities in the mental models and to avoid the researcher's bias in the analysis (Creswell, 2008). The repeating codes were grouped into categories that represented students' conceptions of GHE, and these categories were further analysed and grouped into typologies.

Mental Model No. 32



Review

1. Unable to differentiate the meaning of "greenhouse" and "greenhouse effect".

2. Indicated "amount of CO_2 is more than O_2" will cause greenhouse effect and global warming.

3. Confused with the gaseous exchange in plants.

Figure 2: Figure 2. Mental model of Student 32 on "Greenhouse Effect" On the left and researcher's notes in the "Review" on the right.

Open-Ended Interview

The main objective of the open-ended interview in this study was to further elicit students' conceptions of GHE based on the mental models, as suggested by Kearney and Kaplan (1997) and Tuysuz (2009). Kearney and Kaplan (1997) acknowledged the impact of the interview procedure on a person's cognitive ability. They suggested that creating a visual representation of one's understanding can help the interviewee explore his or her own mental model through the process of mapping it. Thus, based on the mental models, the open-ended interview was conducted with each student using a 5W-and-1H question, which involves what, where, when, who, why, and how questions that are typically used for exploring factors or consequences related to an issue (Shabir, 2015).

The student's respective mental model was used to initiate a conversation regarding conceptions of GHE. The researchers requested the student to explain their drawings of GHE and clarify the meanings of symbols and signs such as arrows and reflective arrows. The main objective of the open-ended interview was to clear up some ambiguities observed by the researchers. Another objective was to elicit students' conceptions of GHE from those aspects which were not found in the drawings. The duration of the interviews ranged from 15 minutes to 30 minutes. The interview audio files were then transcribed verbatim into text files and analysed together with the mental models.

Inductive Analysis

In the theoretical framework on mental models and reasoning developed by Johnson-Laird (1993), induction is described as a thought process that begins with a collection of observations, the purpose of which is to frame a hypothesis that achieves a better explanation and understanding of the phenomenon under study. In order to characterize student mental models, the data were analysed using inductive analysis methods (Patton, 2002). Inductive analysis refers to methods that mainly use comprehensive readings of raw data to extract ideas or patterns from observations made from raw data by the researcher. This interpretation of inductive analysis is consistent with the definition of Strauss and Corbin (1998). In inductive analysis, instead of looking for pre-determined trends, the themes might emerge from the data as the researchers perceived student environmental conceptions. The misconceptions about GHE from an analysis of Student #32's transcripts were grouped according to the questions listed in the interview protocol and by aspects as shown in Table 1.

Table 1: Misconceptions of GHE of Student #32

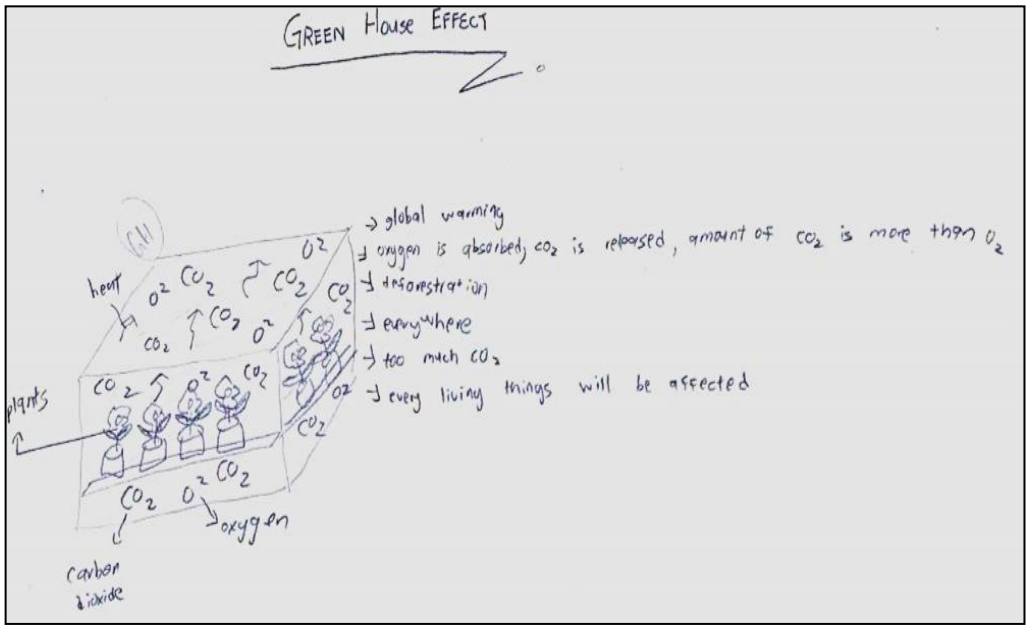
Number	Interview Questions	Aspects				Descriptions of Misconceptions
1.	What is greenhouse effect (GHE)? What do you understand about GHE?	•	•	•	Meaning of GHE	Unable to differentiate the meaning of "greenhouse" and "greenhouse effect".
2.	Where does GHE occur?	•	•	•	Location where GHE occurs	Greenhouse (indicated in mental model)
3.	Why does GHE occur? What are the causes GHE?	•	•	•	Types of greenhouse gases	Confused with the exchange of O_2 and CO_2
4.	When does GHE occur?	•	•	•	Mechanism of GHE	Indicated "amount of CO_2 is more than O_2" will cause greenhouse effect and global warming
5.	How GHE occurs? Can you explain how GHE occurs?					
6.	Who will be affected? What are the effects of GHE?	•	•	•	Impacts of GHE	Unable to differentiate greenhouse effect and global warming

Trustworthiness

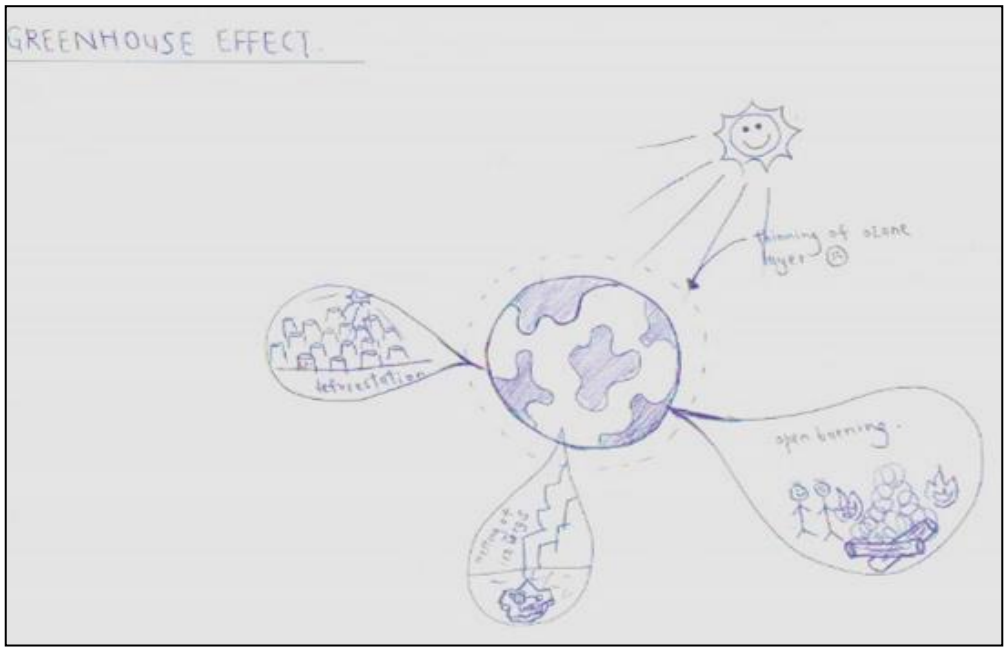
Validity and reliability are two issues with which a researcher should be concerned when designing a qualitative study (Patton, 2002). Qualitative researchers need alternative models that can ensure rigour without sacrificing the relevance of the qualitative data. Among the approaches implemented in this study is triangulation. According to Bryman (2006), triangulation refers to the use of more than one approach in the investigation of a research question in order to enhance confidence in the ensuing findings. Engaging in multiple methods, such as the construction of students' mental models, followed by open-ended interviews will lead us to more reliable, accurate, and trustworthy findings and may reduce the uncertainty of interpretation (Creswell, 2008). A category matrix was constructed to reflect the final categories of students' conceptions. These categories were grouped into typologies that reflected the students' mental models. This process provided a degree of triangulation, reducing the influence of bias and subjectivity, and increasing the validity of data analysis and interpretation of results (Shepardson et al., 2011). The emerging categories of mental models identified during both data analysis and the online questions were also evaluated through peer review.

RESULTS AND DISCUSSION

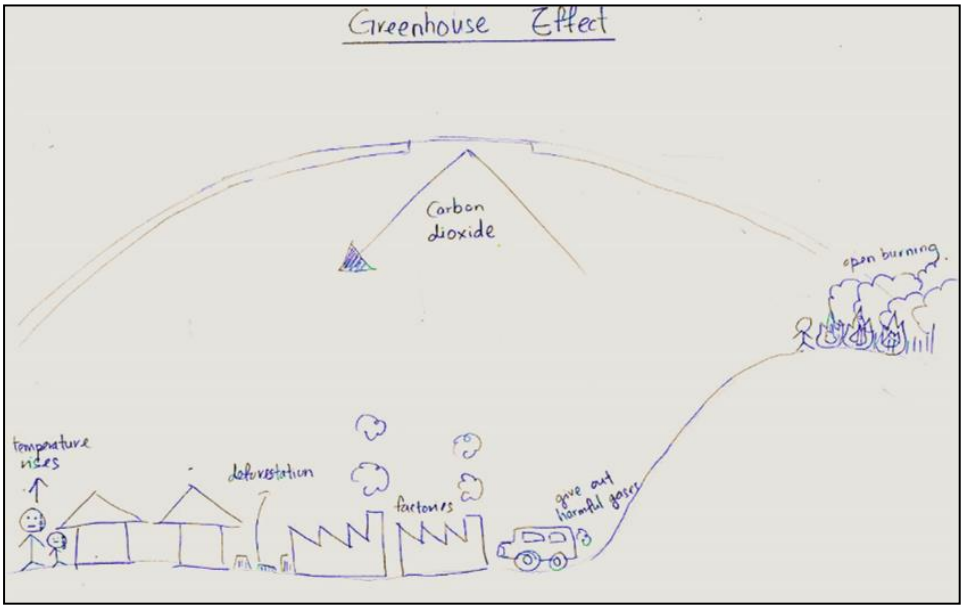
This paper focuses on eliciting students' misconception of the greenhouse effect, which has been discussed in the previous section. According to Saat et al. (2016), clearing misconceptions rooted in students' minds is of utmost importance in order to cause reconceptualization of learning. The evidence also shows that the questions constructed, based on the mental models and interviews, can precisely perceive the common misconceptions among the students. Figure 3 shows four examples taken from the students' mental models.



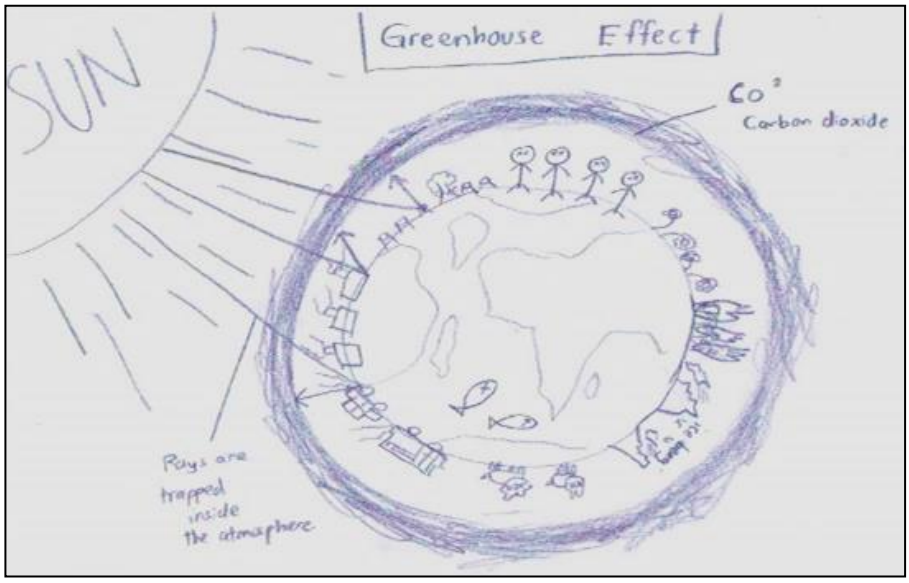
Example 1: Greenhouse effect is similar to greenhouse concept



Example 2: Greenhouse effect has similar concept with ozone depletion



Example 3: Greenhouse effect is due to human activities



Example 4: Greenhouse effect refers to heating mechanism

Figure 3: Four examples of students' mental models

From the inductive analysis of the mental models and interview transcripts, eighteen (18) types of misconceptions about GHE emerged. The analysis was also supported and guided by previous literature in determining common misconceptions in GHE. All the misconceptions gathered during the interview were then rephrased in the form of statements and numbered from M1 to M18, as shown in Table 2. The misconceptions statements were evaluated by two experts in the field of Science Education.

Findings from this study showed that the majority of the students were surprised that GHE is actually a normal phenomenon that occurs naturally, even without the presence of humans. At the end of the study, these students were aware that GHE is needed for human survival, and only excessive GHE will bring life-threatening impacts. This is also in line with findings by Arslan et al. (2012) where the teachers in this study were alerted that the students held many misconceptions about GHE—a topic that the teachers had perceived as easy. These misconceptions were strongly held in students' minds and formed a barrier to the teacher's new instruction. Students' understanding of the topic of GHE is greatly challenged, and their confidence is shaken due to conflicts in knowledge.

In addition, the findings also clearly indicated a conflict between students' existing knowledge—which is incorrect but presumed to be true—with the newly acquired knowledge. These incorrect conceptions became a hindrance for the students in acquiring the correct body of knowledge. Sometimes, even after learning the correct concepts in the classrooms, they still resisted modifying their pre-existing ideas, as was suggested by Khalid (2003). The existing knowledge persists and requires some time and concrete justification to be removed and replaced with new knowledge.

Thus, concrete models can be used to teach this abstract concept of GHE (Gul & Yesilyurt, 2011). For instance, students can be engaged in class discussions to gauge these abstract environment concepts of GHE or may be assigned to determine the common misconceptions of GHE. These learning activities engage learners' minds as they search for those misconceptions and replace them with the correct new knowledge. These independent learning strategies can motivate students in the quest for scientific knowledge and help them to build their knowledge of these abstract concepts.

The results of this study may add to knowledge for future research on the potential of using inductive analysis such as a mental model to determine the students' prior knowledge and to identify misconceptions. The findings of this study reveal the common misconceptions that can add to the existing literature and indicate the strength of inductive analysis in identifying students' conceptions, as supported by Yates and Marek (2014).

Table 2: Misconceptions statements

Misconceptions Codes	Misconceptions Statements
M1	GHE is perceived equivalent to a greenhouse
M2	GHE is considered as an abnormal phenomenon caused by human and did not occur naturally
M3	GHE is considered unnecessary, very bad and dangerous to humans
M4	GHE is not needed for humans' survivals
M5	GHE occurs in Earth's surface only and did not involve atmosphere
M6	Consider air pollution, water pollution and waste dumping as the direct cause of GHE
M7	Carbon monoxide is a minor greenhouse gas
M8	Air pollutants and acidic gases that causes acid rain are regarded as greenhouse gases that traps heat
M9	Identify CFC as the only gases that cause GHE
M10	UV is reflected in GHE instead of sun radiation or heat or infra-red
M11	Giving unsuitable interpretation of where the heat is trapped exactly
M12	Oxygen is described as a cooling gas in opposition with CO2 as a heating gas
M13	Giving unsuitable interpretation in differentiating the mechanism of GHE and thinning of ozone layer
M14	Giving unsuitable interpretation in stating how the temperature of the atmosphere increases
M15	Giving unsuitable interpretation to differentiate GHE and effect of global warming
M16	These students mention GHE directly causes melting of ice caps but give unsuitable interpretation in explaining how GHE causes global warming which then leads melting of ice caps
M17	Giving unsuitable interpretation to differentiate the impacts of ozone depletion are regarded as the impacts of GHE

CONCLUSIONS AND RECOMMENDATIONS

The study provided some insight into the use of inductive analysis in science teaching, particularly in identifying students' misconceptions of GHE. In light of these results, it can be concluded that the mental model is a reliable instrument for assessing students' conceptual understanding of GHE concepts. Based on the overall data analysis, it appears that the students were not able to grasp the basic concept well, however, so they were unable to solve the problem-related questions. To promote effective and meaningful learning, we need to identify the students' misconceptions and find ways to rectify them. Based on the results of this study, teachers can design appropriate lessons that will enhance students' understanding of learning GHE.

Therefore, this research is helpful in providing teachers with information both on students' prior knowledge and on their misconceptions. From the feedback received, teachers could design and institute relevant measures to eliminate their students' misconceptions (e.g., by developing alternative teaching approaches that specifically address students' misconceptions). Further studies could use inductive analysis as a tool for exploring students' misconceptions of GHE and also other topics in biology.

DECLARATION STATEMENT

The lead author* affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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CONFLICT OF INTEREST
The authors declare no self-interest in the study conducted.

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