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Author(s)	Chew-Hung Chang and Liberty Pascua
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Singapore students' misconceptions of climate change

Chew-Hung CHANG and Liberty PASCUA

National Institute of Education, Nanyang Technological University, Singapore

Corresponding author: Chew-Hung CHANG

Email: chewhung.chang@nie.edu.sg

Address: NIE7-03-01, 1 Nanyang Walk, Singapore 637616

Tel.: 6790-3861

Fax: 6896-9135

Dr. Chew Hung CHANG is an Associate Professor at the Humanities and Social Science Education (HSSE) Division of the National Institute of Education in Singapore, where he concurrently holds the position of Associate Dean for Professional Development. Dr. Chang specialises in urban climatology, climate change education and teacher professional development.

Ms. Liberty PASCUA is a Research Associate at the National Institute of Education, Singapore. Her research interests include education for sustainable development and climate change education.

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Abstract

Climate change is an important theme in the investigation of human-environment interactions in Geographic education. This study explored the nature of students' understanding of concepts and processes related to climate change. Through semi-structured interviews, data was collected from 27 Secondary 3 (Grade 9) students from Singapore. The data was subjected to thematic analysis using Chi and Roscoe's (2002) conceptual change framework. The results showed that the students' base knowledge of climate change is composed of incomplete and incorrect elements built within coherent and structurally sound mental models. Due to the consistency of the models in expanding the logic, albeit erroneous, of explaining the climate change conundrum it is posited that students are unaware of mistakes inherent in their judgements. Transformation of these mental models through multiple and deliberate refutations should be foremost in a Geography teacher's pedagogical approach.

Keywords: climate change, misconceptions, mental models, Singapore, Geography education

Introduction

Mental models are physical/spatial and causal/mechanical conceptual structures that are referred to for processes simulation and results prediction (Brewer, 2008) . While indisputably functional, mental models could impair learning if built with incorrect or

incomplete materials, or when ideas within the structure are connected through anomalous linkages (Chi, 2008).

This paper investigates how concepts in climate change beliefs are organized in mental models, which are not representative of the established geo-science knowledge of the phenomenon. Climate change is an important theme in the investigation of human-environment interactions in Geographic education with emphasis typically centred on building core understanding of the science and processes involved with the weather and climate (Dalelo, 2011). In addition to formal instruction, the topic also enjoys recurrent media coverage so that awareness of the topic is high among learners (Ambusaidi, Boyes, Stanistreet, & Taylor, 2012). Exposure to the issue has indeed shaped the worldview of children, usually of a bleak future characterized by a superheated planet (Jonsson, Sarri, & Alerby, 2012; Tan, 2013) which, to some poses imminent catastrophic effects (Özdem, Dal, Öztürk, Sönmez, & Alper, 2014). It is a fact however that awareness does not always indicate accurate understanding. Indeed, there is no dearth in research documenting various misconceptions held by students and the public about climate change. Among these is the confusion over the process of global warming, particularly the manner in which the heat is trapped (Lambert, Lindgren, & Bleicher, 2012). There is also the erroneous perception of a coupling between climate change with other environmental issues such as pollution (Boon, 2010), acid rain formation, smog (Pruneau et al., 2001) and Ozone depletion (Osterlind, 2005).

Such miscomprehensions reflect what Chi and Roscoe (2002) denote as naïve knowledge. Naïve knowledge is either a preconception or a misconception. While a preconception can be easily corrected through instruction, a misconception is extremely resilient and is made up of robust properties that are incorrect, incoherent or incomplete.

With its roots founded on the constructivist perspective, the Conceptual Change Framework as expounded by Chi and Roscoe (2002) emphasises that naïve conceptions in the form of misconceptions must be identified for a targeted approach at conceptual repair. Specifically, it posits that gaps in conceptual understanding are detected through investigating the three interrelated dimensions of coherence, correctness, and completeness. Anchored on these three dimensions, this paper seeks to determine the features of misconceptions that persist despite instruction (Chi, 2008) and how these features are assembled in mental models (Brewer, 2008). A flawed mental model is difficult to untangle and errors, once deeply embedded, have the tendency to multiply and perpetuate (Liarakou, Athanasiadis, & Gavrilakis, 2011). It is the intention of this paper to add to the growing scholarship on climate change education centred on geographic instruction.

Method

This article is part of a research project aimed at establishing baseline data on how climate change is taught and learned in Singapore's schools. Geography is a mandatory subject in secondary level schooling in the city-state. With a curriculum designed to develop core understanding of the environment, climate change occupies a significant amount of curriculum time in both Secondary 2 and 3 (Grades 8 and 9 equivalent) (Chang, 2012). Twenty-seven students, all from Secondary 3 and have finished the lesson on climate change in lower and upper secondary Geography, were participants to the research. The informants were between the ages of 14- 15, of mixed genders and ethnic backgrounds.

The students initially took part in a performance task aimed at diagnosing students' baseline understanding of the phenomenon. Results from said test revealed significant deficiencies in constructed knowledge but more importantly, several

inconsistencies were discovered on how the students constructed their argument (Chang & Pascua, 2014). This prompted the researchers to explore the assumption that there are multiple dimensions to the miscomprehension of students.

Semi-structured interview was facilitative in probing the reasons for the students' answers (Newby, 2010) and in capturing the full range of responses, both the expected and the unforeseen (Check & Schutt, 2012). There were midcourse changes to the data-gathering plan such as shifting to paired interviews to adjust to the participants' schedules. The paired interviews proved to be a serendipitous move such that the students appeared to be more conversational, relaxed and candid compared to those who participated in the one-on-one interviews. Taking heed from Newby (2010), collective interviews actually add richness to the data as the interaction between interviewees diminishes the formality of the activity and balancing power relations in the process. Instead of direct responses to the question, the conversation becomes more of a chat, thus, allowing more room for the issue to be explored with more depth.

Highlighted in this paper were the responses to questions on the causes of climate change. The key questions asked were the following:

- (1) How does climate change happen?
- (2) What are the natural causes of climate change?
- (3) What are human activities that exacerbate the climate change process?
- (4) What is the enhanced greenhouse effect?

As the intention was to gather context-specific answers organic to the Singapore setting, a conscious decision was made to not ask direct questions that would lead students to surface alternative conceptions such as those already identified in the literature. Nonetheless, even with the absence of prompts, the conversations naturally segued to narratives and justifications of how 'the hole in the sky', for example, leads to

global warming. With such accounts, the enquiry technique shifted suitably from asking general to specific questions to allow the informants to articulate their conceptual understanding of the topic. This confirmed that a good number of misconceptions are comprehensive regardless of research location.

Coding of responses followed a procedure that was both structured and iterative (Babbie, 2010). Open coding involved segmenting the responses into themes, after which the thematic patterns were subjected to template analysis vis-à-vis the research dimensions. Template analysis is especially useful when there are pre-determined concepts that serve as codes (Newby, 2010). Accordingly, a coherent model was judged by its consistency in linking ideas systematically while a complete model was assessed by whether the majority of the key elements are present or missing. Finally, a correct model was marked by whether the elements that comprise the structure are (in)accurate. A model was considered flawed if any of these distinctions was not met. Table 1 below summarises the coding dimensions and corresponding indicators.

Table 1. Dimensions and indicators

Dimension	Indicator
Incompleteness	Missing elements
Incorrectness	Confounding ideas
Incoherence	Disjointed links

The three dimensions were first individually teased out in the discussion of results as supported by frequency tables (N=27) and excerpts from the interviews. Original illustrations of mental models were drawn based on the patterns documented and these were integrated in the discussion.

Results

Completeness

The missing elements in students' reasoning were indicative of information deficit. Unfamiliarity with relevant terminologies and processes were detected in their responses.

Table 2. Missing elements

	Frequencies
Natural causes of climate change	22
Natural vs. enhanced greenhouse effect	24
Fossil fuel use as anthropogenic cause	24
Farming as anthropogenic cause	27
Deforestation and carbon oxidation	27
Water vapor as a greenhouse gas	26
The positive feedback loop	26

Natural causes of climate change

Students' understanding of the causes of climate change was limited to the belief that recorded changes are solely due to anthropogenic reasons. While human influences often are highlighted in the prevalent rhetoric on climate change it is also true that the climate goes through natural shifts and, to a degree, such irregularities are aided by processes that are not within the control of humans such as volcanic eruptions and solar activity. Of the 27 students, only one confirmed that climate change is partly due to natural causes. The student referred to the sun as having a key role in the heating process albeit unable to fully defend his response. Four students replied that there may

be natural causes but also immediately argued that humans should be regarded as the sole culprits. The rest maintained that human activities are the sole reason to global climatic changes. An excerpt from the interviews illustrates this point:

S2: It's not natural. Because... erm... humans, they cut down trees. And then if they cut down trees, erm, usually trees are the only one(s) to absorb carbon dioxide. So if they cut down trees, and humans usually takes in oxygen...so if they release more carbon dioxide, it will increase greenhouse effect as well.

Natural vs. enhanced greenhouse effect

There was no clear delineation between the natural and the enhanced greenhouse effect in students' explanations. When asked to differentiate the natural and the enhanced greenhouse effect, three students correctly described the natural greenhouse effect as a vital element for life to be possible on earth. However, the other informants were not able to delineate the two, at times referring to natural greenhouse effect as an essential and also detrimental process to the planet. The informants stalled in responding when asked to elaborate why a seemingly 'good' process is also a 'bad' process. It was apparent that they did not have the vocabulary such as the 'enhancement' of the greenhouse effect to refer to their conceptual notion of why there is increased warming.

Society's carbon footprint

There are three vital fundamentals in building a basic and complete explanation of the enhanced greenhouse effect as caused by anthropogenic factors. Figure 1 below illustrates these.

(Insert Figure 1)

Of the three elements, the students were most familiar with gases. Responses almost always included a name or a type of gas, or a reference to a group of gases. Deforestation was mainly understood for the role of trees as absorbers of carbon dioxide, thus implicitly referring to forests as carbon sinks. There was no indication that carbon oxidation was known as a negative consequence of deforestation. Farming as an anthropogenic factor was never mentioned. Although there was common awareness that transportation and electricity use were related to climate change, explanations supplied were not linked to fossil fuel use and carbon emissions. These results denoted that the informants saw humans as culprits to climate change although their understanding of how it was so was not fully developed.

Water vapour as a greenhouse gas

Carbon dioxide was the most popular among the gases identified, followed by chlorofluorocarbons (CFCs), methane and nitrous oxide. Water vapor, a key greenhouse gas, was missing from the students' conceptual understanding, while carbon monoxide was repeatedly cited as both a greenhouse gas and a pollutant. This interview vignette is an illustration:

S: The greenhouse gases are CFCs, carbon dioxide, nitrous oxide, carbon monoxide, methane.

I: What about water vapour. Is it a greenhouse gas?

S: Uhh. No. No, it is not.

The positive feedback loop

The positive feedback loop refers to the process wherein the enhancement of the

greenhouse effect results in the melting of permafrost. This event causes the exposure of fossil deposits, which then leads to the release of enormous amounts of carbon dioxide and methane into the atmosphere. This exponential addition of greenhouse gases would promote an even more favourable environment for atmospheric temperature to rise, leading to the melting of more land ice. An extended illustration of Figure 1 incorporating the positive feedback loop would look like this:

(Insert Figure 2)

One student successfully described the process and even spelled out the term ‘albedo effect’. The rest, however, declared that they did not have knowledge about the process. A clear comprehension of the mechanics of the loop’s operation would allow a learner to effectively associate how the process in Figure 1 is but a part of a continuous, more complex, cycle with far-reaching effects.

Correctness

A number of superfluous elements comprised the students’ repertoire of concepts, perhaps a result of incompleteness of understanding, which have the capacity of substituting and/or replacing correct concepts.

Table 3. Confounding Ideas

	Frequencies
Chlorofluorocarbons (CFCs) are major greenhouse gases	24
Carbon monoxide is a major greenhouse gas	14

Greenhouse gases are generally regarded as pollutants and are harmful and toxic.	25
The intensification of the heating process is caused by ultraviolet rays	11
Climate change is linked with Ozone depletion	27
Climate change is linked with tectonic activities (tsunami, earthquakes)	15
Others (acid rain, radioactivity, chemical evaporation, heat emission from factories/incineration)	8

The air-conditioner was the most popular household fixture perceived to contribute most to climate change. It is important to distinguish here that the air-conditioner was singled out because it is believed to emit CFCs that destroy the Ozone layer. The informants repeatedly explained that people should use less of the device to curb the amount of CFCs in the atmosphere, thereby allowing global temperature to revert to pre-climate change level. In addition to the air-conditioner, students also stated that the use of aerosols and Styrofoam products significantly alter the Earth's climate. In addition, the use of transportation vehicles as anthropogenic source of carbon also was a popular answer. The justifications given were centred on the rationale that cars give off carbon monoxide. While it is true that carbon monoxide is a greenhouse gas, its impact to and concentration in the atmosphere is significantly less than that of major greenhouse gases such as carbon dioxide, water vapour and methane. It is then taken that this idea was mainly linked to carbon monoxide as an air pollutant than as a greenhouse gas.

The gases

Students' familiarity with the compounds was almost always put next to the idea that the gases cause harm to the atmosphere. Such was evident in terms such as 'unwanted', 'toxic', 'waste' and 'poisonous'. The gases were also referred to as harmful 'emissions', 'pollutants', 'smoke', 'fumes', 'chemicals', 'exhausts' and elements that destroy something, usually in reference to the atmosphere or the Ozone layer or both. Further, the gases as air pollutants were seen to be synonymous to or closely associated with greenhouse gases. It followed that pollutants were also deemed responsible for increased warming on Earth. Some indicated that pollutants destroy the Ozone layer and cause acid rain.

The intensification of the heating process

Reinfried, Aeschbacher, and Rottermann (2012) maintain that radiation conversion on the Earth's surface and the selective absorption of thermal radiation by carbon dioxide; two key processes in climate change, are usually neglected in textbooks. It was earlier indicated that students were least familiar with the process of heat trapping as a result of the enhanced greenhouse effect. The term *retention* is used to better capture the students' conceptual understanding of the heating process. In fact, global warming was not always comprehended as a result of increased greenhouse gas activities.

Consistent with the literature (Andersson & Wallin, 2000; Lambert, et al., 2012; Shepardson, Choi, Niyogi, & Charusombat, 2011), the sun is believed to be the direct source of heat that is kept on Earth and solar radiation in the form of ultraviolet (UV) rays were perceived as the primary agent for global warming. Infrared radiation was seldom cited and in the occasion that it was so, it was supposed to emanate directly from the sun and take the characteristics of a UV ray. The knowledge of ground-emitted heat was not detected in the responses. Interestingly, some indicated that factories,

nuclear power plants, industrial machineries and incineration produce the heat that is retained.

S: Because of factories, there is more heat.

I: Why is that so?

S: They emit hot gases. When they process materials, they use fire. So this heat gets trapped.

The Ozone

Interchangeably referred to as hole, layer and a depleted matter, the Ozone was the most prominent confounding concept in students' conceptual maps. The destruction of the Ozone was almost always associated with global warming and attributed to the following factors: greenhouse gases, CFCs, chemicals, pollutants and extreme heat.

The Ozone is understood as a layer of protection over the Earth that shields the planet from the sun's heat through reflecting solar rays back into space. It then follows that when Ozone gas is depleted this protective layer is assumed to also lose its capacity to bar the heat. The earth's climate and the Ozone layer were perceived as intricately linked so that a change in the structure of the Ozone layer was comprehended as a change in the Earth's climate as well.

Relatedness to other issues

Interestingly, climate change is perceived as coupled with other environmental issues such as tectonic activities, acid rain, radioactivity and pollution. For instance, fifteen students perceived climate change to cause volcanic eruptions and tsunamis. While most were unable to justify their answers, three students opined that increased precipitation would create an overabundance of ocean water, which could then trigger a tsunami. Two students stated that increased temperature could affect the Earth's crust

which then could start volcanic activities. In addition, climate change is seen as a cause of acid rain due to increased precipitation.

Coherence

The students' idea structures when examined holistically were mostly coherent. The reasoning patterns have the ability to expand the logic of their arguments, albeit erroneous, of explaining the climate change conundrum. We take as an example the belief that the Ozone layer shields the earth from the sun's rays. With the concept of a 'layer' prominently poised as a key element in an idea structure, all other related concepts were bent to support this belief. Thus, depletion of gases in the layer causes global warming. CFCs produced by humans destroy the layer, making humans gravely responsible for global warming. A hole in the layer allows the penetration of intense direct heat from the sun, which causes global warming and skin cancer. Indeed, such pattern of reasoning was the norm rather than an anomaly in the responses.

S1: The Ozone layer prevents the heat rays from the sun from actually reaching Earth. So, then, if more heat comes in, we use more aircon, they produce more electricity, more, erm, chemicals and the harmful products go back to into the sky, depleting the Ozone layer, and then it's just a cycle that will keep going on until, everybody dies out. You know.

However, there were also instances when the students fused together certain concepts rather unsuccessfully.

Table 4. Disjointed links

	Frequencies
The functions of the Ozone layer and greenhouse gases	5
The dual role of the Ozone as 'blocker'	3

In attempts to discover alternative explanations, probing questions were asked about the role of greenhouse gases in climate change. The answers often were a combination of confused conceptual linking between greenhouse gases and the Ozone layer. Greenhouse gases were known to 'blanket the earth' while the Ozone was dubbed the 'earth's protection'. Both the Ozone and greenhouse gases were perceived to trap heat. Both were also seen as matter that is destroyed. The confusion between the two was best captured by a student's explanation of a 'greenhouse layer', an element that is formed by greenhouse gases and has both the capacity to trap heat and reflect heat away. The Ozone is believed to shield the Earth from the sun's rays, while also blocking the heat from Earth to escape. Such confusions is depicted in this conversation with two male students:

S1: I really don't know how to explain why these gases can trap heat. I think it's because of the density of the gases that makes the Ozone a little bit denser, then the heat have problem escaping.

I: So, what's the role of the Ozone layer?

S1: Erm, it's to rebound some of the ultra... infrared ray(s) from the sun.

I: Just to clarify, where does the heat come from?

S2: Sun.

I: The sun.

S1: Some came from the sun and some came from industries,
like the processors that generate heat and it is released to the
atmosphere and it is trapped by the gases.

I: So you're saying it's coming from the sun. And you're saying
it's coming from the industries also. You said something about
the heat that's supposed to escape?

S1: Yeah, correct.

S2: And then it becomes contained, yeah, by the Ozone layer.

S1: Because of the Ozone layer.

I: What does the Ozone layer do?

S2: Protects the Earth from UV rays? Yeah, from the sun.

Mental models

The conceptual arrangement of ideas that emerged did not follow a one-way, one-dimensional line of reasoning. The mental models were complex systems, fusions of thoughts both correct and erroneous, with key elements absent or replaced and oftentimes assembled through an intelligible, organised idea structure.

Heat is trapped

The factor of ground-emitted heat was missing from the models. This was replaced by the sun and/or man-made sources as the origin of heat. Confounding ideas such as pollutants and the Ozone layer as elements that trap heat further complicated the model.

(Insert Figure 3)

(Insert Figure 4)

'Something' destroys the Ozone layer

The depletion of the Ozone as a confounding idea conveniently replaced heat trapping in students' conceptual structure. While it was indicated that some students believed that the Ozone traps heat, most of those interviewed expressed that the Ozone reflects heat away from the Earth. Indeed, the intensification of the heating process was attributed to the increase in the sun's capacity to bombard the Earth with more damaging rays as the Ozone's blanket of protection is destroyed by CFCs mostly, and also by other elements such as greenhouse gases, pollutants and heat from man-made sources. Notice that ground-emitted heat was also missing in the structural composition of the models.

(Insert Figure 5)

(Insert Figure 6)

Hybrid model

This model shows how greenhouse gases and the Ozone layer are thought to interact with each other. As gases trap heat from the sun, this stored heat causes the depletion of the Ozone. Dysfunctional Ozone then allows more heat to penetrate the Earth's atmosphere, thus, further intensifying the heat-trapping process.

(Insert Figure 7)

Discussion and conclusion

Chi and Roscoe's (2002) distinction of mental models provided an operable scheme to analyse students' conceptual understanding of climate change. The errors in association confirmed Chi's (2008) claim of a flawed mental model that is largely built with coherent but incorrect and incomplete factors. Even though they have been exposed to classroom discussions on the topic, the students still have major gaps in their understanding. A chief concern is the prevalence of confounding ideas, elements injected into their arguments that have the capacity to substitute correct concepts. Due to the consistency and coherence of the mental in expanding the logic, albeit erroneous, of solving the climate change conundrum, it is posited that the students were likely unaware of the mistakes inherent in their arguments. Similarities with Shepardson et al. (2012; 2009) and Andersson and Wallin's (2000) findings show that the misconceptions are widespread. Among these were the Ozone-related models, the nature and behavior of greenhouse gases, and the source and type of heat that is retained. As Andersson and Wallin (2000) also have observed, the Ozone-related models serve as a convenient and easy route to explain the warming process: as 'the barrier thins out, more radiation can come through' (p.1108).

One unique contribution of this study is its identification of the perceived role of heat in the warming process. While the literature elaborated on students' perception of industrial activities as perpetrators of climate change, the heat generated from these facilities and its purported role in actual atmospheric temperature increase was not explored. In fact, this study determined that learners perceive industrial and nuclear activities as heat generators in addition to being greenhouse gas and pollutant emitters.

In retrospect to climate change as a key feature of human-environment interaction in Geographical inquiry, this study posits that even though the science of

weather and climate are given room in the formal curriculum (Dalelo, 2011), and although there is high and sustained awareness among learners on the topic (Ambusaidi, et al., 2012), educators in both Geography and the Sciences must be cognizant of deeply embedded errors in a mental model as barriers to learning. They must respond through modifying their pedagogy to include identification and direct refutation of misconceptions. For instance, if the function of the Ozone is not clarified and deleted in a conceptual structure, it is likely that new information added would only be appended to an already flawed model (Chi & Roscoe, 2002). To correct persistent misconceptions, students must be made aware of the flaws in their mental models through multiple revisions (Chi, 2008; Chi & Roscoe, 2002).

The need to build accurate understanding about climate change cannot be overemphasised. Indeed, students have been especially pessimistic of a future that they do not quite understand (Jonsson, et al., 2012; Özdem, et al., 2014; Tan, 2013); .As Bord, O'Connor and Fisher (2000) reiterated, bogus knowledge prevents individuals from intelligently responding to the challenges posed by climate change. This is not to claim that correct knowledge is a stand-alone determinant for climate change responsiveness. Indeed, climate literacy alone does not provide sufficient condition to galvanise the younger generation to take action. A belief that is constructed from their accurate, coherent and complete understanding of the issue must also be complemented by a moral responsibility as stewards to the environment. It is indisputable nonetheless that accurate understanding of the processes involved remains a key factor, if not the very driver, for moral responsibility to take shape. This is an area where Geography education has a stake in developing.

While the findings of this research provide meaningful insight as to the nature of climate change misconceptions held by the students, an analysis of curriculum content,

students' receptiveness to instruction, and teachers' content knowledge and pedagogical approaches used would be valuable addition for a more holistic understanding of the subject matter. Such themes will be explored in future studies planned by the authors.

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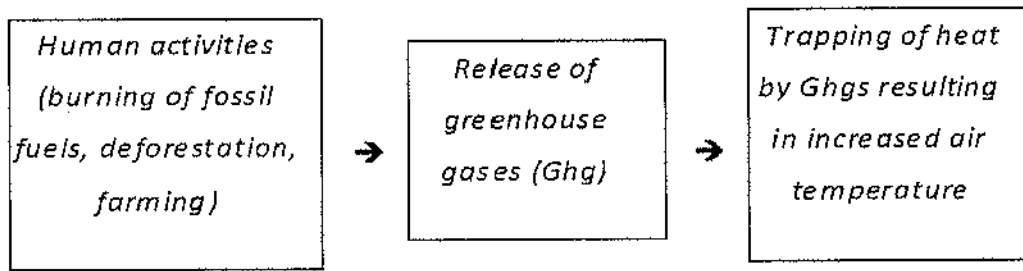


Figure 1. Anthropogenic climate change

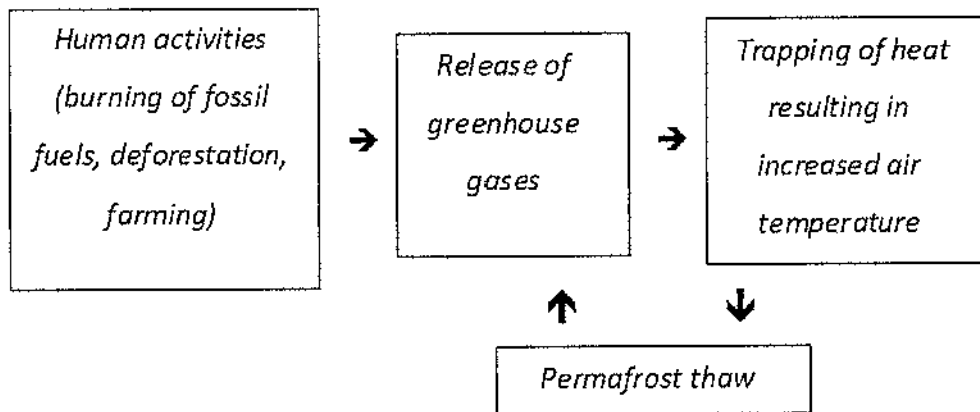


Figure 2. Positive feedback loop

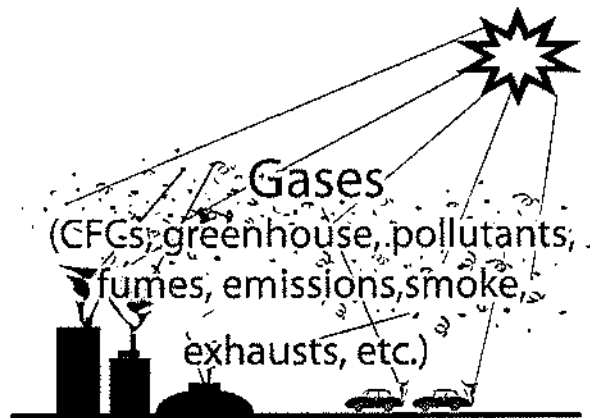


Figure 3. Gases trap heat

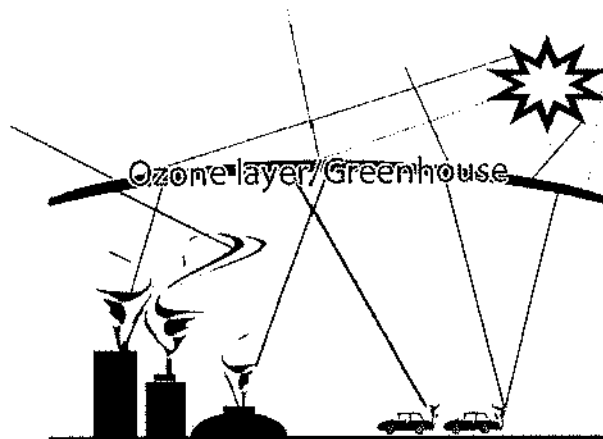


Figure 4. A layer traps heat

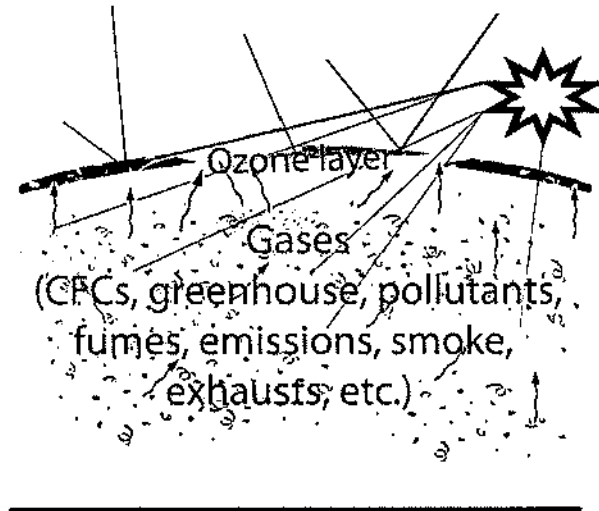


Figure 5. Gases destroy the ozone layer

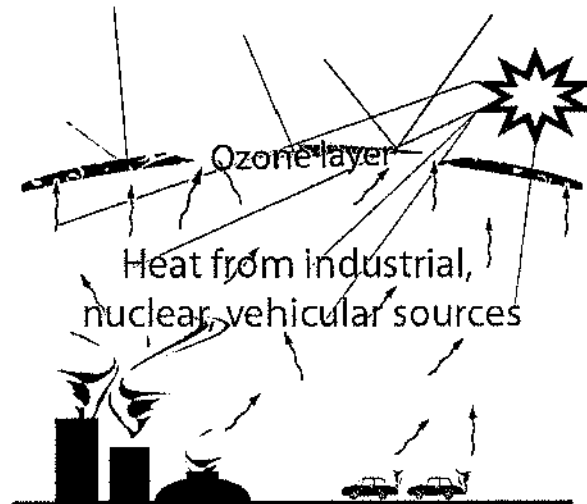


Figure 6. Heat destroys the Ozone layer

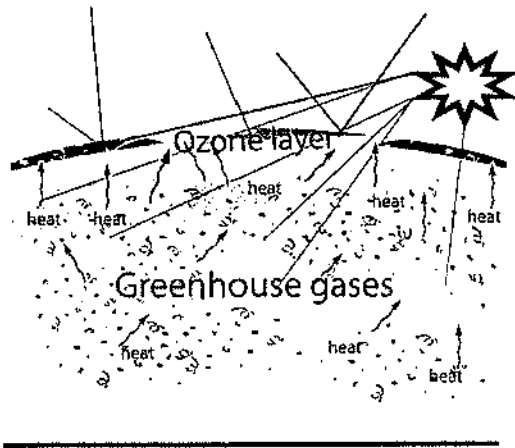


Figure 7. Heat trapped by greenhouse gases destroys the Ozone layer