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Greenhouse Effects in Global Warming based on Analogical Reasoning

Jun-Young Oh[1] · Eui Chan Jeon[2]

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Abstract Using an analogy in science and everyday life is a double-edged sword because they are accompanied by alternative ideas, in addition to scientific concepts. Schools and public education explain global warming by making a common analogy between this phenomenon and greenhouse effects (Chen in Philos Cogn Sci 105–114, 2012). Unfortunately, this analogy sometimes produces various incorrect explanatory mental models. To construct a correct understanding of global warming, it is necessary: first, to investigate the attributes of analogical reasoning; second, to understand these features by restructuring the greenhouse analogy; and third, to explore the problems and benefits of the greenhouse analogy. The characteristics of relations, rather than objects, must be mapped according to the principle of systematicity, but the public tends to preserve the attributes of the base domain, which is mapped relatively easily. In conclusion, certain facets of the prevailing greenhouse analogy cause a distorted public view of climate change. We must use the greenhouse analogy and yet simultaneously emphasize the relations and attributes highlighted and hidden in the analogy during evaluation.

Keywords Analogy · Global warming · Greenhouse effects analogy · Climate change

1 Introduction

According to the 2007 report by the Intergovernmental Panel on Climate Change (IPCC), which was founded in 1988 by two United Nations organizations—the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP)—the Earth's average temperature has increased by 0.74 °C over the past 100 years. Eleven

✉ Jun-Young Oh
jyoh3324@hanyang.ac.kr

[1] Hanyang University, Seoul 04763, Republic of Korea

[2] Department of Environment and Energy, Sejoung University, Seoul 05006, Republic of Korea

of the 12 warmest times since observation began in 1850 have occurred in the last 12 years, indicating that global warming is accelerating. Moreover, if human activities that depend on fossil fuels continue, by the end of the 21st century, the Earth's temperature will have increased by up to 6.4 °C, depending on greenhouse gas emissions (IPCC 2007). In fact, many Mediterranean countries are already dealing with the petrification of coral reefs due to rising temperatures, and North American nations are suffering from the severity of increasing global temperatures as they observe how quickly the glaciers of the Rockies are now receding compared to the past (Yoon et al. 2011).

We consider global warming to be the "average global surface temperature increase from human emissions of greenhouse gases," whereas climate change is "a long-term change in the Earth's climate or of a region on Earth" (Conway 2008). Furthermore, global warming refers to a strong, tangible relationship between human-produced greenhouse gases, global temperatures, and potentially catastrophic consequences that are more readily identified by laypersons (Conway 2008; Corbett and Durfee 2004; Hargreaves et al. 2003; Whitmarsh 2009). Therefore, regarding terminology, "global warming" should lead to less ambiguity and confusion than "climate change."

Global warming is an outcome of a highly complex energy conversion process. To understand this process, we need a more abstract conception that transcends our daily experiences. The greenhouse effect, which is a form of analogical reasoning, is widely adopted and used in school education and mass communication as a strategy to facilitate understanding of energy transfer. In essence, the Earth's atmosphere is akin to the glass windows of a greenhouse and it warms the inside of the greenhouse with solar energy; it also warms the planet that is surrounded by the atmosphere. Greenhouse gases, such as carbon dioxide, play a significant role. However, due to the process of this analogy, people tend to highlight or hide other factors affecting climate change. Thus, this analogical strategy disproves many misunderstandings that are inconsistent with scientific energy transfer in the global climate system.

Accordingly, this study examines the issues concerning how students and the public understand and explain climate change through the greenhouse analogy. It does so by implementing the systematicity principle of Gentner and Stuart (Gentner 1983, 1989; Gentner and Toupin 1986; Gentner and Smith 2012) in the process of analogical reasoning, and by applying the semantic and pragmatic constraints of Holyoak and Thagard (1997), which are added to the goal of the analogist.

To achieve this purpose, we established the following concrete research questions.

1. What is the process of understanding analogical reasoning at an epistemological level?
2. How should we understand global warming based on analogical reasoning?
3. Using the greenhouse analogy, what are the possible issues influencing the development of a proper view of global warming by students and the public?

2 Analogical Reasoning

Throughout the history of science, scientists and science educators have used analogical reasoning to explain fundamentally important issues (Brown 1992; Gentner 1989; Hesse 1966; Thagard 1992; Venville and Treagust 1997; Vosniadou and Ortony 1989), to elaborate and develop concepts (Lakoff and Johnson 1980), and to expand scientific boundaries to generate brand new ideas (Gentner and Markman 1997; Holyoak and

Thagard 1996; Ward 1998). Previous investigations have linked analogical reasoning with problem solving (Gick and Holyoak 1980; Polya 1954; Schon 1979). Gentner's Structure Mapping Theory (1983) has been used extensively in science education to account for the nature of analogical reasoning.

Scientists promote analogies as successful conceptualizations, but they are often considered problematic by the science education research community (Dagher 1995; Duit 1991). Those who study analogies offer frequent reminders that an analogy's useful applicability is limited. Only some aspects of a source domain can be mapped to a target domain. For example, an important aspect of the target domain that has no counterpart in the source domain, or a salient characteristic of the source domain that has no analogue in the topic domain, is nevertheless exported to the topic area. Students are especially vulnerable to forming inadequate ideas due to mapping errors (Harrison and Treagust 2006; Vosniadou and Brewer 1987). Lakoff and Johnson (1980) termed this characteristic "highlighting and hiding": systematicity allows people to comprehend one aspect of a notion in terms of a special source that will necessarily hide other facets of the idea. In allowing people to focus on one angle of a concept, a metaphor or analogy keeps them from centering on other facets that are inconsistent with that metaphor or analogy.

The "grounds for a metaphor, therefore, can be formulated as relations of similitude that can be expressed as comparison statements" (Miller 1993), p. 398. An analogy is perhaps a more creative comparison of less similar relations. An "analogy is a way of aligning and focusing on relational commonalities independently of the objects in which those relations are embedded" (Gentner and Jeziorski 1993, p. 449).

In an analogy, only relational predicates are mapped; conversely, in a literal similarity, both relational predicates and object attributes are mapped. In mere-appearance matches, it is chiefly object attributes that are mapped.

2.1 Analogy in Reasoning and Learning

Duit (1991) perceives analogies as important for generating schemata during learning. A related view holds that analogies are critical in helping students to develop initial models, which they can later improve (Glynn et al. 1995, 1997). Analogies can allow the learner to build on relationships already gained from prior knowledge, rather than starting a model from scratch. Some of these connections may be represented as concrete images or simulations (Clement and Steinberg 2002). Daugher (1994) suggested that analogies can contribute to conceptual changes, but are more likely to produce gradual transformations in ideas, rather than a sudden "ontological shift" of early conceptual change theories. Treagust et al. (1996) also recognized the importance of examining the role of analogies in "everyday" learning, as opposed to seeking to drive radical conceptual changes.

Structure Mapping: Deidre Gentner's work is often cited as foundational in the physics education literature on analogy. According to Gentner's *Structure Mapping Theory*,

These object correspondences are used to generate the candidate set of inferences in the target domain. Predicates from B are carried across to T, using the node substitutions dictated by the object correspondences.

The mapping rules are (Gentner 1983),

1. Discard the attributes of objects;
2. Try to preserve relations between objects; and.

3. The Systematicity Principle centers around deciding which relations are preserved, choosing systems of relations, and dynamic causal information: higher-order connections play a significant role in analogy.

Gentner and Toupin (1986) drew a distinction between object attributes (simple, descriptive properties of objects) and relations (complex, relational properties of objects); she argued that the latter are typically more difficult to access than the former, although this is not always the case. For example, young children tend to produce and select attributional interpretations based on nonliteral comparisons; this pattern contrasts sharply with the adult preference for relational interpretations (Gentner 1980; Gentner and Stuart 1983). These and many other experimental results seem to indicate that the ability to perform figurative comparisons develops gradually and later in life (Inhelder and Piaget 1958).

The Systematicity Principle: The essence of the systematicity principle is coherence among relations. This coherence may be in a causal relationship with implications (Lakoff and Johnson 1980). The core of an analogy is not delivering separate, independent facts, but rather a system of knowledge that is connected between the base domain and the target domain. This principle implicitly prefers the coherence and deductive power of analogies. Systematicity refers to the state in which a system that can be mutually connected and corresponded with is isolated; it is thus more important for the goal, rather than the attributes of the described objects. An analogy requires the connected system to find correlated structures at a high level of order among commonalities between the base and target domains. For example, high order relations mean that the base domain connections must be linked to the causal relationship chain of the target domain. Consequently, the abstract concept (causal law or theory) that is the most important must be corresponded and connected with. However, an analogy cannot use the causal relations between the base and target domains. In essence, the analogy corresponds to the causal relations or implications in each domain *within* the base and target domains.

Figure 1 shows the example of the Rutherford analogy between the solar system and the hydrogen atom. What does this analogy convey to the person hearing it for the first time? Assuming that this person has prior knowledge about the solar system, shown in the top network, they must be able to draw some conclusions about the atom from this analogy (Gentner and Toupin 1986).

Similar to structure mapping, Holyoak and Thagard (1997) outlined the steps involved in learning through analogical reasoning, including: (a) retrieval, (b) mapping, (c) inference, and (d) learning. Moving from the target analog (base domain) to the source analog (target domain), analogies are accessed during retrieval, when the learner is trying to reason about a new situation. During mapping, similarities or correspondences between the source and target are found. Inferences about the two domains are made during the inference, and then "a kind of abstraction of the commonalities shared by the source and target" (p. 35) is developed during learning.

Holyoak and Thagard (1997) further outlined a "multi-constraint theory" of analogical reasoning that explains how analogies are guided by three particular kinds of constraints: (a) similarity, (b) structure, and (c) purpose. The use of analogies is often guided by a similarity of concepts between the base and target domains. In addition, consistent structural parallels often exist between the roles in the base and the target domains. Finally, analogical reasoning is typically guided by a purpose that the analogy intends to achieve. As many theorists have noted, it is useful to decompose an analogy into four major

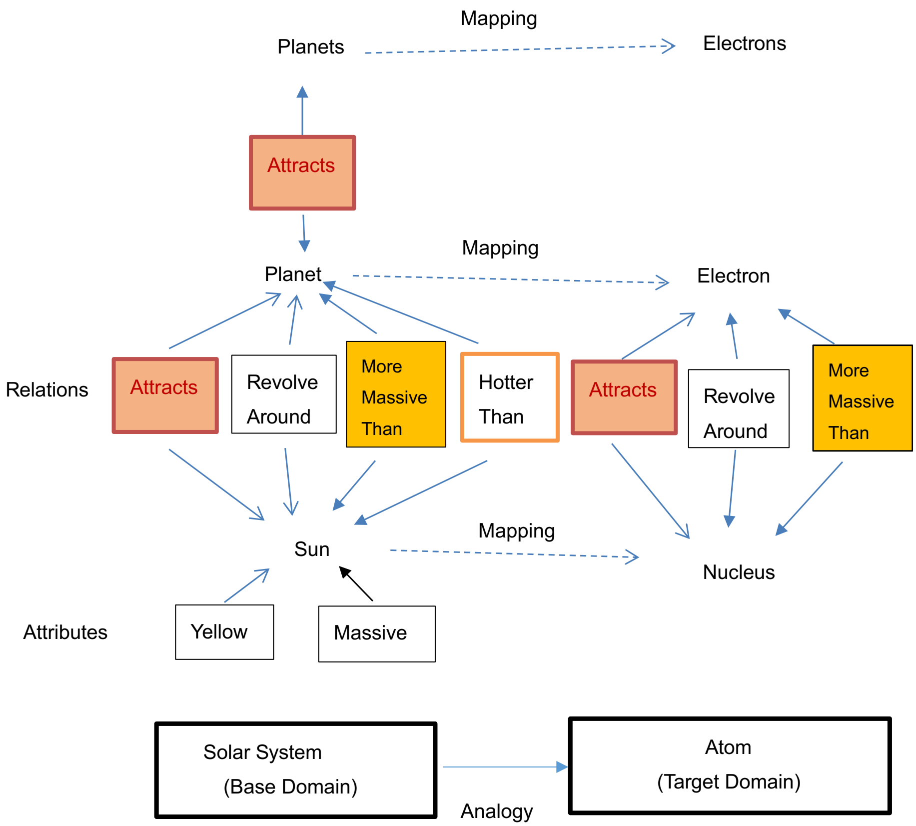

Fig. 1 Structure-map for the Rutherford analogy: The atom is like the solar system (Modified from, Gentner and Toupin 1986)

components: (1) retrieving or selecting a plausibly useful source analog, (2) mapping, (3) analogical inference or transfer, and (4) subsequent learning (Holyoak and Thagard 1989). Analogies vary widely in their appearance, content, and use. They can all be characterized by a set of processes common to all types of analogical reasoning.

Where two cases are present in working memory (either through analogical retrieval or simply by encountering two cases together), mapping involves a process of **aligning** the representations and projecting **inferences** from one analog to another.

Therefore, we also present the following analogical reasoning process, incorporating the investigation by Holyoak and Thagard (1997), which added the goal of the analogist to the study by Gentner et al. (Gentner and Smith 2012; Holyoak 2005). The fact that students are learning shows they are expanding and moving to a higher schema; in the realm of scientific theory, this is an expansion of a paradigm and a partial revolution. Inference can act as a dynamic procedure within the alignment process during mapping, helping one find new relations through causal inference, in addition to helping one to participate in the process, with the purpose and meaning of analogical reasoning serving as *constraints*.

Therefore, it is necessary to adopt the following two constraints, especially during mapping processes throughout the entire process of analogical reasoning.

Constraint 1 The systematicity principle states that a base predicate that belongs to a mappable system of mutually interconnecting relations is more likely to be imported into the target than an isolated predicate. A system of relations refers to an interconnected predicate structure in which higher-order predicates enforce constraints among lower-order predicates (Gentner and Smith 2012). The systematicity principle is part of a mostly explanatory, coherent account of complex human behavior, due to the notion of "why rather than how."

Constraint 2 Pragmatic centrality favors correspondences that are pragmatically important to the analogist, either because a particular correspondence between two elements is presumed to hold, or because an element is judged to be sufficiently central that some mapping for it should be found (Holyoak and Thagard 1989).

We intend to apply Constraint 2 to all steps of forming an analogy for structural mapping.

Retrieva: With some current topics usually active in a person's working memory, they may be reminded of a prior analogous situation through long-term memory. A long-term memory component, analogous to a set of filing cabinets or a computer hard disk, provides raw material (knowledge) for working-memory operations and the products of those operations. The construction of conceptual links enhances an expert's working-memory and long-term memory performance. Because the expert's knowledge is relational, it is easily stored, quickly retrieved, and successfully applied (Glynn et al. 1995).

> Systematicity should increase the transfer accuracy of an analogical mapping. Another factor that should be important during the on-line mapping process is the transparency of the object-correspondences. Transparency is defined at the case of determining the object correspondences and predicate mappings for an analogy or similarity math. Transparency is high when surface similarity correlates well with structural similarity (Gentner and Toupin 1986).

However, we intend to apply a plan and goals for structural mapping of a true analogy, rather than surface simulates:

a. Systematic knowledge of the base domain promotes accurate analogical mapping.
b. The effect of systematicity will be stronger the more difficult (i.e., the less transparent) the analogical mapping.

Evaluation: Once the common alignment and the candidate inference have been discovered, the analogy is evaluated. Evaluating an analogy involves at least three kinds of judgment:

(1) *Structural soundness* whether the alignment and projected inference are structurally constant.
(2) *Factual correctness* whether the projected inferences are false, true, or indeterminate in terms of the target.
(3) *Relevance* whether the analogical inferences are relevant to the current goals.

In practice, the relative importance of these factors varies quite significantly. In domains where little is known or where there is disagreement about the facts (for example, in politics), the relevance of goals may be more important than factual correctness.

During the past 25 years, many studies have evaluated the use of analogies in science classrooms, and various theories on the use of analogies have been developed (Niebert et al. 2012). The most prominent come from Gentner and her colleagues, who formed the structure mapping approach (Gentner 1989; Gentner and Smith 2012), and Holyoak and his colleagues, who created the pragmatic approach (Holyoak 1985; Holyoak and Thagard 1997). We share their views in that we believe mental representations of the source and target domains are crucial for analogical reasoning.

Using an analogy typically involves several steps. Our research aims to apply all three steps (see Table 1). We observe the constraints of planning and purpose (all the steps of retrieval and evaluation), structure (systematicity: mapping), and we apply the constraints to each step, but with varying degrees of relativity, rather than absolute importance (see Table 1).

Table 1 demonstrates the three stages of analogical mapping: a) Understanding the base domain via retrieval, b) A transfer of relations via mapping by using an analogical engine, and c) Reconstructing and learning a target domain via the evaluator's assessment.

There follows shortly an example that applies these steps consistently with the development of Rutherford's atomic model (from Fig. 1; Table 2); that is, the development steps of the atomic model.

2.2 The limitations of Usefully Applying an Analogy

"**Highlighting and hiding**" (Lakoff and Johnson 1980): Systematicity allows people to comprehend one aspect of a concept in terms of a special source that will necessarily hide the notion's other facets. In allowing people to focus on one angle of a theory, an analogy keeps people from centering on other characteristics of the idea that are inconsistent with the analogy (Table 3).

Systematicity allows people to grasp one aspect of a certain target domain in relation to the perspective of one angle of another base domain, which will necessarily hide other features that differ from the base domain. By allowing people to focus on one aspect of a theory (i.e., highlighting), an analogy keeps people from considering other angles of the idea that are inconsistent with the analogy (i.e., hiding).

Table 1 The steps of analogical reasoning

Holyoak and Thagard (1997)	Gentner and Smith (2012)	This research
(a) First		
The retrieval step	Retrieval	(a) Understanding a base domain in order to explain a new target domain
(b) Second		
The mapping step, The inference step,	Mapping Alignment Inference	(b) Transfer relations through mapping
(c) Third		
Learning step	Evaluation	(c) Restructuring and Learning a target domain through evaluation

Table 2 The Planetary model of the atom

Sequences	Sub-sequences		Solar system (Base Domain)	Atom (Target Domain)
(a) Understanding base domain, to explain target domain	Mapping between objects of nodes based on both attributes		Sun Planets	Nucleus Electrons
	Retrieving Relations about base domain *First-Order Relations*		Attract, Massive, Resolve, Hotter	
(b) Transfer relations through mapping	Relations (Preservation of Relationship) *Candidate Second-Order*	Attract	Sun attracts planets	Nucleus attracts electrons
		Massive	Sun is more massive than planets	Nucleus is more massive than electrons
		Revolve	Planets revolve Sun	Electrons revolve nucleus
		Hotter	Sun is more hotter than planets	Nucleus is more hotter than electron
	Relations chain (systematicity principle) *Second-order*	Causal relations chain	Cause (Attract & Massive), Results (Resolve) More hotter is not-preserved,	
	Abstraction	Concepts, laws, theories	Central Force (Gravitation Forces)	Central force Electric Forces
(c) Restructuring a target domain through a kind of evaluation	Restructuring and Learning	Check		More hotter is discard, and Additional attributions, and relations about electric law. Electric charge…

(a) Understanding a base domain in order to explain a new target domain. Introduce a target domain, then cue for retrieval of the base (analog) domain.

In keeping the core goal of a target domain, the data saved in long-term memory are retrieved by activating working memory. In addition, in mapping the two domains, it is relatively easy to correspond with superficial similarity, as well as relations in the base domain with which it is relatively difficult to connect. Here, relations in the base domain are in the lowest order. To retrieve information effectively from long-term memory, it is necessary to find suitable retrieval cues. Thus, as shown in Fig. 2, we adopted the strategy of retrieving not only superficial, but also structural similarities from memory when the retriever focuses on the goal of analogy as the retrieval cue, according to Holyoak and Thagard (1997).

Object attributes and structural relations: In long-term memory (LTM), according to the purpose—which states that the nucleus is in the center of Rutherford's atomic model—the target domain is the retrieval cue, and the electrons must exist on the outside. We will activate automatic memory to retrieve the object attributes, in addition to their relations with the solar system that are familiar to us.

Table 3 A model of greenhouse effects on global warming

Sequences	Sub-sequences		Greenhouse system (Base Domain)	Global warming (Target Domain)
(a).Understanding base domain, to explain target domain	Mapping between objects of nodes based on both attributes		Panes Greenhouse inside	Greenhouse Gases Earth surface
	Retrieving Relations about base domain *First-order Relations*		Infrared radiate, Convection, Visual radiate	
(b) Transfer relations through mapping	Relations (Preservation of Relationship) *Candidate Second-Order*	Infrared radiate	Glass is opaque to infrared radiation reradiated from greenhouse inside	Greenhouse gases absorb infrared radiation reradiated upward by Earth's surface
		Convection	A nursery greenhouse blocks natural convection, between greenhouse inside and surrounds	Greenhouse gases blocks convection of Earth's atmosphere
		Solar visual radiate	greenhouse inside absorbs Solar visual radiation from the Sun because of Glass transmits incoming visual ray of sunlight	Earth surface absorbs Solar visual radiation from the sun because of Greenhouse gases' transparency to visible solar radiation
	Relations chain (systematicity principle) *Second-order*	Causal relations chain	Cause (Solar visual radiate) Results (Infrared radiate) Relation which Greenhouse gases blocks convection of Earth's atmosphere is non-preserved	
	Abstraction	Concepts, laws, theories	Heat energy transfer (Blanket)	Heat energy (slowing)
(c) Restructuring a target domain through a kind of evaluation	Restructuring, and Learning	Check		Relation which Greenhouse gases blocks convection of Earth's atmosphere is discard Additional attributions and relations about Heat energy slowing

In the example, retrieve one of the sun's attributes, such as "yellow," and relations with other planets, such as "hotter" and "more massive."

- In terms of the sun, establish the object *attributes*, such as "yellow," and *relations*, such as "hotter" and "massive."

Use the object attributes and relations to map the two objects, and use "more massive" to map the sun, nucleus, planet, and electrons.

- Set up the object correspondence between the two domains: the sun (i.e., the nucleus) and planet (i.e., the electron). The absolute values of "massive sun (the nucleus) and "less massive planet (the electron)" are transparent object-correspondences that promote accurate mapping.

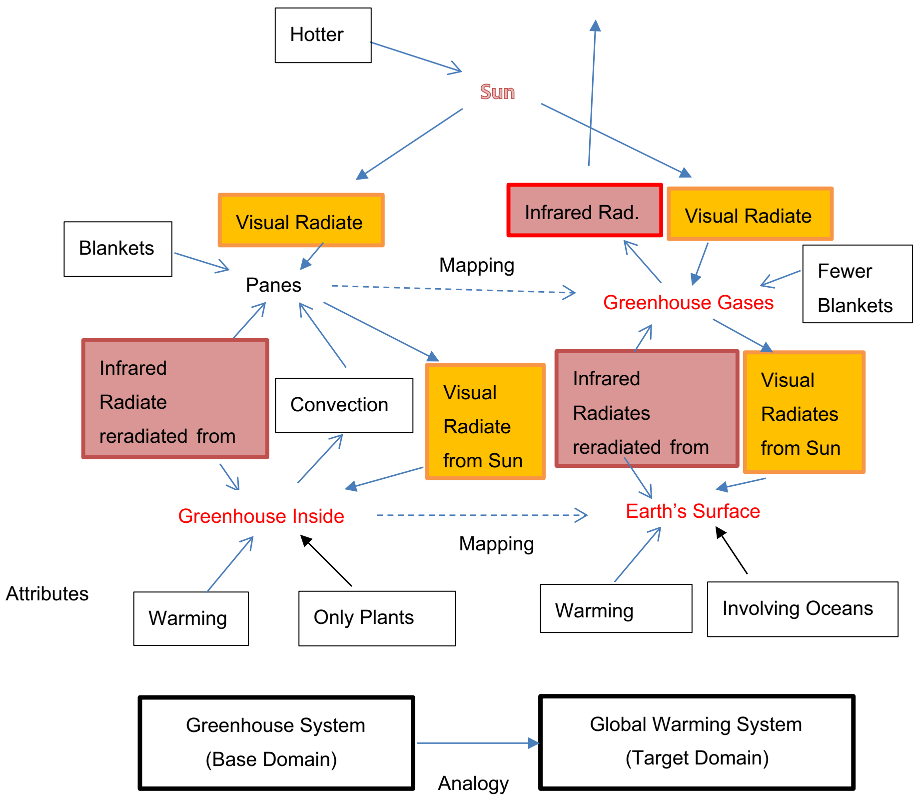

Fig. 2 Structure-map for the analogy: "Global warming is like the greenhouse effect"

(b) Transfer relations from objects in a base domain to objects in a target domain through mapping

Identify relations between the target and base domains, then map similarities between the target and base domains.

Analogy: A large number of relations, but few attributes, are mapped. An analogy is a mapping of relations from objects in a base domain onto objects in a target domain.

For this step, the systematicity principle prefers the relation of commonality in two domains according to preserving relationships, rather than being alone in a single domain. It is possible to align the relation that one is already aware of, and then align by inferring to find a new relation. However, since the relation is aligned through inference according to the purpose of the target domain, this relation is dynamic.

2.3 Alignment

In an analogy, the two situations being compared can be aligned on the basis of a common relational structure.

According to **the rule of preserving a relationship**, one must first discard object descriptions and only correspond with relational structures. In essence, check whether the relations in the base domain are transferred to the target domain and are preserved as relations. These connections have upgraded their order, versus the relations in a single domain. Discard the relations of the base domain with a low order where relationships are not preserved. Gentner (1983), in particular, has emphasized the importance of consistent structural correspondences (**Structural Consistency**) as a criterion satisfying analogical mapping for the rule of preserving a relationship. However, this study refers to the relations that are considered to be "*candidate second-order relations*" to preserve as many relationships as possible in that stage.

In the example, select only the attribute of "yellow," which is the attribute of the sun, as well as its relations, such as "hotter" and "massive."

- Discard object *attributes* such as surface similarity (Vosniadou, 2008) and non-relations such as "yellow" (the sun), then select *relation*s such as "hotter" and "massive."

The selected relations of the base domain are transferred into the relations of the target domain. However, according to the purpose of the target domain, only "massive" is mapped.

- Map base relations such as "more massive than" (sun, planet) to the target domain: "more massive than" (nucleus, electron). [Salient similarity (Vosniadou, 2008), first-order predicates (Gentner 1983)].
- According to the **systematicity principle**, it is necessary to check the causal relations of the base domain to establish a higher-order relationship in the target domain. In addition, it is necessary to correspond the relations (causal chains) in the base domain with the relations (causal chains) in the target domain, thereby transferring the abstract concept, which is the root cause of them. This study refers to this relation as a "*second-order relations*."

Discard or postpone "hotter," which is an isolated relation in the base domain, according to the systematicity principle via the goal.

- Observe systematicity: that is, discard isolated *relations*, such as"hotter than" (sun, planet), and keep systems of relations that are governed by higher-order constraining relations, which themselves can be mapped.

According to the analogical goal, causal relations can be used as an important strategy in inference, and have the benefit of transferring all necessary relations in the base domain.

CAUSE [ATTRACTS (sun, planet) and (Planet, Sun)] and (MORE-MASSIVE-THAN (sun, planet), REVOLVE-AROUND (planet, sun)]. (Additional material provided by this research) [Second- order Predicates, (Gentner 1983)].

2.4 Inference

Analogies permit us to draw new *inferences* about the target. Indeed, one major reason we use analog is to learn something new about the target domain by using our knowledge of a relationally similar base domain.

Once the base and target have been aligned and their common relational structure found, if there are additional parts of the relational pattern in the base that are not present in the target, then this missing pattern will be brought over as a candidate inference. Thus, one way to perceive generating inferences is as a process of *relational pattern completion*.

The relations left in the previous base domain in this step are treated as candidate inferences because "hotter," which is checked or deferred, can be reconfirmed from the goal and saved or newly adopted. However, it is directly connected to evaluation, which is the connection of the structural relation.

Another benefit of analogy is ***abstraction***: that is, we may derive a better understanding based on abstracting the common relational pattern. The transference of such an abstract concept is the ultimate aim of transferring goal-oriented causal relations. There is transference of the central force, such as universal gravitation (an abstract notion), to another central force, such as an electric one.

Abstraction: the base domain is an abstract relational structure.

(In the example, the hydrogen atom is a central force system based on the solar system).

(c) Restructuring and learning a target domain through evaluation. Indicate where the analog breaks down, and then draw conclusions.

We claim that it is necessary to inspect the structural soundness of causal relations, which is the first aspect to be considered in the target domain, and modify or add superficial similarities. This is in addition to the factual correctness and relevance, which are not connected with the base and target domains.

2.4.1 Structural Soundness

Restructuring is the process of a large-scale rearrangement of the target domain's elements to form a new, coherent explanation. This rearrangement can take the form of adding or deleting causal links in the target domain, as well as altering specific concepts (Gentner et al. 1997).

2.4.2 Factual Correctness and Relevance

In the example, "hotter," which was already considered in the previous step, is not considered. This relation's generality is too narrow, with no link to the abstract concept of central force (which is an important goal of the target domain, and thus has a soundness issue). In addition, there is actually no relation in which the nucleus is hotter than the electrons. It is an important element in which preservation is not transferred to the target domain.

Moreover, among the object attributes, the solar system model that is the base domain does not consider other types of mass; yet in the target domain, the nucleus of the hydrogen atom includes an electric charge (which has a different property) in order to apply the abstract concept of electric power. In essence, attributes for which the analogy is not valid must be clearly presented. This must lead to a conceptual change into the new scientific concept of the target domain. Ultimately, during learning, the cognitive structure of the base becomes sophisticated, or a new cognitive structure is formed; in the natural sciences, the existing paradigm is expanded or a new one is established.

3 The Greenhouse Effects of Global Warming

3.1 Understanding a Base Domain to explain a New Target Domain. Introduce a Target Domain, and then Cue the Retrieval of the Base (analog) Domain

The object attributes and structural relations: in the target domain, activate working memory (WM) to retrieve the greenhouse attributes and their relations familiar to us, according to the purpose that the entire Earth is warmed by the atmosphere; the purpose derives from long-term memory (LTM).

Retrieve greenhouse attributes (such as "blanket") and energy transfer relations between the inside and outside panes of the greenhouse (such as "radiate" and "convection") according to the purpose of the target domain, which is the retrieval cue.

- Establish the object *attributes* such as "blanket" and *relations* such as "radiate" and "convective" (panes). *First order relations.*

Map the two objects using their attributes and relations, and first map them by using the attribute that is most suitable for the goal of warming panes and greenhouse gases.

- Establish the object correspondence between the two domains: panes-greenhouse gases and the inside of the greenhouse-Earth's surface.

The blanket functions of the panes–greenhouse gases and planet-electron are transparent object-correspondences that promote accurate mapping.

3.2 Transfer Relations from Objects in a Base Domain to Objects in a Target Domain Through Mapping

Analogy: A large number of relations, but few attributes, are mapped. An analogy is a mapping of relations from objects in a base domain to objects in a target domain.

Discard attributes such as "blanket" (greenhouse panes), and only select relations such as "infrared radiate," "convection," and "visual radiate."

- Discard object *attributes* (i.e.,"surface similarity": Vosniadou, 2008), such as "blanket" (panes), then select relations such as "infrared radiate," "convection," and "visual radiate."

The selected relations of the base domain are transferred to relations in the target domain. However, "radiate" and "convection" are mostly transferred according to the purpose.

- Map base relations such as "radiate" and "convection" (the inside of the greenhouse-panes) to the target domain. "Radiate" and "convection," (the Earth's surface and the inside of the greenhouse) are candidate second-order relations. This study refers to the relations that are considered as "*candidate second-order relations*" because of the preservation of as many relations as far as possible in this stage.

For this step, according to the systematicity principle (which prefers the common relations in two domains, rather than an isolated relation in a single domain, owing to the rule of preserving the relationship), it is possible to first align the relation you know, then form more alignments after making inferences to find a new relation. However, this relation is dynamic because it is aligned by inferring according to the purpose of the target domain.

Discard or postpone the isolated relations in the base, such as "convection," according to the systematicity principle in pursuit of the goal.

- Observe systematicity: that is, discard isolated relations, such as "convection" (the inside of the greenhouse, panes), and keep systems of relations that are governed by higher-order constraining relations, which themselves can be mapped. Here, the mappable system is:

CAUSE [Visual Radiate (Sun, Greenhouse inside) and (Sun, Earth's Surface)],Infrared Radiate (Greenhouse gases, Earth's surface)]. (*Second-order relations*).

Convection, which is not transferred from the base domain to the target domain, is excluded from the causal chain, and thus remains in an extremely low dimension. However, it is necessary to check it in the restructuring step of the target domain.

Abstraction—the base domain is an abstract relational structure.

(Global warming is a heat energy transfer system based on greenhouse effects).

Keep the windows of your glass greenhouse closed tightly in the bright sun on a hot day. The temperature of the air inside the greenhouse soon climbs significantly higher than the outside air temperature. This is the greenhouse effect. There are two things we need to know in order to understand the greenhouse effect. All things radiate, and the wavelength of radiation depends on the temperature of the object emitting the radiation; high-temperature objects radiate the short waves of low-temperature objects, which radiate long waves. The transparency of such as the air, glass, or water depends on the wavelength of radiation. Air is transparent to both infrared waves and visible waves, unless there are nominal amounts of CO_2 in it, in which case it is opaque to infrared. Glass is transparent to the radiations that make up visible light (one direction is shown in Fig. 2), but is opaque to infrared waves (expanded in two directions).

Why does the greenhouse become so hot in bright sunlight? Because the temperature of the sun is very high. This means the waves it emits are very short. These short waves easily pass through both the Earth's atmosphere and the glass windows of the greenhouse. Thus, energy from the sun penetrates the greenhouse's interior, where, except for reflection, the energy is absorbed. The interior of the greenhouse consequently warms up. Like the sun, the greenhouse emits its own waves, but unlike the sun, its waves are longer. This is because its temperature is lower. The reradiated long waves encounter opaque glass windows. Thus, reradiated energy remains in the greenhouse, which grows increasingly warmer. Regardless of how hot as the interior becomes, it will not become hot enough to emit waves that can pass through its panes.

A similar phenomenon occurs in the Earth's atmosphere, which is transparent to solar visual radiation (i.e., that which first visually radiates from the sun). The Earth's surface absorbs this energy (which then visually radiates from greenhouse gases), and reradiates part of this longer wavelength (infrared energy radiates from the Earth's surface to atmospheric gases). Atmospheric gases (mainly carbon dioxide and water vapor) are absorbed and re-emitted; they cannot escape the Earth's atmosphere, and they consequently warm the Earth (infrared radiation). This process is essential for humans and most other living species, for the Earth would otherwise be a frigid -18 °C. Our present environmental concern is that increased levels of carbon dioxide and other atmospheric gases in the atmosphere will make the Earth too warm.

However, in the greenhouse system, heating mainly occurs due to the ability of glass to prevent convention currents from mixing the cooler outside air with the warmer inside air. Thus, the greenhouse effect plays a bigger role in warming the Earth than it does in the warming of greenhouses (see Fig. 2).

3.3 Restructuring and Learning a Target Domain Through Evaluation

We claim that it is necessary to modify or add superficial similarities, in addition to the causal relations that must be considered in the target domain.

3.3.1 Structural Soundness and Relevance

Of course, greenhouse gases do not play a role in the forced convection that occurs inside the greenhouse, which was considered in the previous step. This relation is an important one because preservation is not transferred. This is because convection, which is an energy transfer method inside the greenhouse, is not natural but rather is forced; thus, it is excluded from the role of greenhouse gases in relation to the Earth, thereby violating structural soundness.

3.4 Factual Correctness and Relevance

Moreover, according to the abstract concept of solar energy transfer, new relations (such as saving solar energy from the oceans and the emission of infrared rays above the surface) are considered, as well as clouds, glaciers, and latent heat.

In addition, property attributes such as greenhouse panes play an important role in terms of blocking energy from leaving the greenhouse; yet greenhouse gases play a bigger role in delaying the release of, rather than preserving, energy. Without a roof on the greenhouse, there is no energy blocking effect; thus, the temperature drops immediately. Accordingly, one may think that there would be an immediate transformation if greenhouse gases are not emitted.

As the opacity of greenhouse panes throughout the greenhouse gradually increases, the temperature inside the greenhouse also rises. As such, we know that greenhouse gas emissions, which occur due to human economic activities, make the Earth increasingly warmer. During learning, the existing cognitive structure can be expanded, rising to a higher dimension of cognitive structure. In the natural sciences, one can better understand global warming in terms of a paradigm.

A nursery greenhouse works via two mechanisms (Bell 2007, p. 71):

First, glass transmits incoming, visible wave-lengths of sunlight, but is opaque to longer-wavelength, infrared (heat) radiation. Thus, the glass admits more radiation than it allows to escape. In this sense, a nursery greenhouse is somewhat analogous to the atmosphere. The principal components of air (nitrogen and oxygen) transmit most sunlight down to the Earth's surface, but trace amounts of greenhouse gases (such as carbon dioxide, water vapor, and methane) absorb most of the longer-wavelengths that are reradiated upward by the Earth's surface.

Second, a nursery greenhouse blocks natural convection and its glass structure physically traps warm air, which readily escapes if a panel is opened in the roof. In this sense, the greenhouse analogy breaks down, because the so-called greenhouse gases do not block convection in the Earth's atmosphere. Indeed, atmosphere convection carries both sensible warmth and latent heat from the Earth's equator to its poles.

The idea that heat is a material-like, physical object is also intrinsic to the greenhouse metaphor. A greenhouse keeps its interior warm by preventing heat from leaving through thermal convection; that is, via the transfer of heat by the actual movement of warmed air. When air is warmed, it expands and rises, carrying thermal energy with it. What happens inside a greenhouse is a mechanical process, in which heat is carried and dispersed by observable movements of air. When we analyze thermal convection within a greenhouse, we focus on the movement of air, a three-dimensional object that inherits many properties of various materials. Thus, when we discuss thermal transfer within a greenhouse, it is not only appropriate, but also necessary to adopt a framework that treats the subject of analysis as a material object. In this way, the greenhouse metaphor implies an ontological assumption about the nature of heat; that is, that the subject of thermal transfer is a material-like object (Chen 2012, pp. 108–109).

4 Explanatory Mental Models of Greenhouse Effects

Regarding the mental models of most students and the public on greenhouse effects, studies in South Korea and abroad demonstrate that mental models on greenhouse effects are generally classified into 5 types. The findings are as follows.

In **Model I**, students understood the mechanism of greenhouse effects as a phenomenon in which the sun's rays or heat hit or are reflected by the atmosphere, and greenhouse gases return to the Earth (Rebich et al. 2006). Most students thought greenhouse gases only consisted of carbon dioxide.

Students in **Model II** believed that the sun's rays, heat, or energy are captured in the atmosphere, and thus increase the global temperature (Rebich et al. 2006). In essence, they considered that if the sun's rays are absorbed by the Earth, they could not then subsequently escape the Earth's atmosphere.<Incomplete process–>.

In **Model III**, according to many studies (Boyes and Stanisstreet 1997; Meira 2006; Rebich and Gautier 2005; Jeffries et al. 2001; Kwak 2004), many students asserted that the biggest factor in the greenhouse effect is the creation and loss of the ozone layer (which they perceived as heat particles containing heat, which enter the atmosphere easily if there is a hole). Students held onto some conceptual errors, such as those relating to the ozone layer or the use of unleaded petrol, regardless of their age (Boyes et al. 2004). This is similar in the case of students in California, US (Rebich et al. 2006), the UK (Boyes and Stanisstreet 1992; Boyes et al. 2004), Greece (Michail et al. 2007; Papadimitriou 2004), China (Boyes et al. 2008) and Santiago de Compostela, Spain (Meira 2006).

Students of **Models IV** and **V** did not know the mechanism of the greenhouse effect, but merely represented it through melting glaciers, factories, or pollution. This implies that students had their own interpretations of greenhouse effects, based on impressions formed via the mass media or from personal experience (Kwak 2004).

In particular, the effect of the oceans was not mentioned at all (The Ocean Project 2009). This is because, whilst warmth may flow from the sun and heat up the global atmosphere, the oceans produce cold currents and, thus, cannot warm the Earth. Students tended to perceive the warmth as actually existing heat particles that are ultimately consumed like fuel.

It will be possible to establish a foundation to promote understanding of global warming and climate change in science education if we design curricula and courses that can nurture students' scientific thinking and ability, based on their mental models of greenhouse effects (Kwak 2004; Kook 2003).

5 Discussion

Analogy and metaphors are similar but nonetheless different. An analogy involves mapping the knowledge of the base domain with that of the target domain. This mapping process makes the relations of the objects in the base domain consistent with those in the target domain (Gentner 1989). While an analogy has the clear goal of problem solving and inference, a metaphor is a more comprehensive concept that does not set its primary goal as problem solving or inference. A metaphor is intended to increase the mental imagery of the primary literal expression of language.

Such analogical reasoning is known as an important mental process for solving pending issues of daily life, specialized problems in mathematics, physics and chemistry, or creative thinking. When a new problem must be solved, people recall similar problems they have solved before, and adjust the solutions they used at the time according to the nature and features of new problems in order to solve them. An analogy addresses the issue of similarity. The process of retrieving familiar problems, mapping these familiar problems with unfamiliar ones, making inferences based on the above information, and schematic learning formed when unfamiliar problems are successfully solved represents the function of effective analogy. This is generally referred to as analogical thinking or reasoning.

Analogies are an important part of the cognitive process because they include problem solving, creativity, learning, and making inferences (Gentner 1983; Holyoak and Thagard 1996; Keane 1988). Cognitive psychological studies on analogies actively began in the 1980s, and the trend was led by researchers such as Gentner (1983), Holyoak (1985), and Keane (1988). Our study proposes an improved model of the structure mapping theory developed by Gentner (1983) and Gentner and Smith (2012). This is an important addition to the pragmatic schema model by Holyoak and Thagard (1995), which further emphasizes the purpose of analogy.

This study first uses the normal systematicity principle of analogies to explore highlighting and hiding, which inevitably occurs in explaining abstractions. This study also examines the intention of the public to highlight and preserve object attributes (which are intentionally hidden, superficial similarities), rather than the relevance between objects of the systematicity principle.

Second, this study investigates the problems of the public's mental models, which explain global warming based on the concept of energy.

5.1 Reflecting Highlighting and Hiding

5.1.1 Highlighting

<Obstinate to causal relations in the base domain according to the purpose of the systematicity principle>.

Regarding the forced convection that occurred inside the greenhouse, considered in the previous step, greenhouse gases do not in fact play such a role. Even though the convection relation in the base domain of the causal relations is transferred to the target domain, it is not supported during evaluation. However, since the base domain is a more familiar concept than the target domain for people, and they omit the evaluation step, they remember convection as a circulation of particles.<**Mental Model II**>.

5.1.2 Hiding

<Relations ignored in the base domain based on the systematicity principle>.

Since only the object relations of the basic domain are moved to the target domain according to the systematicity principle, it is difficult to consider new relations (such as storing solar energy in the ocean and emitting infrared rays above the Earth's surface). In effect, during mapping, this effect of the oceans is ignored because it is limited to the relations inside the greenhouse in the base domain. Thus, the effect of the oceans is ignored.

<The base object attributes are hidden according to the systemacity principle, but the public highlights these attributes>.

The object attributes are ignored and only relations are transferred according to the systemacity principle, but the public maintains and highlights the unique attributes of greenhouse panes in perceiving that global warming disappears immediately when there is no reflection of solar energy on greenhouse panes of the base domain, as well as that energy is ignored after a little absorption and panes.

The visible rays of solar energy, which greenhouse gases do not absorb (rather, the rays pass through the atmosphere), are the cause of heating the Earth's surface. However, the public infers that solar energy must be able to pass through the greenhouse panes, and believes that more solar energy enters by destroying the ozone layer. In essence, the attributes of greenhouse panes are hidden, but the public highlights them.**<Mental Model III>**.

In addition, property attributes such as greenhouse panes play an important role, like a blanket that blocks infrared, radiated energy that leaks out from the inside of the greenhouse, but greenhouse gases play a prominent role in delaying the emission of this energy. However, during mapping, although the object attributes are discarded and only the relations are transferred, the attributes of the base domain are nonetheless highlighted. Since people categorize greenhouse gases as naturally occurring and caused by human activities, there is an inference about global warming: this is that it has the function of warming the inside of the greenhouse by blocking the infrared radiated energy of the base domain in causal relations. Thus, if there is no roof on the greenhouse, the energy blocking effect is weakened and the temperature drops immediately: this may lead people to perceive that there would be an immediate transformation if greenhouse gases are not emitted.<**Mental Model** I>.

5.2 Concept of Energy

There is a need for a conceptual change. Rather than the psychological perspective of heat in the greenhouse effect as particles, with certain hot objects (e.g., hot molecules) directly conveying energy (a direct process) and becoming colder, it is necessary to adopt the idea that heat energy is statistically a holistic, kinetic energy. This energy comprises the many particles that form gas or other substances, while temperature is a scientific energy, with the emergent process of the average kinetic energy of those particles.<**Mental Model I, Mental Model II, Mental Model III**>.

6 Conclusion

Many researchers perceive analogies to be a double-edged sword in education or daily life, because they are accompanied not only by scientific concepts, but also alternative ideas (Niebert et al. 2012). Our research generated the following findings:

First, inferences made through analogies must reflect the greenhouse analogy, in which an inference about the target domain, made through causal relations in the base domain, is the most important. The aim is to explain goal-oriented global warming. Unfortunately, the public's knowledge is mostly focused on memorization. It is, thus, difficult to apply and store; accordingly, it is forgotten immediately and becomes an improper concept.

Second, the greenhouse analogy is highly appropriate for inducing motives and emotional perspectives, rather than a cold cognitive one; therefore, it must be actively used. This is because we are not familiar with the alternatives of atmospheric effects proposed by scholars.

Third, we must use the greenhouse analogy and yet simultaneously emphasize the relations and attributes highlighted and hidden in the analogy during evaluation. People form fallacious conceptions because this process is omitted. Furthermore, the public preserves attributes rather than simply moving the relations to another domain. For example, greenhouse panes and greenhouse gases do not always have consistent functions and attributes.

Fourth, the analogy must be actively used because it is a useful means to reach the goal in familiar domains, which may provide good motives to direct it to the public.

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Jun-Young Oh is Assistant Professor of the Hanyang University, at Seoul campus, the Republic of Korea. He received his B.A. in Science Education from Kongju National Teachers' College, South Korea, his M.S. in Astronomy from Yonsei University, South Korea, and his Ph.D. in the Philosophy of Science and Science Education from Pusan National University, His research focuses on Scientific Method based on Philosophy and History of Science, and Global Climate Change based on Analogical Reasoning, and a researcher whose research interests lie mainly in the integration between Natural Science, Science Education, and the Philosophy and History of Science.

Dr. Eui-Chan Jeon Full Professor of the Department of Environment & Energy at Sejong University, served as the Dean of External Affairs and the Dean of Graduate School. Prof. Jeon obtained his Ph.D. of Environmental Management from Seoul National University in 1996. He served as the president of the Korean Society of Climate Change Research (2014) and the president of Korean Society of Atmospheric Environment (2011). Also, he was a co-president of National Assembly Climate Change Forum, and is charged to the Social Administrative Committee chair of the Regulatory Reform Committee, the chair of Climate Change Division of the National Committee on Green Growth and the vice president of Korean Academy of Environment Science.