# AN EXPLORATORY STUDY ON
# THE COMPONENTS AND PROCESS OF
# LEARNER-GENERATED VISUAL ANALOGY

**By**

**SEOYON HONG**

Master's Thesis

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Major: Educational Technology

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# ABSTRACT

An Exploratory Study on the Components and Process of
Learner-generated Visual Analogy

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The ability to reason by analogy is an important feature of human cognition and creativity, which is pervasively used in both everyday life and expert thinking. In education, analogies are used to introduce a new concept by associating it with what learners already know. Previous research on instructional analogies has shown their positive effects on learning, and has hence proposed instructional models that incorporate them in teaching, such as Teaching With Analogies Model by Glynn (1989) and the General Model of Analogy Teaching by Zeitoun (1984). While valuable, this type of research only posits limited insight on how learners generate analogies and how they perceive the use of a visual analogy. Thus, the depth of insight into instructional strategies for effective and engaging activities is also limited.

The purpose of this study was to understand how learners generate visual analogies and perceive the use of visual analogies in learning by using think-aloud protocol analysis, visual task analysis, interview and survey. Four learners participated in this study to generate their own visual analogies about chemical bonding while thinking aloud. The collected protocol and visualization data were analyzed using the coding scheme developed from literature review.

The results showed that the learners were engaged in six stages: planning, understanding concept, searching for visual analogy, elaborating on visual analogy, matching, and monitoring. They spent the majority of time to understand the presented concept and to elaborate on their visual analogies. In *understanding concept*, the learners reread the excerpt, identified critical attributes, and compared attributes. In *elaborating on visual analogy*, they described and modified visual analogies. Nevertheless, the learners were hardly engaged in evaluating the limitations of their final visual analogy. In terms of visualization, the learners consistently used the following five types of visualization: simple, selective, appendant, conceptual and strategic visualizing. Moreover, the learners perceived the use of visual analogy as helpful for understanding the learning content and also enjoyable. Yet they found it challenging to come up with their own analogy.

Based on the findings, the following implications can be drawn. First, the process of generating visual analogy is not necessarily supported by visual cues. In this study, the learners tended to use verbs as cues to come up with analogies, which implies providing various verbal and visual cues for learners to facilitate the generation process when using learner-generated visual analogies. Second, the learners' minimal engagement in evaluating their visual analogies may explain the possible misconception caused by analogies, which thus suggests the need for providing feedback. Third, the use of learner-generated visual analogy is used as a tool for understanding abstract concept not only by associating it with a familiar concept, but also by selectively attending to the critical attributes of the concept learnt. Finally, the task of generating a visual analogy encourages visualization of both the analogy itself as well as the learning content, which can support learning.

Keyword: *visual analogy, learner-generated visual analogy, analogical reasoning, human visual intelligence*

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# I. INTRODUCTION

## 1. Background of the Study

Learning is largely associated with understanding a concept because concepts play essential roles in human reasoning (Jonassen, 2006). Concept learning serves as a foundation for principle and procedure learning as well as for higher order thinking (Gagné, 1968; Jonassen, 2006; Lim, 2012). Recognizing such importance of concept acquisition, educational researchers have explored various ways to introduce new concepts and to facilitate more effective concept learning. Some examples of these instructional strategies include providing an advance organizer, constructing a concept map, and presenting example and non-example cases (Ausubel, 1977; Driscoll, 2005; Merrill, 1983; Novak & Cañas, 2006).

In particular, Ausubel (1977) emphasized the importance of relating a newly learned concept to what learners already know, distinguishing meaningful learning from rote learning (Ausubel, 1977; Driscoll, 2005). To help learners connect the new concept and their prior knowledge, Ausubel suggested the use of advance organizer and anchoring idea. An advance organizer used at the beginning of learning activates learners' prior knowledge and presents a framework of materials to be learned. An anchoring idea refers to the specific, relevant idea already stored in learners' cognitive structure and it provides the entry points for new information to be connected (Driscoll, 2005). By suggesting these instructional strategies, Ausubel (1977) highlighted the importance of connecting the learning content to learners' prior knowledge in concept learning.

In a similar way, Reigeluth (1999) suggested the use of instructional analogies as to bridge the newly learned concept to the familiar concept. An analogy can be defined as "an explicit, non-literal comparison between two objects that describes their structural, functional, and/or causal similarities" (Gentner, 1983; Newby, Ertmer, & Stepich, 1995). Indicating a comparison between two objects, an analogy consists of the following form: "X is like, may be compared to, resembles, or works like Y" (Stepich & Newby, 1988a). In teaching-learning context, analogies have largely been used as explanatory devices or as discovery tools (Harrison & Treagust, 1993). The instructional analogy serves as a bridge between the new concept, also referred to as the target concept, and the familiar concept in learners' prior knowledge (Gentner, 1983). For instance, in explaining the structure of a cell structure, an instructor can use an analogy of a city and relate each component in the cell to the attributes of a city. The cell wall may be associated with the city border, the water vacuole with the water dam, and the atom with the government of the city.

The findings from previous research have demonstrated the effects of instructional analogies in enhancing conceptual understanding, retention, application of a new concept and motivation. Newby et al. (1995) conducted the experimental studies to examine the immediate and delayed effects of instructional analogy on learning physiological concepts. The results showed that the college students who received the instruction with the analogy performed significantly better than those who did not receive the analogy, both immediately and after a delayed time. Harrison and Treagust (1993) also found that using analogies which are familiar to learners and represent the shared attributes precisely can promote conceptual understanding. Furthermore, Venville and Treagust (1996) identified the key roles of analogies in conceptual change as a sense maker, a memory aid, a transformer, and a motivator.

The term analogical reasoning is used to describe the cognitive process of producing and interpreting an analogy. It involves the transfer of structural or relational information from the analogy to the target (Vosniadou & Ortony, 1989). Regardless of how remote the analogy and the target are, successful analogical reasoning depends upon the capability to perceive similarities and differences (Vosniadou & Ortony, 1989). When integrated in instruction, analogical reasoning requires learners to think about similarities and differences between the newly learned concept and their prior knowledge as well as integrate the new concepts into the existing schema.

Analogies can be delivered verbally, visually or using both verbal and visual representations. A verbal analogy is an analogy explained in written or spoken language whereas a visual analogy, also named a pictorial analogy, is presented in forms of a diagram or a picture. The studies that compare the effects of verbal analogy and visual analogy have shown the effectiveness of visual analogy in learning complex concepts (Noh, Yang, & Kang, 2010). This is because visual analogies convey the relation between the target concept and the analog more clearly (Bean, Searles, Singer, & Cowen, 1990). Furthermore, Curtis and Reigeluth (1984) explained that the use of analogy leads to recognize a relationship in terms of a visual while comparing and contrasting two concepts from different domains. This implies that analogies may cause visual thinking. Therefore, visual analogy which overtly depicts the relation between the target concept and the source concept can support conceptual understanding.

Among other determinants of the effectiveness of instructional analogies, research findings reveal that the familiarity of the analogies is crucial (Choi, 2012). To maximize the familiarity of the analogies, learner-generated analogies have been examined for their influence on learning (Noh et al., 2010). For instance, Lee, Kim, and Kim (2003) compared the effects of analogies generated by text developer, by instructor, and by students. The results showed that the student-generated analogies were more effective for simple concept learning, while the instructor-generated analogies were more effective in conveying complicated concepts. Since the essence of analogy is the comparison between the familiar concept and the unfamiliar concept, the learning effectiveness of analogy depends on how familiar the learners are with the analogy used. Therefore, if learners were to generate an analogy for themselves instead of being given an instructor-generated analogy, learners will be inclined to use familiar concepts which can thus promote conceptual understanding (Wong, 1993).

According to Noh et al. (2010), self-generated visual analogies were perceived as helpful to understand scientific concepts, to improve creative thinking, and to increase motivation and interest in science. Being given the opportunity to develop their own analogies, learners reported that they were able to translate the scientific concepts into familiar language. Compared to other types of learning activities, self-generated visual analogies were perceived as stimulating creativity more because the learners needed to make a comparison across seemingly unrelated concepts. Lastly, the learners felt that the process of analogy generation increased motivation since it was novel and interesting experience (Noh et al., 2010).

In addition, Wong (1993) conducted a qualitative study to examine the effects of learner-generated analogies as a learning task. He viewed the process of creating an analogy as a problem solving task, and thus, designed an analogy task according to the literature on analogical reasoning models and problem solving. The results showed that the use of learner-generated analogies not only enhanced the understanding of a scientific phenomenon, but also enabled the learners to correct misconceptions by validating the accuracy of their own analogies. Furthermore, Glynn (2007) also insisted that even when instructors provide an analogy, it may be helpful to ask learner to create their own analogies to verify that learners have not formed misconceptions.

While several researchers have proposed instructional models for instructors to incorporate verbal and visual analogies in teaching (Brown & Clement, 1989; Glynn, 1991; Kim, 1991; Zeitoun, 1984), there has been relatively little research on learner-generated visual analogies. Consequently, there is a need to develop a set of strategies to support learner-generated visual analogies for effective learning. Previous research on instructional models for instructors provide only limited insight on how learners generated analogies and how they perceive the use of visual analogies. The question of whether the process of learner-generated visual analogy differs from the process of analogical reasoning proposed by previous research is valuable to ask. Moreover, there is also a need to understand what difficulties the learners experience while generating a visual analogy.

Therefore, the purpose of this study was to examine the components and the process as well as the learner perception of learner-generated visual analogy in concept learning. Based on the results of this study, the process of learner-generated visual analogy, the role of learner-generated analogy in learning and the instructional implications were discussed.

## 2. Research Questions

The purpose of this exploratory study was to examine the components and the process of learner-generated visual analogy as well as the learner perception of the use of visual analogy. The components and the process of learner-generated visual analogy were examined by using think aloud method and protocol analysis. The learner perception was examined by the interview and the survey questionnaire. For these purposes, the following research questions were investigated in this study.

1. What are the components and process of generating a visual analogy by learners?

2. How do learners perceive the use of learner-generated visual analogy as learning activity?

# 3. Definition of Terms

## 3.1 Concept Learning

Concepts are "representations of classes of objects, symbols, or events" that share common properties or attributes (Jonassen, 2006; Merrill, 1983). Bruner, Goodnow, and Austin (1967) defined concept learning as "the search for and listing of attributes that can be used to distinguish exemplars from non-exemplars of various categories". Concept learning in this study refers to learning not only the attributes of concepts, but also relationships among concepts (Jonassen, 2006).

## 3.2 Analogy

An analogy is defined as "an explicit comparison between two objects that describes their structural, functional, and/or causal similarities" (Gentner, 1983; Newby et al., 1995). An analogy consists of a target, an analog, and a connector (Gentner, 1983; Stepich & Newby, 1988b). In educational context, an analogy is used to introduce an unfamiliar concept by relating to a concept already familiar to learners. Hence, a target refers to the concept to be learned. An analogy is a familiar concept that learners already know. A connector reflects the relation between the target and the analog. Sometimes, more detailed explanations regarding both similarities and differences between the target and the analog may also be provided.

## 3.3 Learner-generated Visual Analogy

A learner-generated visual analogy in this study refers to an analogy that is formulated by learners and expressed mainly in visual form. It may be accompanied by labels and supplementary explanations in text, but the main mode of representation is visual. A learner-generated visual analogy contains the three elements of an analogy aforementioned (Gentner, 1983; Wong, 1993).

# II. LITERATURE REVIEW

## 1. Analogy

### 1.1 The Use of Analogies in Learning

In discussing the use and effects of analogy in learning, it is necessary to first review the definition of an analogy. Gentner (1983) defined an analogy as “an assertion that a relational structure that normally applies in one domain can be applied in another domain”. He also distinguished an analogy from other kinds of domain comparisons (Gentner, 1983). The four types of domain comparisons are literal similarity, analogy, abstraction, and anomaly. To understand the difference between each type of domain comparisons, a few preliminaries are necessary. First, there is an object-attribute shared between the target and the source. These object attributes include structural characteristics like color, size and shape. Then, there is relational predicate which is relations between objects. Let us take an atom and solar system for instance. The comparison of round shapes between an atom and the sun is shared object attributes. That the electron revolves around the nucleus like the plants do around the sun points to relational predicate.

The degree of attributional similarity and relational similarity between the source and the target differentiates each type of domain comparisons as shown in Figure II-1. According to Gentner and Markman (1997), *analogy* exhibits a high degree of relational similarity with little attribute similarity. At the opposite end of analogy is *mere-appearance* which exhibits a high degree of attribute similarity, but no relational similarity. *Anomaly* shares neither significant attribute nor relational similarities. *Metaphor* covers a wide range from relational comparisons to attribute comparisons.

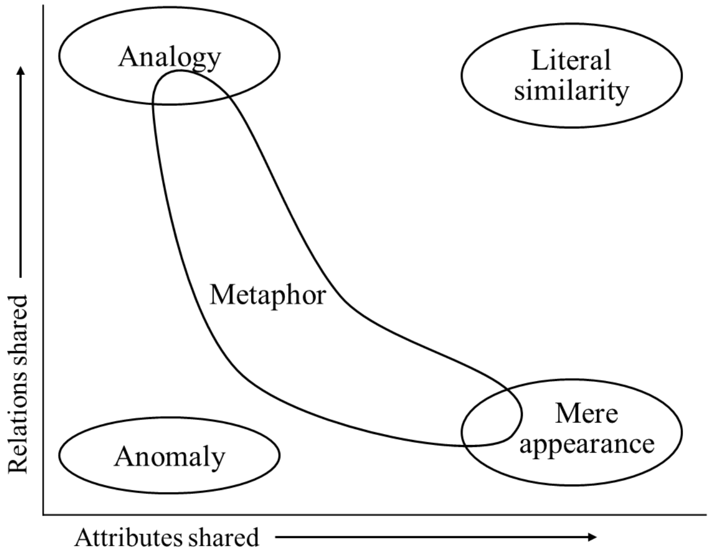



Figure II-1. Similarity Space (Gentner & Markman, 1997)

In teaching-learning context, analogies have largely been used as explanatory devices or as discovery tools by bridging a familiar concept and an unfamiliar concept (Gentner & Toupin, 1986; Harrison & Treagust, 1993). A familiar concept is what learners already know, also referred to as the source, the base domain, or schema already existing in memory (Vosniadou & Ortony, 1989). It serves as the analogy to which similarities and differences are transferred (Gentner, 1983). An unfamiliar concept is what learners need to learn, mostly called the target concept (Gentner, 1983). Many learning theories, such as

Ausubel's meaningful learning, constructivist learning theory, and Piaget's assimilation and accommodation, demonstrate the importance of creating connections between the new information and pre-existing knowledge (Pittman, 1999). And analogies act as cues to stimulate such connection.

In particular, the use of instructional analogies has been pervasive in science education because science is rich with concepts that are abstract and cannot directly be observed by senses (Vosniadou & Ortony, 1989). Analogies can help understanding concepts by visualizing the abstract concepts and by comparing the concept to the similarities of learner's real world (Duit, 1991; Thiele & Treagust, 1994). Curtis and Reigeluth (1984) analyzed analogies used in science textbooks, and concluded that analogies were most useful for complex and difficult concepts. They found that analogies based on structural relationship were used for easier, more concrete concepts while analogies based on functional relationship were used for more difficult and abstract concepts (Curtis & Reigeluth, 1984). Newby et al. (1995) conducted the experimental studies to examine the immediate and delayed effects of instructional analogy on learning physiological concepts. The control group received instruction without analogy while the experimental group received instruction with analogy. The results showed that college students who received instruction with analogy performed significantly better than those who did not receive analogy.

More recently, with the increased focus on constructive learner-centered learning, learner-generated analogies have been examined. Pittman (1999) insisted that the use of analogy may fail if the learners do not understand the analogy itself. Lee et al. (2003) examined the effect of analogies generated by textbook developers, instructors and learners. In this study, the analogies were either presented by the textbook developers or the instructors or generated by the learners in learning the concept of plate tectonics. The results showed that the instruction using the student-generated analogies was more effective than when the analogies were presented by textbook developers and instructors. However, the learners perceived that the analogies generated by textbook developers were more accurate than those generated by themselves. As evident in this study, the learner-generated analogy has shown to support learning.

### 1.2 Classifications of Analogy

Instructional analogies can be classified into various categories. In fact, several researchers have analyzed analogies used in instruction and in textbooks and attempted to present classification schemes of analogies (W. H. Choi, 2012; Curtis & Reigeluth, 1984; Pae & Chung, 2006; Thiele & Treagust, 1994; Venville & Treagust, 1996). Table II-1 summarized these classifications.

Analogical relationship refers to the nature of relationship between the target concept and the analog. The analogous relationship can be structural, functional, or both structural-functional. The presentation format refers to how the analogy is expressed verbally or visually. The condition of analogy refers to the content of the target concept and the analogy, and can be divided into three categories: concrete-concrete, abstract-abstract, and concrete-abstract. The position of analogy is the placement of analogy in terms of when the analogy is introduced to learners. Analogies can be introduced at the beginning of instruction, during the instruction and at the end of instruction. The level of enrichment is determined by how much explanation is presented. A simple analogy contains the target, the analog and the connector, whereas an enriched analogy states both the grounds for and the limitations of analogous relationship. The different roles of analogies identified by the educational researchers include a sense maker, a memory aid, a transformer, and a motivator.

Table II-1. Analogy Classification Schemes

| Curtis & Reigeluth (1984) | Thiele & Treagust (1994) | Venville & Treagust (1996) | Choi (2003) | Pae & Chung (2006) |
|---|---|---|---|---|
| Analogical relationship | | | Analogical relationship | |
| Presentation format | Format | | | Presentation |
| Condition | | | Condition | Condition |
| Position | | | | Placement |
| Level of enrichment | Level of enrichment | | Level of enrichment | Level of enrichment |
| | Analog explanation | | Description | Explanation |
| | Limitation | | | Limitation |
| | | Role of analogy | | Role of analogy |
| | | | Systemicity | |
| | | | Source of analogy | |

## 1.3 Visual Analogy

There are two major ways to communicate an analogy: verbal representation and visual representation. Visual analogies are also called pictorial analogies or graphic analogies (Issing, 1990; Spezzini, 2010). Previous studies have shown the effects of combining verbal and visual analogies. Verbal analogies stimulate learners to visualize an obscure, abstract concept (Bean et al., 1990). However, the shortcomings of verbal analogies are that the learners need to read and interpret the verbal description of the analogies, drawing the analogies in their mind. Depending on the learners' visual tendency and knowledge of the analogy content, they may not be able to visualize the analogy as intended, which can lead to misconception. In contrast, visual analogies can help learners' visualization by explicitly presenting the analogy and thus, enhance learners' understanding of a concept (Bean et al.,1990; Schwartz, 1993). They are, in other words, short-cuts to direct comparisons (Spezzini, 2010). Therefore, the visual analogies facilitate the visualization of verbally communicated analogies as well as restrict learners' arbitrary visualization, supporting more accurate comprehension of the analogy presented to the learners (Kim, 1991)

Researching findings have shown the effects of visual analogies in learning. Issing (1990) investigated the effects of visual analogies in a physics course. The results showed that the visual analogies supported learners' understanding of structural and functional concepts. Moreover, Salih (2008) also recommended the use of visual representation of the analogy, the target concept or both to assist the analogical reasoning and understanding. Sometimes, analogies may be represented both verbally and visually. Bean et al. (1990) studied the effects of visual analogies in high school biology class and found that the students who received both visual and verbal analogies showed better comprehension.

# 2. Analogy-related Reasoning

## 2.1 Case-based Reasoning

Case-based reasoning (CBR) is a model for problem that draws upon past experiences of a person (Aamodt & Plaza, 1994). Although CBR is largely used to understand and perform problem-solving, it can also help to understand the process of analogical reasoning since both of these cognitive process rely on previous experience and prior knowledge. CBR model explains that a problem is solved by finding a similar past case and reusing it in the new problem situation. In fact, in order to retrieve a similar case from long term memory, one is required to make a comparison and choose the most appropriate case. Therefore, both the analogical reasoning and CBR involve similar cognitive processes of forming a connection, applying and modifying the chosen object or case. The retrieved case which is used to solve the given problem can even be treated as intra-domain analogy. In this respect, CBR and analogy can be regarded almost as synonyms, and hence the discussion of CBR is relevant to this study.

Aamodt and Plaza (1994) insist that CBR utilizes specific knowledge of previously experienced, concrete problem situations which are referred to as *cases*. A case means a problem situation in CBR; a past case denotes a previously experience situation and a new or unsolved case is a new problem. Another important aspect of CBR is that it is an approach to "incremental and sustained learning" because each time a problem has been solved a new case is retained for future problem.

The CBR cycle has four major processes of retrieving, reusing, revising and retaining (Aamodt & Plaza, 1994). First, when a new case is defined, the most similar previous case is retrieved from the case library. During this process, matching of the new problem and the past case takes place. Secondly, the solution and knowledge from the retrieved case is reused to solve the new case. Then, the process of revising the proposed solution from the retrieved case takes place by applying it to the real life situation or evaluating the outcome. If failed to solve the new case, the proposed solution is revised. Finally, the case is retained as a new learned case or as a modified case. In this process of CBR, both general and specific knowledge plays a role. While specific knowledge is represented the retrieved case, general knowledge operates to support the overall processes. Figure II-2 below demonstrates the CBR cycle.

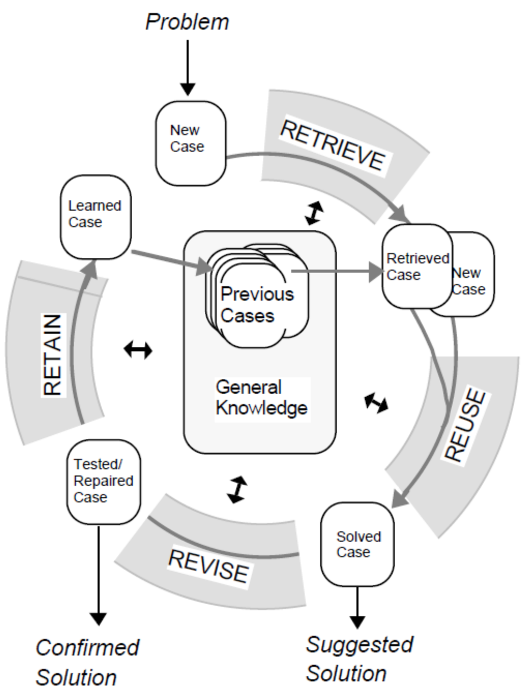



Figure II-2. Case-based Reasoning Model (Aamodt & Plaza, 1994)

So how does each process of retrieving, reusing, revising and retaining work? And what knowledge do we need in this process? To understand the CBR processes more in depth, it is necessary to look at tasks, methods employed, and knowledge needed for each process. These subordinate elements described what is required in order to practice CBR. Tasks are the goals for each process. Methods are applied to perform tasks. And to apply methods, respective knowledge is required. There may be several subtasks under the top-level task. For instance, in the retrieve process, one needs to identify relevant descriptors, search to find a past case, match the relevant descriptors to the past case and select the most similar case. The task decomposition of CBR is shown in Figure II-3. Tasks are written in bold letters, while methods are in italics. Straight lines represent the relation between tasks, and stippled lines the relation between tasks and methods.

Studies have shown empirical evidence for CBR, demonstrating the role of previous experiences in problem solving and learning. For instance, experts like fire commanders rely heavily on past experience than on abstract principles when making decisions with a high degree of uncertainty (Klein & Calderwood, 1988). Also in learning a new skill, people tend to use past experience (Aamodt & Plaza, 1994; Jonassen & Hernandez-Serrano, 2002). Recognizing such prevalent role of case, instructional designers have researched different strategies not only to engage learners' past experience in learning, but also to provide meaningful learning experience. Jonassen and Hernandez-Serrano (2002) suggested using narrative stories to offer learners indirect experiences. These stories provide much richer examples that they will serve a similar role in CBR as direct experience. Anchored instruction and goal-based scenarios also have similar approaches.

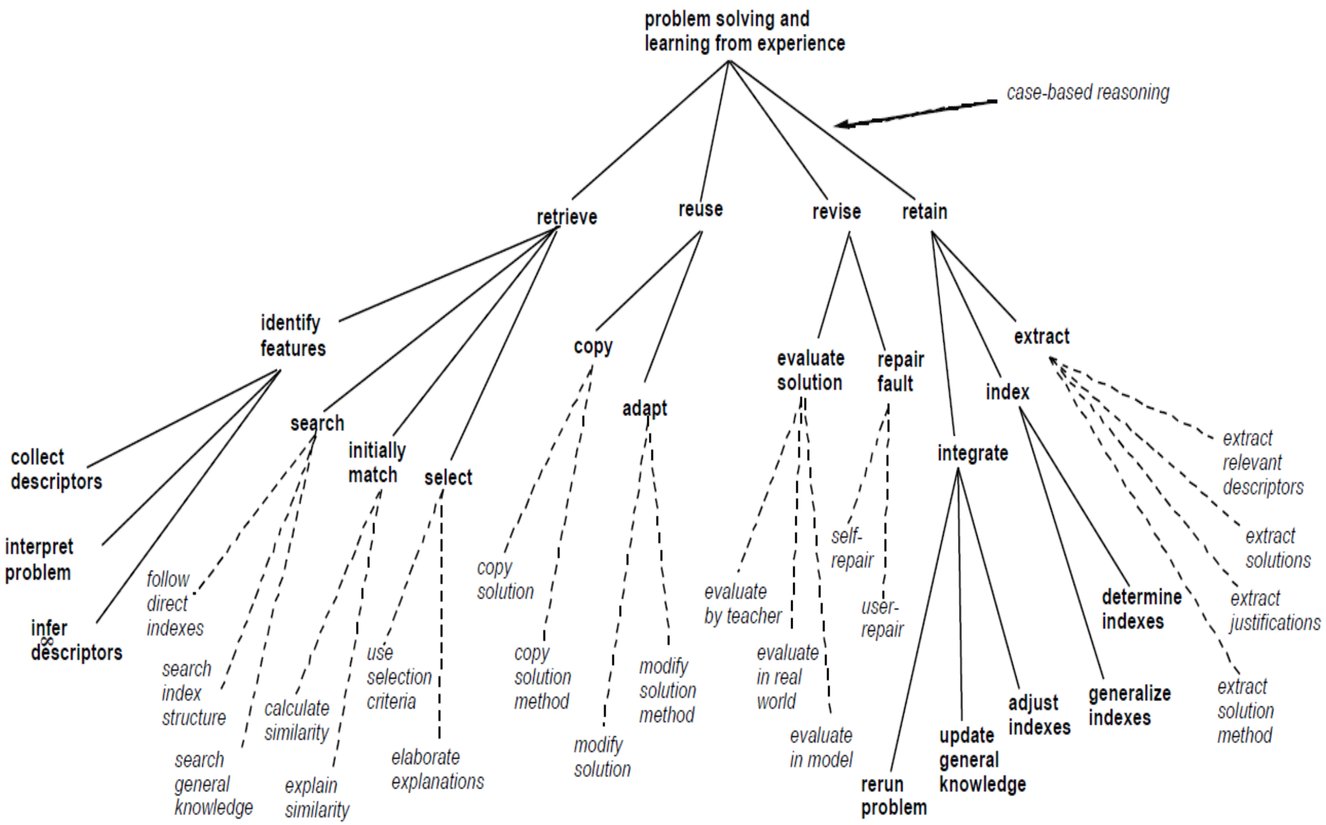



Figure II-3. Task Decomposition of CBR (Aamodt & Plaza, 1994)

## 2.2 Analogical Reasoning Models

Reasoning by analogy is pervasive in everyday way of thinking and speaking (Lakoff & Johnson, 1980; Sternberg, 1977a). When we try to explain something novel or make a decision in an unusual situation, we think based on what we know or have experienced from the past (Sternberg, 1977a). What is and what involves in such reasoning process? Rumelhart and Abrahamson (1973) distinguished analogical reasoning from remembering. In contrast to remembering which operates based on contents stored in memory, analogical reasoning operates based on the memory structure or relationships between concepts stored in memory. Therefore, following this definition of reasoning, Rumelhart and Abrahamson (1973) further explained that reasoning would involve judgment of the similarity or dissimilarity between concepts. In trying to understand the process of analogical reasoning, psychologists have presented models of analogical reasoning from different perspectives. In this section, few of these theories from information processing theory and componential theory will be briefly reviewed.

Coming from the perspective of information-processing theory, Spearman (1973) proposed three major principles (Sternberg, 1977b). These principles, in order, are apprehension of experience, eduction of relations, and eduction of correlates. The apprehension of experience involves encoding of the base concept and the presented analog. That is, the person first needs to understand basic characteristics of each. Based on such mental representation, the person then recognizes and draws out a relation between the base and the analog, inferring the relational rule between the two. According to Spearmen (1973), a relation refers to any attribute that mediates between two or more concepts. Finally, once the person recognizes the existence of relation between the base and the analog, the education of correlates takes place by applying the inferred rule to produce a new analog by associating (Sternberg, 1977b).

Shalom and Schlesinger (1972) also identified the selection rule and the connection formula in analogical reasoning (Sternberg, 1977b). The selection rule refers to the logical relationship among analogy terms. The connection formula means a particular formula employed by the individual to recognize the relationship among analogy terms. Analogical reasoning is the formation and application of the connection formula by the individual. According to Shalom and Schlesinger (1972), the person may go through a trial-and-error process before finding the final analogy.

Furthermore, Johnson (1962) insisted that analogical reasoning involves such problem-solving operations as inductive and deductive operations. During the inductive operation, the person will identify the specific attributes of the target and the analog and draw a relation between them. The deductive operation, then, corresponds to the process of applying the relation (Sternberg, 1977b).

Moreover, Sternberg (1977a, 1977b) proposed the componential theory of analogical reasoning. In this theory, the process of analogical reasoning is fragmented into three general categories under which six information-processing components exist. The three general categories of components are attribute identification, attribute comparison, and control. These components occur consecutively. The attribute identification involves forming an internal representation upon which further reasoning is based. The person first needs to identify attributes and values of the base term. The attribute comparison occurs by inferring the existence of relations, forming an analogous rule, applying the rule, and testing the validity of operations. Finally, the control component involves producing a response by identifying a new analog, and monitoring such selection. According to Sternberg (1977b), some components of analogical reasoning may repeat until the person had decided that he has reached an unique analogy solution.

Although the analogy related reasoning reviewed here stem from different theoretical background, they overlap in certain way. For instance, both Spearmen (1973) and Sternberg (1977b) recognized first understanding the base and the target term. Though being given different names, all of the aforementioned analogical reasoning models share the components of analogous relation inference and application. In general, the process of analogical reasoning seems to proceed in four major steps: encoding the target, inferring the relation, applying the relation, and responding to create an analog. In fact Sternberg (1977b) have compiled five of the analogical reasoning models to see the overlapping procedures of analogical reasoning and the resulting comparison is shown in Table II-2.

Table II-2. Literature on Analogical Reasoning (Sternberg, 1977b)

<table>
<tr><th></th><th>Johnson (1962)</th><th>Shalom & Schlesinger (1972)</th><th>Spearmen (1973)</th><th>Sternberg (1977b)</th></tr>
<tr><td>Encoding</td><td></td><td></td><td>Apprehension of experience</td><td>Attribute identification</td></tr>
<tr><td>Inference</td><td>Inductive</td><td>Forming a connection formula</td><td>Education of relations</td><td rowspan="2">Attribute comparison</td></tr>
<tr><td>Application</td><td>Deductive</td><td>Applying the connection formula</td><td>Education of correlates</td></tr>
<tr><td>Response</td><td></td><td></td><td></td><td>Control</td></tr>
</table>

## 2.3 Learner-Generated Analogical Reasoning Model

Most of analogical reasoning models examined the process of finding an analogy when given a set of the base term, the analog, and the target as they are based on an analogy test. Although it still involves formulating a new analogy, it is different from the process of learner-generated analogy in that the learner needs to establish an analogical relation on his or her own instead of having to identify and apply the relation decided externally.

Salih (2008) proposed the model of learner-generated analogical reasoning which involves three phases: reception phase, interaction phase, and emergent phase. In the reception phase, the learner is exposed to the target concept that is to be learnt, and establishes understanding of the concept. In the interaction phase, the learner tries to create an analog by repeatedly comparing and modifying it to best represent the target concept. Salih (2008) insisted that in this phase, learner's analogy generation process is affected by learners' emotion, presented stimulus, and recall. Learners need to be motivated in order to engage in analogy generation process. Stimulus refers to key words and structural features of the target concept that facilitated the generation of analogies. Recall refers to remembering the attributes of both the target and the analog concepts. Learners need to reserve the access to both of these concepts in order to generate analogies. Salih (2008) also insisted that learners will go through several steps of matching, evaluating, modifying and creating analogies until they are settled with the final analogy. In the emergent phase, the final analogy is produced and expressed either verbally or visually. Figure II-4 illustrates the self-generated analogical reasoning model.

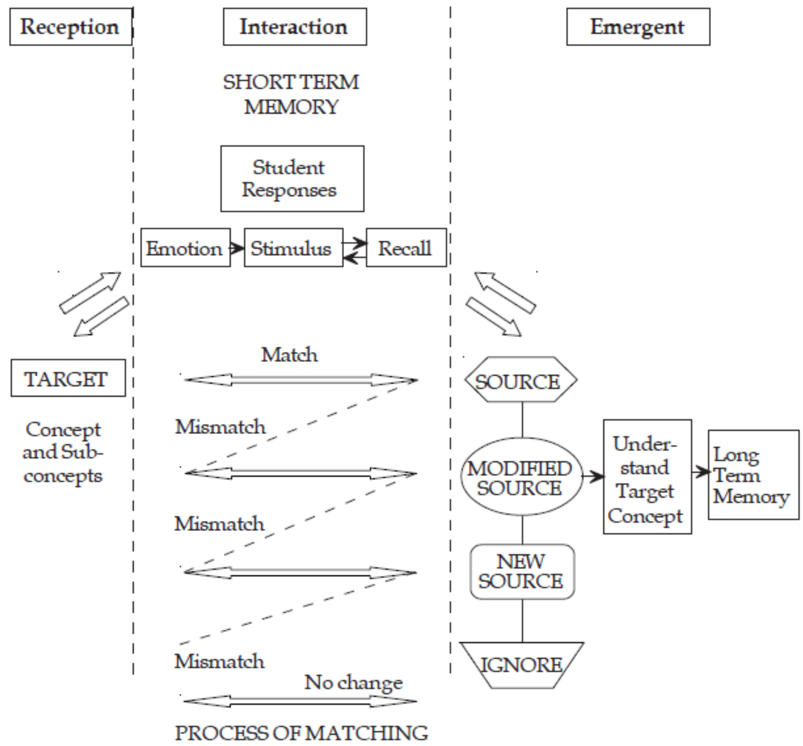



Figure II-4. Self-generated Analogical Reasoning Model (Salih, 2008)

Salih's self-generated analogical reasoning model shares commonalities with the models described in Table II-2 to some extent. For instance, both Sternberg (1977b) and Salih (2008) stated that one may repeat the process of producing, validating, modifying or creating analogies several times. Another similarity is that the models include a stage or phase of understanding the target concept, identifying its attributes and matching the target concept and the generated analogy.

## 2.4 Analogy and Visual Intelligence

In this section, the concept of visualization and visual intelligence will be briefly reviewed in relation to analogy and analogical reasoning. Analogy and visual intelligence have been thought to be related to each other. Curtis and Reigeluth (1984) insisted that the use of analogies causes visual thinking to occur. By visual thinking, they refer to mental images or models that are formed while comparing and contrasting the target concept and the analogy. The use analogies, according to Curtis and Reigeluth (1984), leads to see a relationship in terms of a picture

Heo (2006) presented three perspectives of visualization depending on how it is defined and used in different fields of study. The first perspective sees visualization as phenomenalizing. It is external representation like an image or an illustration. Visualization is treated only as a physical output. Therefore, from this perspective, visualization and visual materials used in education are judged by their effectiveness to deliver learning content. The second perspective, however, understands visualization as internal representation and mental imagery. Visualization in itself is seen as thinking process. Finally, the third perspective views visualization as one type of cognitive system. Similar to Gardner (1983)' theory of multiple intelligence, this perspective accepts the concept of 'visual intelligence'. It focuses on ability to use visual intelligence to reproduce external knowledge or information in a meaningful way.

Winn (1982) differentiated visualization used in education into two: visualization in learning and visualization in instruction. According to him, visualization in learning refers to visualization as an internal cognitive processing by learners. For instance, Rha's and Stevick's definition of visualization falls into this category. According to Rha (2007) and Stevick (1986), visualization is a mental process for explaining, expecting, operating, and creating objects, processes or events through imagery formats. In contrast, visualization in instruction is about supporting strategies. For instance, Gilbert's definition of visualization belongs to this category; he defined visualization as "the systematic and focused visual display of information in the form of stables, diagrams, and graphs" (Gilbert, 2005).

Zeitoun (1984) specified visual imagery as one of the elements that are thought to be related to analogical reasoning performed by learners. His statement is also supported by Winn (1982) who insisted that analogy involves visual processes. The process of recognizing attributes and forming a structural relation between the target concept and the analogy necessarily involves visualization either internally or externally (Winn, 1982). Which part of human visual intelligence is involved in analogical reasoning? To answer this question, it is necessary to first review the human visual intelligence theory.

Rha (2003, 2010) stated that human visual intelligence involves three dimensions: interpretation, operation, and creation. The interpretation dimension involves understanding the external physical environment. Very naturally, human beings tend to interpret and react to what they see through their vision. We judge height, distance and existence in reacting to physical world that we live in. Secondly, human beings can operate visual representations inside their brain. For example, when we make visualizations of how to get to a certain restaurant, we are operating physical objects visually. Another example can be found in imagery training. Imagery training is widely used in sport by visualizing mental rehearsal. Tiger Woods once said that he always visualized before the swing. In addition to physical objects, visual operation also can apply to conceptual objects, and this visual operation in fact is involved in analogical reasoning partially, if not unavoidably. Finally, the third operation of human visual intelligence is creation. Creation is rather unrealistic and mystic aspect of visual intelligence. For instance, dreams, futuristic visualization, and illusions are affiliated with creation operation. At this point, it is limited to understand creative capacity of human visual intelligence.

# III. METHODS

## 1. Research Procedure

The purpose of this study was to examine the components and process of learner-generated visual analogy and to investigate learner’s perception and satisfaction of using visual analogy as learning activity. For this purpose, the study used think-aloud protocol analysis, interview and survey. The overview of the research procedure is shown in Figure III-1.

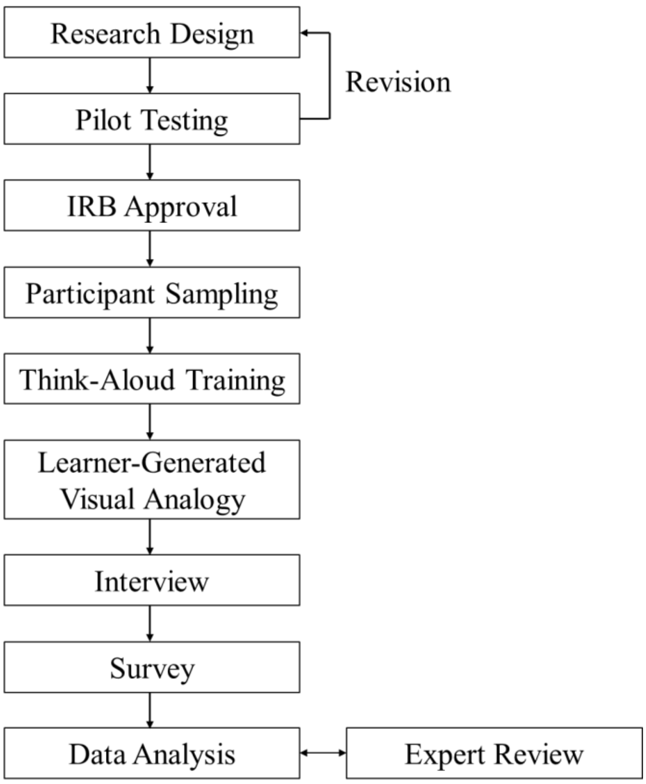



Figure III-1. Research Procedure

First, literature review on analogical reasoning, analogy, visualization, and think-aloud protocol was conducted to develop the think-aloud training material and the visual analogy generation task. The think-aloud training material was adopted from Cho (2005) who used the think-aloud method to examine the analogical transfer process in problem solving. The training material included solving visual problems, summarizing a text, and thinking of a case related to the text. In order to prepare a reading passage for visual analogy, an excerpt from the high school chemistry textbook was used. The concept of chemical bonding was chosen for the study since it consists of two sub-concepts of ionic bond and covalent bond, which therefore asks the participants not only to understand individual attributes, but also to compare and contrast between the two sub-concepts.

Then, the pilot study was conducted with a graduate student with major in education to improve the developed passages and instructions for learner-generated visual analogy. After the pilot study, he suggested that the participants should be briefly introduced to what a visual analogy is and given some examples. He also mentioned giving enough time for the participants to think about and generated a visual analogy. Revisions were made to include a brief introduction to what a visual analogy is and some examples of visual analogies. One practice question on generating a visual analogy about the law of conservation of mass was added so that the participants will be familiarized to the task.

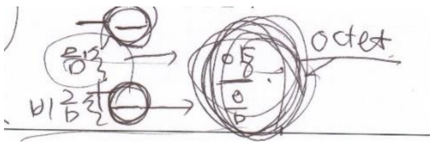
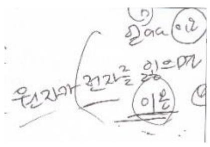
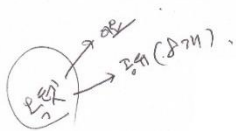
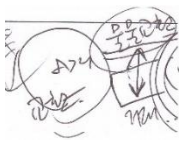
Four learners participated in the study individually, and the whole process took approximately two hours. First, the participants were trained in the think-aloud method for 30 minutes. The researcher explained the background and the application of the think-aloud method and showed a demonstration. Then, the participants were given problem solving questions to practice think-aloud. During the practice, the researcher intervened only to help the participants to continue thinking aloud. After the think-aloud training, the researcher explained the definitions of an analogy and a visual analogy used in teaching and learning and some examples of visual analogies.

After the think-aloud training, the participants completed the visual analogy generation task for two science concepts: the law of conservation of mass and the chemical bonding. The entire process was audiotaped and observed by the researcher. The researcher did not interfere except when the participants stopped thinking aloud for more than ten seconds. Only if then, the researcher encouraged the participants to continue to think aloud. The researcher recorded non-verbal data such as hand gestures and body movements as well as visualization activities. The experiment was finished when the participants decided they had generated the analogies that sufficiently explained the concepts.

When the participants finished generating the visual analogies, the researcher conducted a follow-up interview. In order to clarify the participants' thinking and reasoning process and strategies, the researcher asked the participants to reflect upon their process of making an analogy. The researcher also asked about why the participants had come up with such analogies, what difficulties they experienced, how they thought about visualizing an analogy and if they had used analogies to study before. The interview was audiotaped. In addition to the interview, the participants completed the survey questionnaire and rated each item on a 5-point Likert scale.

Consequently, in this study, two types of data were collected: verbal protocol and visualization data. Verbal protocol refers to the verbal data collected from the think-aloud method (Van Someren et al., 1994). Visualization data includes visualizations, such as notes, diagrams, and visual analogies, generated by the participants during the task. For analysis, raw verbal protocol was transcribed into text with timestamps. Following the guidelines for analyzing think-aloud data, verbal data was segmented at points where there was a sentence break or a pause for more than three seconds (Ericsson & Simon, 1993; Van Someren et al., 1994). Secondly, visualization data was scanned as digital images, fragmented into smaller coherent pieces and given id numbers as shown in Table III-1. Finally, the collected data was coded independently by two researchers.

Table III-1. Examples of Fragmented Visualization Data

| Data ID | Visualization |
|---|---|
| C-1 |  |
| C-2 |  |
| C-3 |  |
| C-4 |  |

## 2. Participants

Data was collected from four participants, two males and two females aged between 23 and 27. Three of the participants were college students and one graduate students. The major of three participants was not related to science and thus had very little background in science. Only one participant had high prior knowledge in science. All of the participants were from Seoul, South Korea. Though different institutions, they all attended institutions located in Seoul. The demographics of the participants are shown in Table III-2.

Similar to other qualitative research methods, the think-aloud method seeks rich data from a small sample (Fonteyn, Kuipers, & Grobe, 1993). This non-random convenience sample was used because the task of generating a visual analogy while practicing think-aloud required certain level of cognitive ability. According to Piaget (1964), the fourth developmental stage called formal operational stage from adolescence through adulthood is when theoretical and abstract thinking as well as inductive and deductive reasoning start to develop. In addition to the task of generating a visual analogy, the participants were also asked to think-aloud. Although research has shown that the think-aloud method does not interfere with thought and regulation process (Van Someren, Barnard, & Sandberg, 1994), it can still cause working memory overload. Therefore, it was necessary to select participants who would be able to handle such cognitive process.

Moreover, this particular sample was selected because of the verbalization skills that were necessary for collecting think-aloud protocol data. According to Van Someren et al. (1994), verbalization skill is one of the important properties to consider when selecting participants for a think-aloud study. While there may be individual differences, young children usually find it difficult to engage in thinking aloud (Van Someren et al., 1994). Therefore, college or graduate students who would be more capable of thinking aloud were selected for this study.

Table III-2. Participant Demographics

| Participant | Age | Gender | Major |
|---|---|---|---|
| A | 25 | Male | Economics |
| B | 23 | Female | Science |
| C | 27 | Female | Education |
| D | 26 | Male | Korean History |

# 3. Data Collection and Instruments

## 3.1 Think-aloud Method

Initially, the think-aloud method was developed from the introspection in psychological research (Van Someren et al., 1994). The introspection assumed that a researcher can observe internal events occurring in one's consciousness as one can observe events in the outside world. With the wave of behaviorism, however, the introspection method received criticisms for its limitations in scientific, objective analysis. Variations of introspective methods followed by using verbal reports as data. With verbal reports, the researchers could avoid subjective interpretation. Moreover, while retrospective interview or survey may be inconsistent with the participant's cognitive and metacognitive processes during the task, the think-aloud verbal data is more likely to be complete and consistent with the participant's thinking (Fonteyn et al., 1993).

The think-aloud method is being used to investigate a variety of research topics in both psychological and educational research. It is used to investigate expert knowledge, problem solving process, reading comprehension, usability testing for online or computer-mediated learning environment, and visualization process (Davey, 1983; Eveland Jr & Dunwoody, 2000; Heo, 2006; Van Den Haak, De Jong, & Jan Schellens, 2003). While the aforementioned research uses think-aloud as research methodology, other educational research has also shown that the think-aloud method in itself can be applied as an instructional or learning strategy. For instance, Baumann, Seifert-Kessell, and Jones (1992) showed that the think-aloud instruction promoted elementary students' comprehension monitoring abilities.

With the instructions for think-aloud and some practice tasks, the think-aloud method is expected not to interfere with one's thinking (Ericsson & Simon, 1998; Van Someren et al., 1994). The verbal protocol, which is the verbal reports collected from the think-aloud method, consists of rather incomplete sentences or phrases because the participants do not monitor their verbalization process. Also, the verbal protocol often provides a relatively incomplete record of complex cognitive processes which can be complemented by conducting a follow-up interview. Moreover, using analysis methods with high inter-coder reliability, it is possible to explore many aspects of cognitive and meta-cognitive processes from the think-aloud verbal protocol (Ericsson & Simon, 1998).

## 3.2 Visual Analogy Generation Task

The visual analogy generation task consisted of two parts: reading an excerpt on a science concept and generating a visual analogy. Nonetheless, prior to generating their own visual analogies, the participants needed to understand what a visual analogy is and to get used to thinking about a visual analogy. Therefore, several examples of visual analogies were presented, for each of which the researcher also provided oral explanation.

Two science concepts, the law of conservation of mass and chemical bonding, were selected from Korean middle school and high school science textbooks. Since the textbooks are authorized by the Ministry of Education, the excerpts from the science textbooks were used without editing. However, all visual diagrams were removed. This was to reduce possible influence of visual cues on the participants' analogies since visual representations can serve as an anchoring to structural analogies. As a result, only the textual information was presented to the participants, which might have hindered deeper understanding of chemical bonding. Following the excerpt, the task instruction was given to the participants as follows: "Please draw an analogy that can explain chemical bonding while thinking aloud. For example, you can think about what chemical bonding is like, and visualize your analogy. You may write or draw on the scratch paper provided". The participants were given blank papers and a four-color pen.

Since the law of conservation of mass was an easier concept adopted from a middle school science textbook, it was expected that the participants had already learned the concept. Hence, it was used as a practice question for the participants to get used to generating their own visual analogies and performing the think-aloud method. Consequently, the visual analogies for the law of conservation of mass were not included in the analysis for this study. Only the visual analogies pertaining to the chemical bonding was analyzed.

The topic of chemical bonding was selected for the following reasons. First, it was complex enough with two subordinate principles of ionic bonding and covalent bonding. The participants were expected not only to identify two different types of chemical bonding, but also to compare and contrast between the two. Second, chemical bonding is generally a difficult and yet basic topic for those students who do not have much prior knowledge in chemistry.

## 3.3 Interview

When the participants finished generating visual analogies, a follow-up interview was conducted to further clarify the process of learner-centered visual analogy generation and to investigate the learner satisfaction and perceived helpfulness. The interview was semi-structured. The interview questions were prepared prior to the experiment, consulting to the previous research (Noh et al., 2010). First, the researcher asked the participants to reflect on and explain the steps in which they made the analogies and some thoughts they had while making the analogies. They were also asked why they came up with such analogies, if they had any previous experience of using analogies, if they were satisfied with their own analogies, and how visualizing an analogy had helped their learning. Table III-3 shows the interview questions.

Table III-3. Interview Questions

1. Please explain your own analogy. Why did you choose this as your final analogy?
2. Can you recall and explain the steps you took to create the analogy?
3. Why do you think you made this analogy? (E.g. similar shape or size, recent experience, etc.)
4. What were the difficulties you experienced during making your own analogy?
5. How did making an analogy help you learn the concept of chemical bonding?
6. How did drawing an analogy help you learn the concept of chemical bonding?

*(table continues)*

7. How did drawing an analogy help you make your own analogy?
8. How well does it represent the concept of chemical?
9. Have you used your own analogy or heard a teacher's analogy before for your study? If so, please explain the learning content and the analogy.
10. In your past experience, how did the analogy help you learn?

## 3.4 Survey Questionnaire

The survey was conducted to measure learner perception and satisfaction. Learner perception is an important construct to examine particularly for learner-centered learning activity (Chung & Lim, 2000). It provides meaning insights for instructional designers to decide if an instructional strategy or learning activity will be reused and how it can be further improved. In this study, the questions were adopted from the study by So and Brush (2008) and Lim (1999). So and Brush (2008) examined perceived learner satisfaction in a blended learning environment. They constructed ten items, and the Cronbach's alpha coefficients were .85. Lim (1999) explored factors affecting learner satisfaction in the web-based online discussion, and the Cronbach's alpha coefficients were .93. The total of ten items were constructed to examine overall satisfaction with the learner-centered visual analogy generation activity. The participants were asked to rate each item on a scale from 1 (strongly disagree) to 5 (strongly agree).

## 4. Data Analysis

### 4.1 Protocol Analysis

Protocol analysis is a technique for analyzing qualitative verbal data collected from the think-aloud method which avoids bias and subjectivity. Protocol analysis is used predominantly for the study of cognitive processes (Van Someren et al., 1994). Previous research using the think-aloud method examined the problem solving process, the metacognitive activities, the visualization process, and the analogical transfer process (Cho, 2005; De Backer, Van Keer, & Valcke, 2012; Heo, 2006). Transcribed verbal protocols are coded with a coding scheme and sometimes for further analysis, are aggregated into episodes which correspond to a single element in the propose model (Van Someren et al., 1994). In this study, the purpose of protocol analysis was to examine the cognitive and metacognitive components and process during the visual analogy generation task. The analysis process is shown in Figure III-2 below.

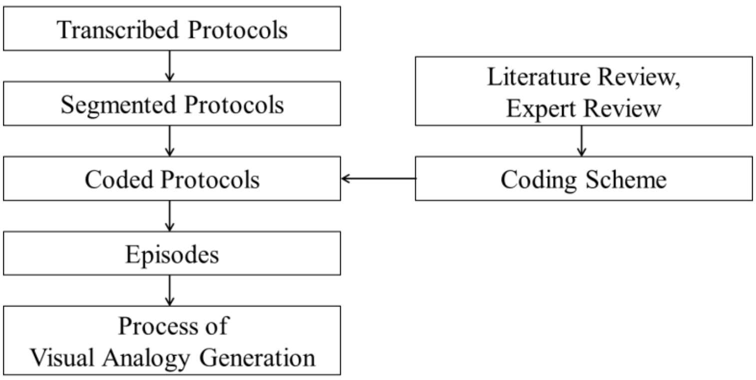



Figure III-2. Protocol Analysis Process

The first version of coding scheme was developed from literature review. Relevant researches were found using such keywords as ‘self-generated analogy’, ‘think-aloud’, and ‘visualization’. The coding scheme was mainly based on three studies on the visualization process of verbal information; the learners’ metacognitive knowledge; and the learner-generated analogical reasoning model (De Backer et al., 2012; Heo, 2006; Salih, 2008). Then, two researchers made revisions by analyzing the verbal protocol from the pilot study using the first version of coding scheme. The second version of coding scheme was then reviewed by three experts, one Ph.D. in educational technology and two doctoral candidates in educational technology. The experts reviewed the components and rated on a 5-point Likert scale regarding explicability, validity, appropriacy, generality, and comprehensibility. The mean scores for each criteria were 5.00 for explicability, 5.00 for validity, 4.00 for appropriacy, 4.67 for generality, and 4.67 for comprehensibility. Revisions were made after reviewing experts’ comments. The final protocol coding scheme is shown in Table III-4.

Table III-4. Protocol Coding Scheme

| Category | Subcategory | Description | Coding code |
|---|---|---|---|
| Understanding concept | Identifying attributes | Finding, defining, and describing any concepts, components, properties or principles | UIA |
| | Identifying critical attributes | Stating the importance of certain content | UIC |
| | Comparing attributes | Comparing similarities and differences between two or more concepts | UC |
| | Paraphrasing | Restating concept in another form, mainly in learners' own words | UP |
| | Thinking of examples | Providing learner-generated examples of the concept being learnt | UE |
| | Rereading | Reading aloud; Re-reading important information; Re-reading after confusion | UR |
| Searching for analogy | Searching with thinking | Stopping think-aloud and thinking about ideas | ST |
| | Brainstorming | Searching for ideas by questioning or brainstorming while thinking aloud; Using paraphrases or personification to search for ideas | SB |
| Matching | Matching components | Mapping components of the target concept onto the analogy | MC |
| | Matching principle | Mapping principles of the target concept onto the analogy | MP |

*(table continues)*

| Category | Subcategory | Description | Coding code |
| --- | --- | --- | --- |
| Elaborating analogy | Describing analogy | Explaining the learner-generated analogy while or after visualization | ElD |
| | Modifying analogy | Modifying and elaborating the learner-generated analogy | ElM |
| Evaluating analogy | Evaluating analogy | Checking completeness or correctness of the analogy | EvA |
| | Deciding final analogy | Selecting the final analogy | EvD |
| Planning | Detecting task demand | Reading task instructions; Identifying task | PD |
| | Planning problem-solving approach | Developing reading plan; Developing action plan | PA |
| Monitoring | Comprehension monitoring | Noting lack of comprehension; Claiming understanding; Demonstrating comprehension by repeating; Demonstrating comprehension by elaborating | MoC |
| | Progress monitoring | Reflecting on the quality of the progress made; Reflecting on strategy use | MoP |

Two researchers, both master's students in educational technology, analyzed the segmented verbal protocols independently using the coding scheme after practicing coding with the data collected from the pilot study. Once the researchers finished analyzing the segmented verbal protocols, they discussed to resolve differences in coding. The inter-coder reliability was substantial (Kappa = .88). The coded protocol was aggregated into episodes which represented one category in the coding scheme. Following the method used by Cho (2005) and Heo (2006), segmented protocols were aggregated into one episode if three or more protocols were coded as the same category consecutively. Until another episode appeared, it was assumed that the previous episode continued.

Once all episodes were identified, individual participant's process was examined by analyzing how episodes were related to each other. Then, the general process of learner-generated visual analogy was schematized based on most frequently observed episodes and stages. The final process of learner-generate visual analogy was presented after investigating the percentages of time spent for each episodes.

## 4.2 Visualization Analysis

The verbal protocol collected from the think-aloud method heavily contains information regarding the participants' thinking process during the visual analogy generation and relatively little regarding the visualization process. Thus, in order to examine the visualization process, it was necessary to analyze visualization data, including notes, diagrams, and visual analogies made by the participants. The visualization analysis used the five categories of visualization presented by Heo (2006). Originally Heo (2006) suggested six categories of visualizing according to the visual attributes; however, the sixth category–visualization with rehearsal for teaching– did not appear in this study and thus, not included in the final coding scheme (see Table III-5).

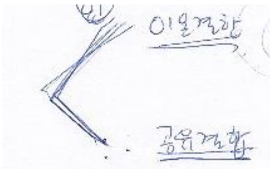
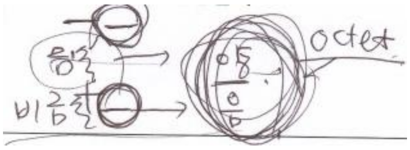
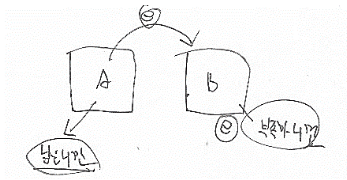
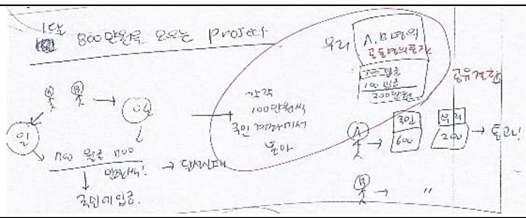
Table III-5. Visualization Coding Scheme

| Category | Description |
|---|---|
| Simple visualizing | Visualizing without cognitive processing, such as writing down topics |
| Appendant visualizing | Confirming or highlighting what has already been visualized, such as underlining, circling, boxing, or drawing lines to show relationship |
| Selective Visualizing | Summarizing or transforming text while making sure of the content |
| Conceptual Visualizing | Visualizing and representing the text in a logical way |
| Strategic Visualizing | Visualizing analogy or metaphor |

The first category is simple visualizing which involves visualizing without much cognitive processing. Examples of simple visualizing are copying down titles, subtitles, or concept names. The second category is appendant visualizing which is confirming or highlighting what has already been visualized, such as underlining, circling, boxing, or drawing lines to show relationship. The third category is selective visualizing. It is summarizing or writing down a certain part of text that the learner has selected while reading text. Selective visualizing is different from simple visualizing in that the learner verifies the content and transforms the original text that he or she chooses to summarize or pay attention to. The fourth category is conceptual visualizing. It refers to visualizing and representing information by the learner's own logical way, including diagrams, graphs and tables. In this study, the term was modified to conceptual visualizing. Finally, the fifth category is strategic visualizing. Whereas the former categories involves visualizing the incoming information, strategic visualizing with analogy and metaphor associates the incoming information with concepts or objects from a different domain for effective learning. Table III-6 shows examples for each visualization category.

The fragmented visualization data was combined with corresponding verbal protocol. This was to understand the context of visualization. Using the five categories of visualization, two researchers independently analyzed segmented visualization data. The inter-coder reliability was substantial (Kappa = .98). The results from visualization coding were combined with the protocol analysis results and represented in the process of learner-centered visual analogy generation.

Table III-6. Categories and Examples of Visualization

| Category | Example |
|---|---|
| Simple visualizing |   |
| Appendant visualizing |   |
| Selective visualizing |  |
| Conceptual visualizing |   |
| Strategic visualizing |  |

# IV. Results

## 1. Process of Visual Analogy Generation

The first research question in this study was to examine components and process of learner-centered visual analogy generation. For this purpose, patterns of learner-centered visual analogy generation were analyzed using the verbal protocol, visualization data and interview.

### 1.1 Analogy Generation Process

#### A. Patterns of Analogy Generation

In this section, the commonly observed patterns of visual analogy generation by learner are discussed. After the protocol analysis, segmented protocols were aggregated into episodes which represent the subcategories in the process of generating a visual analogy. The patterns for each participant were schematized by following the order of coded episodes. Figure IV-1 reveals the process of each participant's visual analogy generation.

The results from episode analysis showed that learners were engaged in six different stages while generating a visual analogy. On average, they went through 12.5 episodes (*SD* = 3.1). Participant A had exceptionally small number of episodes compared to three other participants with only eight episodes. All the other participants ranged between 13 and 15 episodes.

Such episodes as *describing analogy* and *matching principle* were observed from all four participants with the highest frequencies. The frequencies of metacognitive episodes like *evaluating,* and *monitoring* varied. In fact, *evaluating* did not emerge as an episode. Moreover, the overall process did not differ with the level of prior knowledge, except that the participant with high prior knowledge in chemistry was able to use relevant examples like chemical formulas.

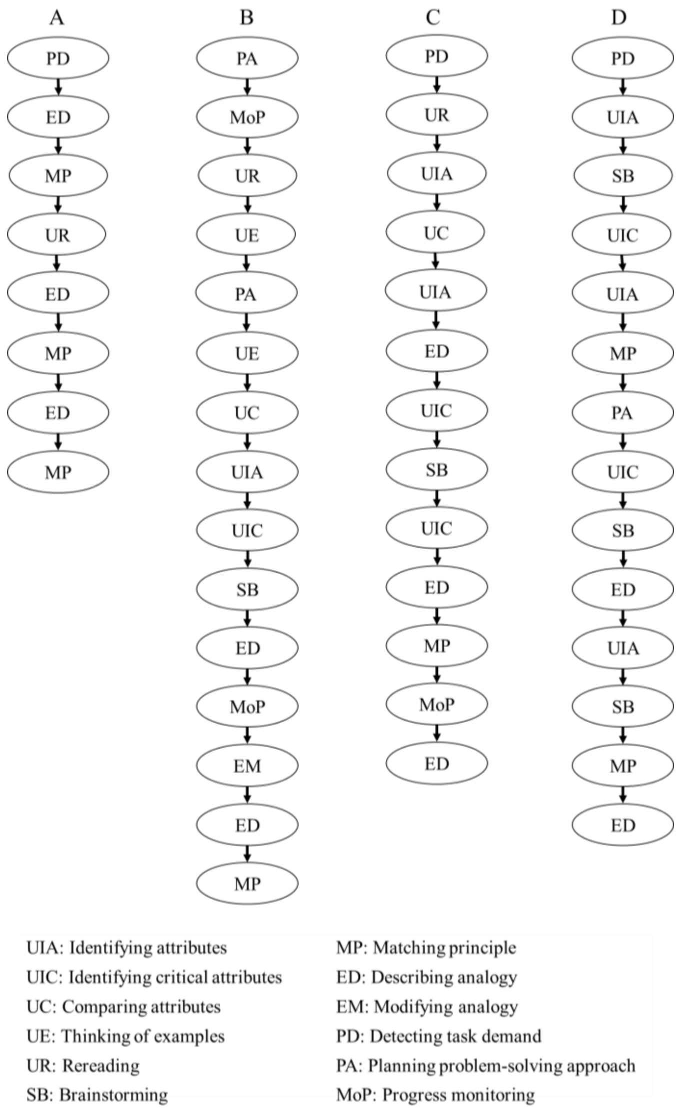



Figure IV-1. Analogy Generation Process by Participants

The following common patterns were observed among the four participants. First, they all began the process of visual analogy generation with planning either by detecting the visual analogy task or by setting up a problem-solving approach to accomplish the task. To detect the visual analogy task, they read the instruction and checked the materials provided to them. For example, participant C, after reading the task instruction, turned the pages to find that she was given blank scratch papers and the last page reserved for the final visual analogy. Planning approach at the beginning of the task involved verifying what should be done first before making a visual analogy. For instance, participant B planned to "look at the definition first". Participant C also explicitly stated that she "needed to understand this so that [she] can make an analogy".

Secondly, after planning, the participants proceeded to build understanding of chemical bonding. Understanding repeatedly involved identifying attributes of chemical bonding, identifying critical attributes, comparing the two types of chemical bonding, and rereading the provided excerpt. Understanding began by rereading the excerpt. After reading the excerpt, the participants paraphrased the concepts of ionic bond and covalent bond in their own words in order to comprehend the concepts. The role of paraphrasing may have played an important role in searching for an analogy since some participants used personification to explain using less academic and livelier expressions. For example, participant B explained ionic bond as being "unkind" because it transfers electrons completely from one atom to the other and covalent bond as being "nice" because it shares an electron pair. The participants also used onomatopoeia to describe the process of bonding, using sound expression like "jjak-jjak". This may be seen as the participants' attempts to understand the unfamiliar concept expressed in formal academic language by using familiar expressions.

Since there were two types of chemical bond, the participants highlighted the difference and the similarity between ionic and covalent bond. In comparing the two concepts, the participant eliminated auxiliary information and focused on what they thought was the key idea. As a result, they recognized the importance of certain attributes, such as the atoms' tendency to have eight electrons, the total transfer of electron from one atom to another, and the sharing of electrons. All of the participants were able to discern the differences between ionic and covalent bond which were represented in the analogies; however, the similarity–satisfying the octet rule– was represented only in two analogies. Only one participant with high prior knowledge was able to elaborate the similarity and difference using an example. Figure IV-2 demonstrates how the subcategories of understanding concept are related.

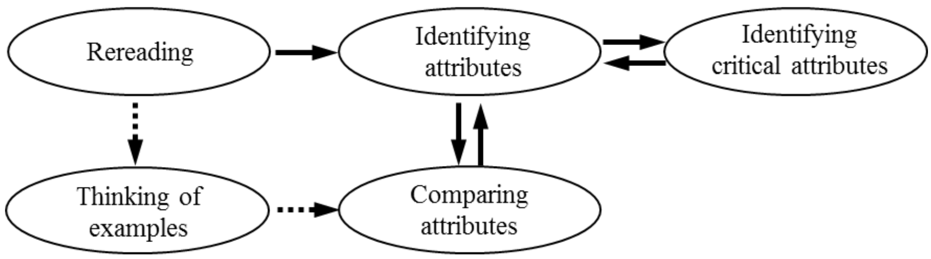



Figure IV-2. Subcategories of Understanding Concept

From the understanding stage, participants tended to either search for an analogy or directly proceed to elaborate on their analogies. In searching for an analogy, participants repeated the critical attributes of concepts identified by themselves earlier. More particularly, they tended to focus on verbs which describe the principle of chemical bonding. Anchored on verbs, such as ‘share’, ‘transfer’, and ‘give and take’, they tried thinking of analogies by replacing the subjects, such as electrons and atoms.

> “Sharing...what’s there that shares something...” (Participant B)
> “Gain electron, gain electron…hmm” (Participant C)
> “Military? Something that forms stability...” (Participant C)
> “They need to transfer…transfer…” (Participant D)

Elaborating on the created analogy was consisted of two elements: describing the analogy and modifying the analogy to the learning content. In this stage, the participants identified components of their own analogies and described the analogy.

> “There is a person with personality type A and another person with personality type B. Personality type A is very relaxed and…type A person met type B person. They fell in love. When they fall in love…um…when they are in a relationship, one person has to take a step back to be considerate for the other. So they try to adjust their relationship by stepping back and forth.” (Participant A)

> “Let’s say there is a goal to save ten million won within a year. It’s like a bet. You have to save up one million won within a year in this project. And few people applied to this project. So there are two people, A and B. Person A earned eight million alone and B also earned eight million. And there is this job which A and B have to work together and they get two million. They can get divide two million and each get one million. Or if they don’t want to get one million won separately, they can together make one bank account

> under with name and put two million there. So this two million won is now both A and B's." (Participant B)

As shown in the verbatim, some participants described the analogy in a way of storytelling. In most of the analogies generated, the atoms were represented as people. Participant A's analogy was explicitly about interpersonal relationship. Participant B's analogy was about how two pairs of people can achieve the set amount of money in different ways analogous to chemical bonding. Participant C used two villages forming different types of alliances by either sending married people to one village or sharing armies and land together. While participant D's analogy for ionic bond included person, his analogy for covalent bond was comprised of magnetic fields which were not at all related to interpersonal relationship.

Moreover, three of the participants used the same analogous situation to explain ionic and covalent bond. To explain two different principles of chemical bond which have the same condition of satisfying octet rule, the participants adjusted sub-elements of the analogy while maintaining the overall analogous situation. Participant A, B, and C used the same analogous situation to explain ionic bond and covalent bond as follows:

> "For example, there are only A, B, C, and D in this project team. C had only D to give and D only has C to receive from. So they are satisfied. So C has ten million but gives two million…now C has eight million to achieve the goal. For D, six million plus two million…has earned eight million…so they are very satisfied because they both benefited. So electrostatic attraction has formed because they helped each other. In conclusion, all four satisfied

> octet rule, but covalent bonding is they may sacrifice a little bit but make a shared bank account together to achieve the goal and in this case C complete gives money away to D to satisfy the octet rule." (Participant B)
>
> "We can think that there are two villages. This is Africa and there are villages in Africa. There is village A and village B, and there is common enemy C. Village A and B are different families…fighting against enemy C to maintain stability. In case of ionic bond, males in one village find females in the other village to get married. They need to get married, males in village B and females in village A so it's blood alliance. So from now on they are allied by blood and new village AB is formed. But in case of covalent bond, they just say 'let's live together'. Our village has this many males and your village has that many males so we just make a treaty and live together. So they can share weapons and armies." (Participant C)

Participant D, however, used two completely distinct analogies. In his analogy for ionic bond, he used a person, which represents a nonmetallic element, consuming only the yolk of an egg, which represents an electron in a metallic element, to explain ionic bond. For covalent bond, he used the analogy of magnetic fields.

Finally, the four participants performed metacognitive activities, such as monitoring and evaluation, consistently throughout the process of visual analogy generation. Since most of metacognitive activities appeared in only one or two segmented protocols, only few metacognitive episodes were included in the analysis result. The monitoring statements was made in the middle of understanding stage and explanation stage, which implies that the participants were monitoring consistently throughout the visual analogy generation task. The participants monitored the process in two aspects. First, they monitored their understanding of chemical bonding. Because the participant has little background knowledge in chemistry, they made sure they understood the content correctly. Monitoring comprehension included questioning themselves about accuracy of their understanding and clarifying parts that they had trouble understanding. For example, during the interview conducted after the task, participant C claimed that she "checked if [she] was thinking consistently". After making such monitoring assertions, they usually went back to the understanding stage to reread the excerpt or identify attributes. Secondly, the participants monitored the strategies and the process of visual analogy generation. This included reflecting on the creativeness of analogies, deliberating on how to express visual analogies and explaining what he or she was doing. Some examples of monitoring statements are as follows:

> "There can be more analogies than this one but…" (Participant A)
> "I thought about the definition while reading." (Participant B)
> "I understood up to here." (Participant C)

In contrast to monitoring, evaluation judged the quality of analogy in terms of its correctness and completeness in explaining the chemical bonding. While evaluation appeared in coded segments of verbal protocol, it did not appear as an episode. In most cases, participants made brief evaluation and continued to search for an analogy or describe an analogy.

Thus far, the process and patterns of generating a visual analogy were examined. The overall process of generating a visual analogy can be concluded by integrating the commonly observed patterns among the participants as illustrated in Figure IV-3. The direction of arrow indicates the sequence of stages in the process. The thickness of arrow signifies the number of observed course of generation process. The thinnest line represent courses that appeared only one or two times among the participants, while the thickest line represent courses appearing more than five times. Therefore, the general process of visual analogy generation is demonstrated with the moderately thick lines and the thickest lines. The thinnest lines show subsidiary stages.

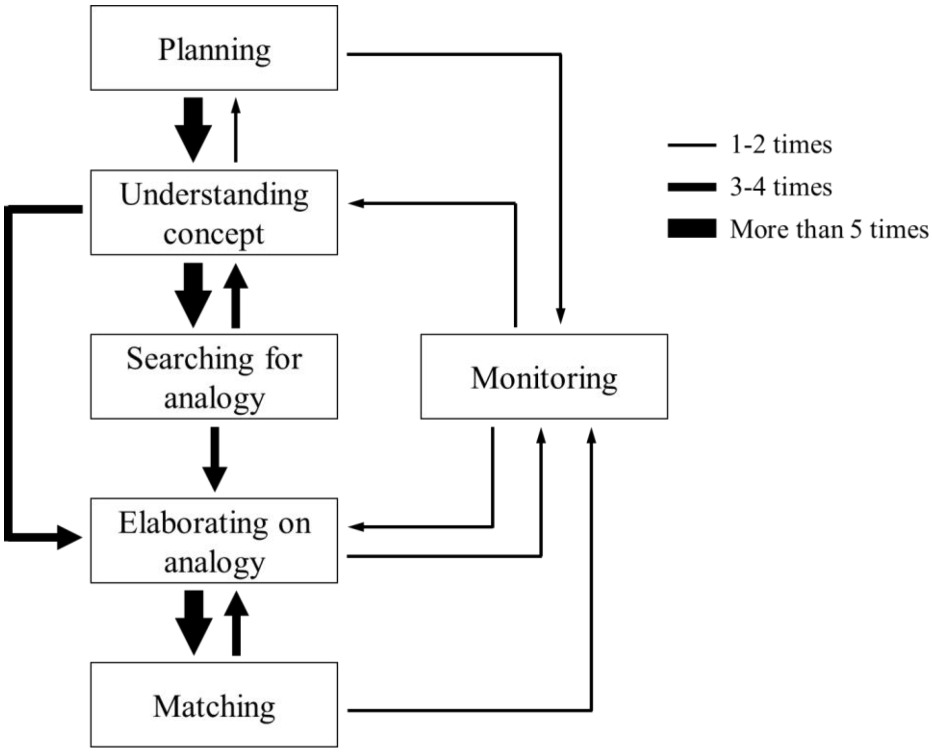



Figure IV-3. Process of Generating an Analogy

B. Time Used for Analogy Generation

Because the patterns of visual analogy generation do not represent how much time was allotted for each stage, it was necessary to examine the amount of time spent for each stage. The analysis of time use can be carried out either by using the absolute value of time measured in second or by examining the percentages of time used. In this study, because the total amount of time was different for the participants as shown in Table IV-1, the percentage of time was analyzed to examine the time use and to compare the patterns among the participants. As shown in Table IV-1, the average time spent for generating a visual analogy is 855.5 second (*SD* = 334.3). Participant B was engaged in the task for the longest time.

Table IV-1. Total Amount of Time Used

| | Total time (sec) |
|---|---|
| A | 532.0 |
| B | 1262.0 |
| C | 990.0 |
| D | 638.0 |
| Mean | 855.5 |

The percentage of time spent for each stage by individual participants is shown in Table IV-2 and Figure IV-4. Participant A spent nearly 40 percent of the time in describing an analogy and less than five percent for searching, evaluating, and monitoring. Participant B spent 70 percent of the time in identifying attributes and thinking of examples to understand concept as well as describing the analogy.

This result was interesting since participant B had the highest prior knowledge in chemistry and yet had invested as much time as 30 percent in identifying attributes and thinking of examples in understanding stage. Participant C used more than half of the time to understand the concept. Similarly, participant D also spent most time in understanding.

Table IV-2. Percentage of Time Spent by Participants

| | P | U | S | El | M | Mo | Ev |
|---|---|---|---|---|---|---|---|
| A | 1.7 | 24.2 | 3.6 | 40.6 | 21.6 | 3.9 | 4.3 |
| B | 2.3 | 33.8 | 4.6 | 37.0 | 11.6 | 3.6 | 7.1 |
| C | 8.0 | 54.3 | 6.3 | 15.3 | 5.5 | 8.6 | 2.1 |
| D | 7.7 | 33.7 | 26.2 | 13.0 | 13.9 | 1.3 | 4.2 |

**Notes.** P: Planning, U: Understanding concept, S: Searching for analogy, El: Elaborating analogy, M: Matching, Mo: Monitoring, Ev: Evaluating analogy

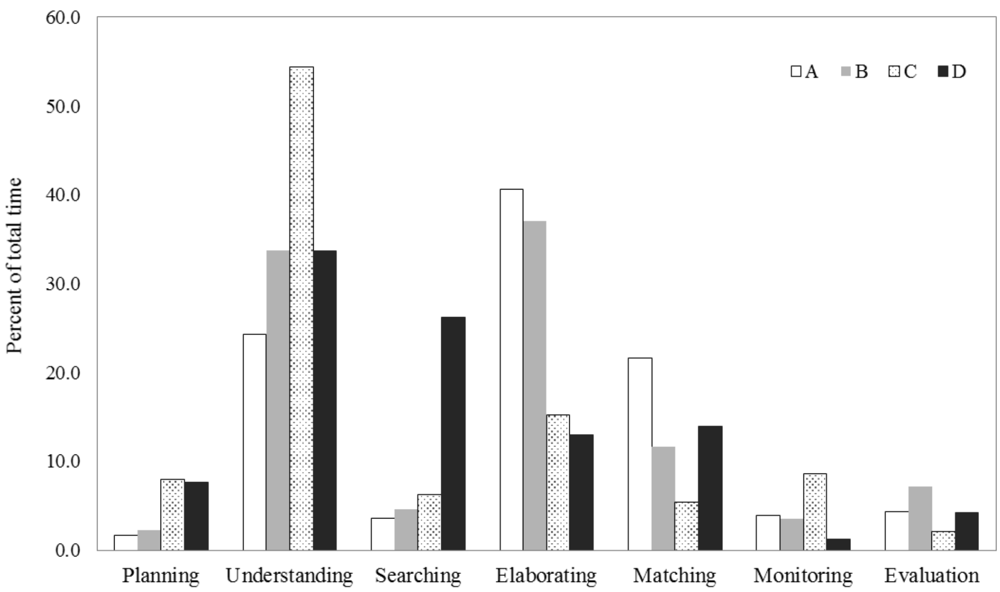



Figure IV-4. Percentages of Time Spent by Participants

It was thus evident that the participants spent the majority of time to understand the presented concept and to elaborate their analogies. While understanding the concept, they reread the excerpt or identified the concept by paraphrasing for the most of the time. Describing the analogy accounted for more than 15 percent of the total time. In contrast, the participants spent relatively little time modifying the analogy. Moreover, monitoring comprehension and progress showed very small percentage of time. Since monitoring involves one's metacognition, it may not have been reflected in the think-aloud. The average time in second is shown in Table IV-3 and the percentages are shown in Figure IV-5.

Table IV-3. Average Time for Each Stage

| | P | U | S | El | M | Mo | Ev | Total |
|---|---|---|---|---|---|---|---|---|
| Mean | 41.5 | 327.0 | 76.5 | 229.3 | 101.3 | 39.8 | 40.3 | 855.5 |
| SD | 29.9 | 188.0 | 63.4 | 167.5 | 39.4 | 33.8 | 33.3 | 334.3 |

**Notes.** P: Planning, U: Understanding concept, S: Searching for analogy, El: Elaborating analogy, M: Matching, Mo: Monitoring, Ev: Evaluating analogy

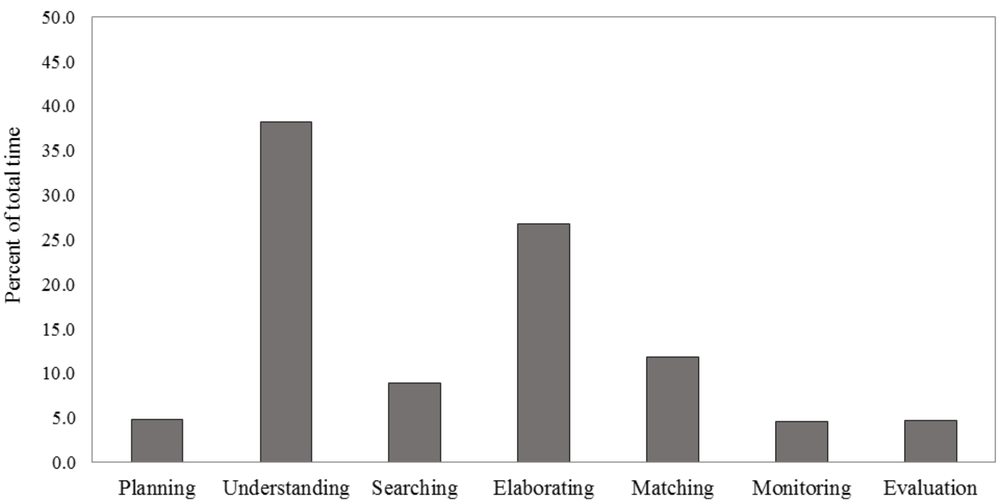



Figure IV-5. Percentages of Average Time for Each Stage

## 1.2 Visualization Process

### A. Patterns of Visualization

The visualization data was analyzed according to visual attributes suggested by Heo (2006). After the analysis, the coded visualization data was connected to corresponding analogy generation episode. The amount of time spent for visualization was also analyzed. Participant A, as shown in Figure IV-6, used two types of visualization: conceptual visualizing and strategic visualizing. He visualizing only during elaborating analogy and matching principle. He used strategic visualizing for 66.7 percent of the time he was describing the analogy. After he had made the analogy for covalent bond, he used conceptual visualizing to match the analogy to the concept of covalent bond which accounted for 8.7 percent of time. He used visualization for 28.9 percent of the total time.

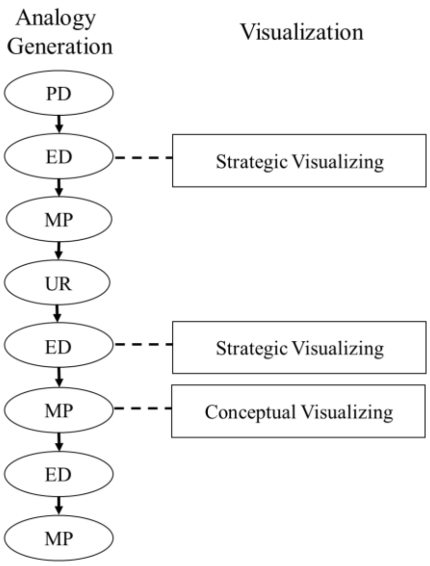



Figure IV-6. Visualization Process for Participant A

As evident in Figure IV-7, participant B made four types of visualizations: simple visualizing, appendant visualizing, conceptual visualizing and strategic visualizing. While understanding concept, participant B used conceptual visualizing for 15.7 percent, simple visualizing for 4 percent, and appendant visualizing for 2.8 percent of the time. While describing the analogy, the participant visualized the analogy for 57.4 percent of the time. In total, participant B visualized 32.1 percent of the time she was generating the visual analogy.

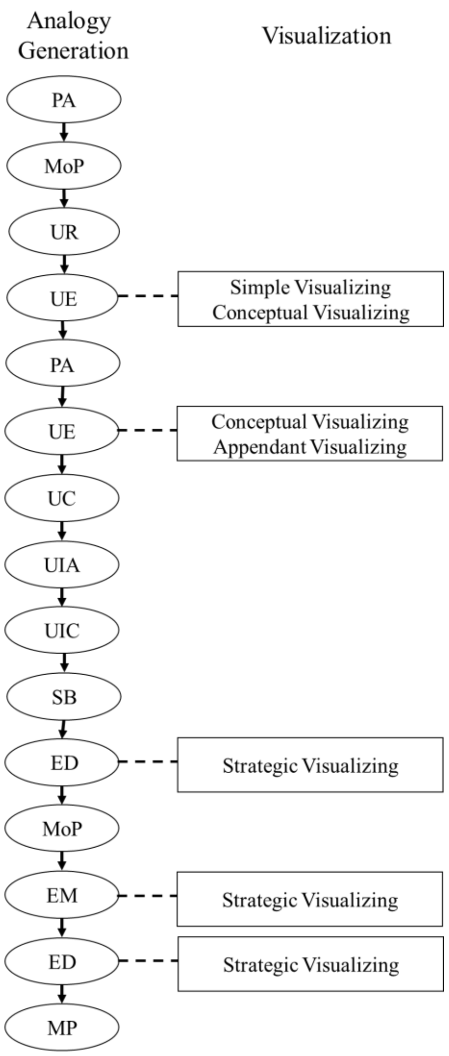



Figure IV-7. Visualization Process for Participant B

Participant C used all five types of visualizations as shown in Figure IV-8. Out of the total time, the participant visualized for 34.1 percent. While rereading the excerpt, the participant wrote down phrases like ionic bond, covalent bond, and losing the outermost electrons. To identify attributes and particularly critical information, she used conceptual and appendant visualizing. Simple visualizing was used to brainstorm ideas for an analogy. Finally, similar to other participants, she used strategic visualizing for 43.7 percent of the time while describing the analogy.

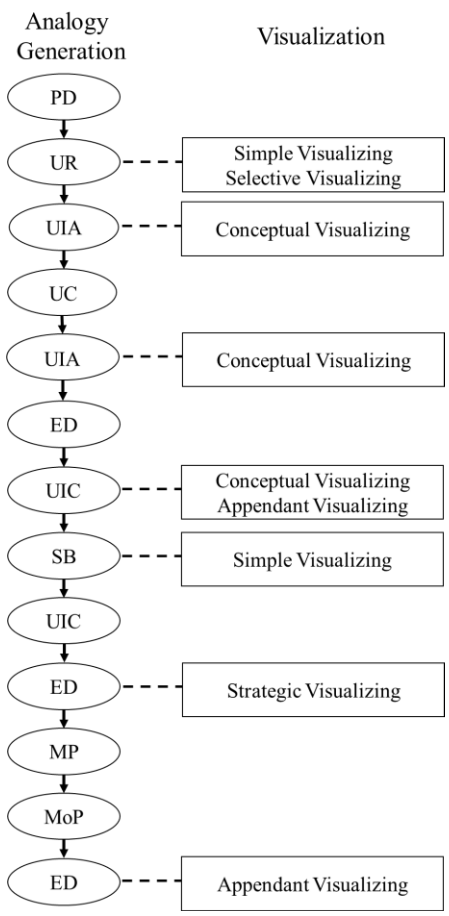



Figure IV-8. Visualization Process for Participant C

Participant D exercised three types of visualizations as shown in Figure IV-9. Conceptual visualizing was used while understanding the concept. Strategic visualizing was used while describing the analogy and matching the concept and the analogy. Appendant visualizing was also used while describing the analogy. In total, participant D used visualization for 21 percent of the times, which was the least amount of time for visualization among the four participants.

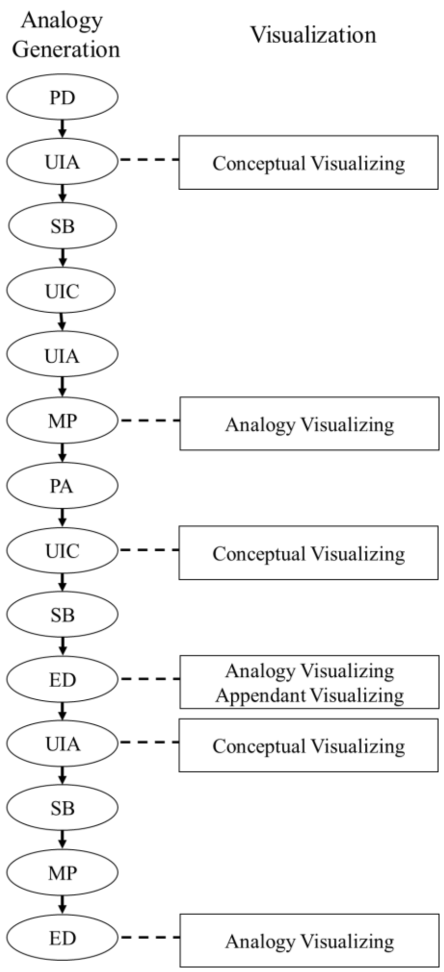



Figure IV-9. Visualization Process for Participant D

## B. Time Used for Visualization

On average, the participants used 3.5 types of visualizations for 257.8 seconds (*SD* = 134.2). In other words, the participants visualized for 30.1 percent of the total time. All participants used conceptual and strategic visualizing. Conceptual visualizing was most frequently used while identifying attributes, whereas strategic visualizing was most frequently used to describe an analogy. In contrast, metacognitive stages did not involve any visualization. Table IV-4 shows what percentage of time in each stage the participants visualized.

Table IV-4. Percentages of Time Used to Visualize in Each Stage

| | Understanding concept | Searching for analogy | Elaborating | Matching |
|---|---|---|---|---|
| Participant A | | | | |
| Conceptual | | | | 8.7 |
| Strategic | | | 66.7 | |
| Participant B | | | | |
| Simple | 4.0 | | | |
| Appendant | 2.8 | | | |
| Conceptual | 15.7 | | | |
| Strategic | | | 57.4 | |
| Participant C | | | | |
| Simple | 5.6 | 29.0 | | |
| Appendant | 2.2 | | 19.2 | |
| Selective | 2.6 | | | |
| Conceptual | 16.4 | | | |
| Strategic | | | 43.7 | |
| Participant D | | | | |
| Appendant | | | 2.4 | |
| Conceptual | 23.7 | | | |
| Strategic | | | 56.6 | 14.6 |

## 1.3 Process of Visual Analogy Generation

### A. Process of Visual Analogy Generation

The results described thus far be integrated to demonstrate the overall process of visual analogy generation as shown in Figure IV-10. The overall process integrates the two dimensions, analogy generation and visualization, into one process. As discussed earlier, the analogy generation dimension contains six stages: planning, understanding concept, searching for visual analogy, elaborating on visual analogy, matching and monitoring. Though included in the coding scheme, evaluation was excluded from the final process as it did not appear as an episode during the analysis. The arrows in the figure denote the direction of progress. The relative size of each box implies the amount of time learners spent during each stage. Since the participants invested the majority of time in *understanding concept* and *elaborating on visual analogy* stages, the progression of sub-processes were also demonstrated. The portion below the dotted line in each stage shows the type of visualizing used for each stage. As noted, *planning* and *monitoring* stages did not involve visualizing.

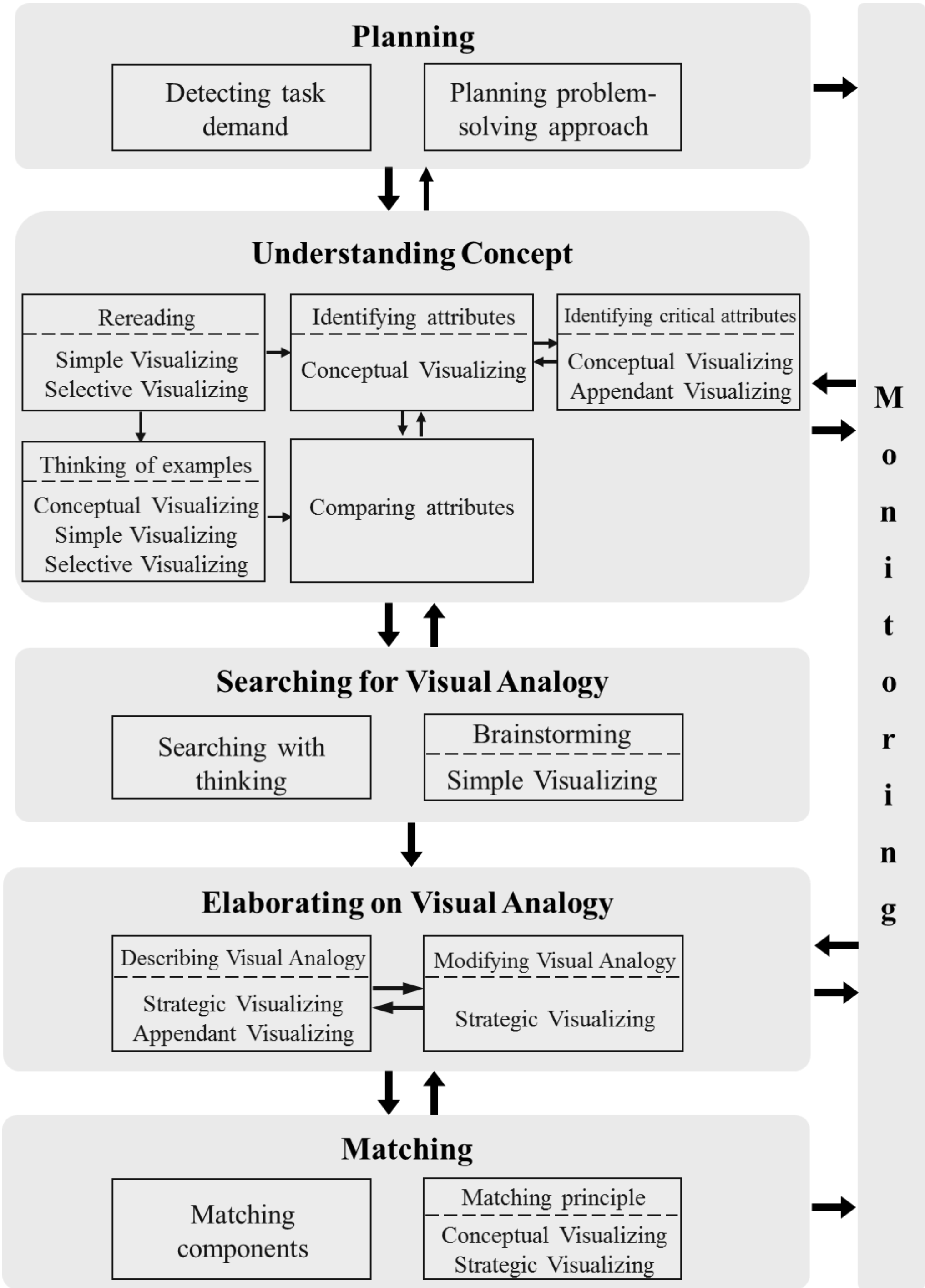



Figure IV-10. Final Process of Visual Analogy Generation

B. Strategies for Generating a Visual Analogy

When the participants were asked to describe how they came about in generating the visual analogies, there were two strategies commonly used by the participants. First, the participants identified the critical attributes of each type of chemical bonding and concentrated on these attributes to search for and elaborate their visual analogies. Some participants answered that they wanted to represent as much detail as possible, but in the end concentrated on key concepts.

> "I gave up on describing every detail and focused on expressing only what is important." (Participant A)
>
> "The difference was that here electrons are shared and here electrons are completely given away to another part. So I took this as the central premise." (Participant B)
>
> "When I thought of an analogy, I tried looking for the key point. (Participant C)
>
> "Instead of conveying everything, I took part that's most important." (Participant D)

All of the participants focused on the differences between ionic and covalent bond, and conveyed the difference in their analogies.

> "It took me some time to find what it is, but the octet rule was the key and these were two different ways to obtain eight electrons." (Participant C)

> "I wanted to emphasize the difference, so here, I focused on the transfer of electron and here I wanted to represent commonly shared component." (Participant D)

For most of the participants, the atoms were replaced with such analogs, as people, organism, or magnetics, and the electrons were depicted as love, friendship, money, land, army, and magnetic fields. The underlying principle of transferring or sharing electrons was represented in the final visual analogies. In all analogies, combination of some kind was illustrated analogously, three of which was also related to certain purpose. For instance, in participant A's analogy to go camping together was the purpose of friendship while participant C's analogy depicted the stability as the purpose of alliance between two villages. Participant B's analogy portrayed the octet rule as the amount of money that people had to earn to win a bet. Although the extent to which attributes were represented analogously differs among the participants, all of them contained the key principles of chemical bonding.

Secondly, as shown by the protocol analysis, the participants also insisted in the interview that they contemplated on the verbs that describe the key attributes in searching for visual analogies.

> "I thought like something has to share or something is given away to fit into some standard. I think I tried to replace the objective with something abstract." (Participant B)

> "Exchanging for something good is similar to what happens between people or friends." (Participant A)

Although it may be due to the nature of concept used in this study, the participants showed tendency to concentrate more on functional features than structure of atom or chemical bonds. Therefore, they used verbs that describe these functional aspects as cues. Because the participants attempted to think of an analogy that involves exchanging and sharing, they often came across analogies that are related to human being either directly or indirectly. Friendship, exchange of money, and village alliances described in three analogies all occur between persons or groups of people.

## 2. Learner Perception

In this study, learners' perception of the use of visual analogy was examined using the survey questionnaire and the interview. The survey to measure learner perception and overall satisfaction included ten items for which the participants rated on a 5-point Likert scale. The participants were generally satisfied with the use of learner-generated visual analogy with the mean score of 3.65. For further investigation, the participants were interviewed regarding their scores and the mean scores for each questionnaire item were calculated. The survey results are included in the Appendix E.

The participants perceived the activity of generating their own visual analogy as fun and novel experience which they would like to recommend to others. In the follow-up interview, Participant D said that he had "never used an analogy to study, but it seems helpful". In contrast, two other participants had previously encountered the use of analogy either of their own or an instructor's. Participant A acknowledged that analogies are used in teaching and learning, mostly for science subjects. Despite the difference in previous experience of using analogies in learning context, the participants agreed that the use of visual analogy was fun and novel and that their interest for the topic increased by using the visual analogy.

Furthermore, the participants showed positive response with the mean score of 4.25 ($SD$ = .96) to helpfulness of using a visual analogy in understanding the relationship between the two types of chemical bond. In addition to enhancing the comprehension of the relationship, the participants also responded with the mean score of 3.75 (*SD* = .50) that the use of visual analogy helped understand each type of chemical bond.

In the follow-up interview, the participants perceived that the use of learner-generated visual analogy was helpful for the following reasons. First, because in order to generate an analogy, they needed to understand the concept. In doing so, they reread the excerpt several times and turned their attention to identifying the key attributes, which helped them understand the concept. Secondly, the participants perceived that visualizing an analogy was useful since visualization helped represent the concept more clearly than verbal descriptions of the analogy. Visualization by explicitly depicting the connection between the concept and the analogy was perceived to help both understanding the chemical bonding and monitoring the analogy generation process.

> "Expressing it as a drawing made me to try to understand the process correctly. To know the difference between a covalent bond and an ionic bond, the drawings have to be different. Also I can see from my own drawing what parts are missing." (Participant D)

Lastly, the participants also responded that learner-generated visual analogies helped clarify confusion. To create a visual analogy, the participants needed to select attributes, usually two to three, to represent. In most cases, these attributes were critical to understanding the presented scientific concept. In one case of participant C, the attributes portrayed in the final visual analogy also included the attribute that the participant had difficulty understanding. Participant C said she could not understand why the atoms had to bond with each other. As she kept rereading the excerpt, trying to follow the logic and thought about the chemical phenomenon, she was eventually able to grasp the purpose of chemical bonding. The purpose of chemical bonding–achieving stability by having eight electrons– was then represented in her visual analogy as the two allied villages' stability against the other village. Likewise, the learners depicted what they thought was most important or what they initially had trouble understanding in their visual analogies, which they perceived to be useful for their understanding.

> "The analogy I made is organized around what I might be confused with. For example, I couldn't understand why they had to bond together. So I kept thinking about it while making my own visual analogy." (Participant C)

The item regarding the difficulty of creating a visual analogy received the lowest mean score of 2.00 (*SD* = .82). The participants found it difficult to come up with a visual analogy on their own for two reasons. First, they wanted to be creative in formulating the visual analogy. Therefore, they tried to think of funny or unique analogies which however was difficult. The participant B, after seeing the examples of visual analogies provided by the researcher, tried to come up with a groundbreaking visual analogy, but she could only come up with visual analogies that are rather mundane.

> "I tried my best to think creatively." (Participant A)

> "It was difficult to come up with an analogy easily because I felt like I had to make an analogy that was completely different situation." (Participant B)

Moreover, the participants responded that visualizing made the process of generating an analogy difficult. Producing a coherent drawing of a visual analogy was not easy for the participants because they kept modifying the visual analogy or placing additional lines, circles or boxes while describing the visual analogy verbally. One participant also said that it was difficult to visualize what he intended. This had to more do with the participants' drawing skills to express the intended analogy and less with the difficulty of coming up with a visual analogy.

> "I wanted to express as many things as possible." (Participant D)

> "It was difficult to draw like the examples shown here, as one complete, well-arranged diagram." (Participant A)

# V. Discussion

## 1. Process of Learner-generated Visual Analogy

The process of learner-generated visual analogy presented in this study did not differ largely from those processes of analogical reasoning proposed by previous research. Sternberg (1997b) suggested that there were four stages commonly mentioned by the literature on analogical reasoning: encoding, inference, application and response. Similar to his description, the process consisted of encoding of the learning concept in *understanding concept*, inference and application in *searching for visual analogy*, and *matching*, and response in *elaborating on visual analogy*.

Compared to the previous research, the process of learner-generated visual analogy presented in this study differed in two aspects. First, the learners in this study tended to use verbs as textual cues. By using the verbs that describe the chemical bonding, the learners were able to draw functional relationships between the target concept and the analogy beyond comparing surface features.

The tendency to use verbal cues observed is inconsistent with Gentner (1983)'s structure mapping process. According to the structure mapping process, analogical mapping occurs from text to text or from visual to visual conditions. However, in this study the learners tended to generate a visual analogy based on the textual information. Although the learners produced various visualizations during the process, there was no significant evidence found in this study to suggest that visualizations were the cues for generating a visual analogy. Instead, the visualizations made during the learning were used to organize the learning content and help the learners understand the presented concept. This may be due to the fact that most of the learners did not have enough prior knowledge in chemistry. Without sufficient prior knowledge, they might not have been able to visualize the structure of ionic or covalent bonding that could contribute to the generation of a visual analogy. Had they been able to construct a diagram for chemical bonding processes, visual cues may have affected the visual analogies as suggested by Gentner (1983).

Secondly, the learners showed minimal engagement in evaluating their final visual analogies. Compared to the amount of time spent to understand the presented concept and elaborate on the analogies, the learners in this study spent less time evaluating the quality of analogy and examining the limitations of analogies. The learners also tended to become fixated on one or two analogies instead of trying to come up with several visual analogies and choosing the most appropriate one.

This finding draws contrasts with the results from Wong's research (1993) where the learners validated their own analogies to correct misconceptions. This may be due to the different orientation of the tasks. Wong (1993) used the learner-generated analogies to evaluate learners' explanations of a scientific concept. The learners were asked not only to create and apply the analogy to explain the given concept, but also modify their analogy. In this study, the learners were only asked to create a visual analogy that can explain for chemical bonding. Therefore, the engagement in evaluation can differ depending on how the task is presented to the learners, and when not required, the learners will be less likely to explain the limitations of their visual analogies which can potentially lead to incorrect or excessive mapping.

## 2. Roles of Learner-generated Visual Analogy in Learning

While the use of learner-generated visual analogy supports learning in general, two specific roles of learner-generated visual analogies can be discussed based on the results of the study. First, the learner-generated visual analogy is used as a tool to help understand the structure of a concept. The process of generating a visual analogy revealed that the learners selected and focused on essential information. For instance, in the final visual analogies, such attributes as transferring and sharing electrons were explicitly represented while electron shells or atoms were omitted. In order to make an analogy, the learners needed to not only understand the concept, but also be able to distinguish critical attributes. To distinguish critical attributes, they reread the excerpt several times thoughtfully and identified the structure and relationship between the properties of the presented concept.

Mayer (1993) referred to this process of recognizing and concentrating on the critical attributes as selecting which is one of the three cognitive processes supported by an analogy. In Mayer's framework for metaphoric aids in learning, three possible cognitive processes can be supported by the use of instructional analogy: selecting, organizing, and integrating. The findings in this study suggest that a learner-generated visual analogy facilitates selecting by directing learners' attention toward key information, organizing by using the familiar concept as the framework, and integrating by relating the presented concept and the visual analogy.

Previous research suggested that an analogy in learning serves as an explanatory device or a discovery tool (Gentner & Toupin, 1986; Harrison & Treagust, 1993). In a similar way, the learners in this study used the visual analogies as explanatory devices to understand the new concept. This finding is consistent with the finding presented by Noh et al (2010); learner-generated visual analogies were perceived as helpful to understand scientific concepts.

Lastly, the task of generating a visual analogy encourages the learners to use various visualizing strategies throughout the learning process. The learners did not restrict using visualization to elaborate on a visual analogy, but also used visualization while understanding the presented concept as well as searching for a visual analogy. The learners also used different types of visualizations including simple visualizing, selective visualizing, appendant visualizing, conceptual visualizing, and strategic visualizing.

Previous research on visualizing demonstrated the positive relationship between visualizing and comprehension as they help accommodate and remember incoming information effectively (Cohen & Johnson, 2012; Kulhavy & Swenson, 1975; Sung, Leem, & Kim, 2010). The act of visualizing is also thought to expand one's thinking and facilitate creative thinking (Rha, 2010). Many educational researchers have recognized that visualizing a particular object or concept is an important cognitive ability to improve performance and maximize learning by organizing knowledge (Clark & Lyons, 2004; Kulhavy & Swenson, 1975; Sung et al., 2010). The findings in this study suggest that the use of learner-generated visual analogy can encourage the visualization of learning content, which can support learning.

## 3. Instructional Implications

Based on the findings of this study, the following instructional implications can be drawn. First, it is necessary to provide feedbacks to learners' visual analogy. The learners in this study paid less attention to examining the limitations of their visual analogies. While generating a visual analogy and formulating the connection between the new concept and the familiar concept can facilitate learning, inadequate or excessive mapping can result in misconception. Depending on their previous knowledge and understanding of the concept, learners may also leave out critical information. In fact, the results in this study showed that the learners' visual analogies represented the properties of concept to different extent. Therefore, the learners should be given opportunities to validate their final visual analogies.

Providing feedback can prevent inadequate or excessive mapping since feedback provides explanatory and corrective information regarding the learner performance and the learning process (Choi, 2008; Hattie & Timperley, 2007). An instructor may provide feedback about the quality and limitations of the learner's visual analogy. Feedbacks can also be given by peers. For instance, Pittman (1999) used peer feedback to allow the learners discuss various analogies with others and evaluate their own analogies.

Secondly, when using the learner-generated visual analogy, an instructor needs to guide the generation process to reduce the difficulty of coming up with an analogy. When using the learner-generated analogy, Petrie and Oshlag (1993) highlighted the importance of providing examples of visual analogy. Since learners will most likely be inexperienced in creating a visual analogy, the guidelines regarding the definition and examples of visual analogies can support learners..

In addition to presenting examples, an instructor can provide various cues including both verbal and visual. An instructor should consider presenting different verbal and visual cues because the relationship between the types of cues and analogy mapping is yet to be verified. While previous research has shown that the visual representation of the target concept may trigger an analogy generation (Gentner, 1983; Salih, 2008), the findings in this study showed that the learners were also able to generate a visual analogy from verbal cues. Therefore, an instructor can provide various verbal and visual cues to help learners generate visual analogies.

# VI. Conclusion

The purpose of this exploratory study was to examine the components and the process of learner-generated visual analogy in concept learning, and learner perception of the use of the learner-generated visual analogy. For this purpose, the think-aloud protocol, the visualization data, the interview responses and the survey results analyzed to answer the following research questions:

1. What are the components and process of generating a visual analogy by learners?
2. How do learners perceive the use of learner-generated visual analogy as learning activity?

To examine the process of generating a visual analogy, four learners participated in the study. The participants met with the researcher individually to receive think-aloud training and generate a visual analogy. They were given a text-based excerpt from a Korean high school chemistry textbook about chemical bonding to produce a visual analogy. The entire process was recorded and observed by the researcher. Upon the completion of visual analogy generation, the participants completed the questionnaire followed by the semi-structured interview. The think-aloud protocol was transcribed and coded by two researcher independently using a coding scheme. The coded protocols were aggregated into episodes for further analysis. The visualizations made by the participants were also analyzed according to their visual attributes. Finally, analysis results were integrated to propose the overall process of generating a visual analogy.

The results showed that the learners were engaged in six stages: planning, understanding concept, searching for visual analogy, elaborating on visual analogy, matching, and monitoring. The progression of stages was not in a linear fashion since the learners repeatedly went through understanding concept, searching for visual analogy, elaborating on visual analogy, and matching. The learners spent the majority of time to understand the presented concept and to elaborate on their visual analogies. Throughout the process, the learners also monitored their understanding of the presented concept and the progress of visual analogy generation.

While generating a visual analogy, the learners consistently practiced the five types of visualization: simple, selective, appendant, conceptual and strategic visualizing. In *understanding concept* stage, simple, selective, appendant, and conceptual visualizing were used. In *searching for visual analogy* stage, simple visualizing was occasionally used. In *elaborating on visual analogy* stage, analogy and appendant visualizing was used. Among the five types of visualization, conceptual visualizing and strategic visualizing were used most frequently. The results suggest that the use of visual analogy encourages using visualization through the process.

In terms of learner perception, the learners were generally satisfied with the use of learner-generated visual analogy as learning activity. They perceived the use of visual analogy as helpful and enjoyable, and yet found it challenging to come up with their own visual analogy. By generating a visual analogy, they were able to comprehend the properties of each type of chemical bonding as well as the relationship between the two bonding. Visualizing an analogy was useful to represent and understand their relationship more clearly. Nevertheless, some participants felt pressure to be creative in their analogies and found it difficult to visualize every detail of analogy they produced.

This study used qualitative methodology with a relatively small sample and therefore is limited in providing generalizable results. Considering the findings and limitations of this study, future research is suggested as follows. First, the effects of using a visual analogy should be further examined. Glynn and Takahashi (1998) had previously shown the positive influence of visual analogies presented in the science textbook on learners' recall of the target concept both immediately after the study and after two weeks. Nevertheless, there is insufficient evidence found in this study to conclude that the learner-generated visual analogy supports learner's memory. Therefore, future research can investigate the effects of a visual analogy on learning achievement and retention as well as the comparison between a learner-generated visual analogy and an instructor-generated visual analogy.

Second, future research can investigate the role of visualization in the generation of visual analogies. In this study, learner's visualizations did not directly influence their visual analogies. Instead, the visualizations helped the learners organize and understand the learning content written in text. The mapping seemed to occur between verbal cue and the visual analogy, which was inconsistent with previous research on the structure mapping process (Gentner, 1983). The role of visualization in generating a visual analogy should further be researched which will help comprehend the process of generating a visual analogy more deeply.

Third, the influence of learner characteristics on learner-generated visual analogy can be studied. The scope of this study was limited to examine what learner characteristics affect the process of generating a visual analogy and the properties of learner's visual analogy. The research on such learner characteristics as field dependency and visual tendency, will provide insightful understanding and implications to enhance the use of learner-generated visual analogy.

Lastly, the use of visual analogy in various tasks and domains of learning can be further studied. A majority of research on the use of analogy in learning has concentrated on science since scientific concepts are abstract and unobservable. However, the use of analogy can be explored in various domains and for different learning tasks such as comprehension of text, problem-solving and creative thinking.

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# APPENDIX

## Appendix A: Think-aloud Training Material

### ‘소리내어 생각하기 (Think Aloud)’ 설명

◆ ‘소리내어 생각하기’란?

‘소리내어 생각하기’는 1900년대 초의 내성법에 기반을 두고 있습니다. 내성법은 바깥 세상을 관찰하듯이 의식에서 일어나는 일들을 관찰할 수 있다는 아이디어에서 출발하였으며 과제수행 중간에 자신이 어떠한 생각을 하였는지를 설명하도록 합니다.

‘소리내어 생각하기’는 문제를 해결하는 동안 머리 속에 떠오르는 모든 생각을 말하도록 합니다. 이 때 다른 사람이 개입하거나 질문을 하지 않으며, 다만 ‘소리내어 생각하기’를 중단했을 때는 계속 생각을 말하도록 유도합니다. ‘소리내어 생각하기’는 과제를 수행하는 동안 말하는 것은 거의 자동적으로 이루어지기 때문에 생각의 흐름을 많이 방해하지는 않습니다.

◆ ‘소리내어 생각하기’의 활용 영역

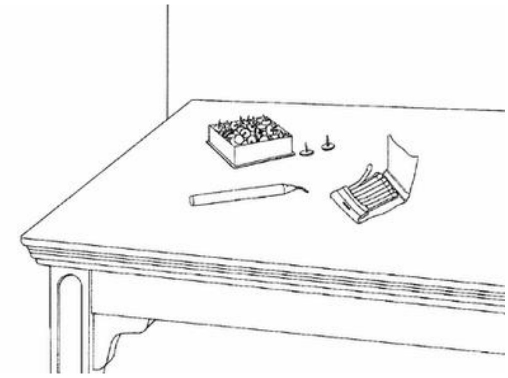
‘소리내어 생각하기’는 다양한 연구분야에서 많이 사용되고 있습니다. 교육공학에서는 과제분석을 하거나 사용편의성 검사를 할 때 사용됩니다. 과제분석은 무엇을 가르칠 것인가를 결정할 때 실시하는데 전문가가 실제 과제를 수행할 때 어떤 지식을 사용하는지를 알아야 할 필요가 있습니다. 사용편의성 검사는 학습자가 컴퓨터로 만들어진 교육자료를 손쉽게 사용할 수 있는 지를 검사하는 것으로서 학습자에게 과제를 제공하고 그 과제를 해결하는 과정에서 ‘소리내어 생각하기’를 하도록 함으로써 교육자료의 문제점을 발견합니다.

또한, 독서교육에서는 ‘소리내어 생각하기’를 통해서 읽기과정을 직접적으로 관찰할 수 있기 때문에 학생들의 읽기능력을 평가하는 방안으로도 활용되고 있습니다.

◆ ‘소리내어 생각하기’ 연습

아래 문제를 해결하면서 자신의 머리 속에 떠오르는 생각들을 모두 말로 표현해 보십시오. 생각을 최대한 많이 말로 표현하는 것이 중요합니다. 문제해결에 필요하다면 종이에 그림을 그리거나 글을 써도 괜찮습니다.

**문제 1)** 아래 그림을 보면 책상 위에 압정이 든 상자, 성냥, 초가 있습니다. 이들 도구들을 이용하여 초를 벽에 부착해 보시오.



**문제 2)** 아래 그림을 보고 <처음 상태>에 있는 둥근 원판들을 <목표상태>로 옮겨 놓으십시오. 단, 큰 원판이 그 보다 작은 원판 위에 올라갈 수 없으며, 한 번에 하나의 원판만을 옮겨 놓을 수 있습니다. 필요하다면 뒤에 제공된 종이에 그림을 그리거나 글을 써도 괜찮습니다.

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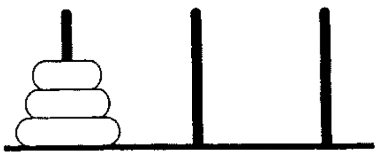

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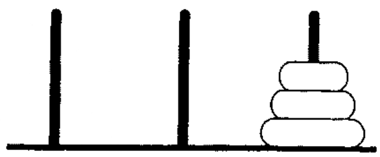


**문제 3)** 다음 글을 읽고 물음에 답하시오.

인간은 성장 과정에서 자기 문화에 익숙해지기 때문에 어떤 제도나 관념을 아주 오래 전부터 지속되어 온 것으로 여긴다. 나아가 그것을 전통이라는 이름 아래 자기 문화의 본질적인 특성으로 믿기도 한다. 그러나 이런 생각은 전통의 시대적 배경 및 사회 문화적 의미를 제대로 파악하지 못하게 하는 결과를 초래한다. 여기에서 과거의 문화를 오늘날과는 또 다른 문화로 보아야 할 필요성이 생긴다.

홉스봄과 레인저는 오래된 것이라고 믿고 있는 전통의 대부분이 그리 멀지 않은 과거에 '발명'되었다고 주장한다. 예컨대, 스코틀랜드 사람들은 킬트(kilt)를 입고 전통 의식을 치르며, 이를 대표적인 전통 문화라고 믿는다. 그러나 킬트는 1707 년에 스코틀랜드가 잉글랜드에 합병된 후, 이곳에 온 한 잉글랜드 사업가에 의해 불편한 기존의 의상을 대신하여 작업복으로 만들어진 것이다. 이후 킬트는 하층민을 중심으로 유행하였지만, 1745 년의 반란 전까지만 해도 전통 의상으로 여겨지지 않았다. 반란 후, 영국 정부는 킬트를 입지 못하도록 했다. 그런데 일부가 몰래 집에서 킬트를 입기 시작했고, 킬트는 점차 전통 의상으로 여겨지게 되었다. 킬트의 독특한 체크무늬가 각 씨족의 상징으로 자리 잡은 것은, 1822 년에 영국 왕이 방문했을 때 성대한 환영 행사를 마련하면서 각 씨족장들에게 다른 무늬의 킬트를 입도록 종용하면서부터이다. 이때 채택된 독특한 체크무늬가 각 씨족을 대표하는 의상으로 자리를 잡게 되었다.

킬트의 사례는 전통이 특정 시기에 정치.사회적 목적을 달성하기 위해 만들어지기도 한다는 것을 보여 준다. 특히 근대 국가의 출현 이후 국가에 의한 '전통의 발명'은 체제를 확립 하는 데 큰 역할을 담당하기도 하였다. 이 과정에서 전통은 그 전통이 생성되었던 시기를 넘어 아주 오래 전부터 지속되어 온 것이라는 신화가 형성되었다. 그러나 전통은 특정한 시공간에 위치하는 사람들에 의해 생성되어 공유되는 것으로, 정치.사회.경제 등과 밀접한 관련을 맺으면서 시대마다 다양한 의미를 지니게 된다. 그러므로 전통을 특정한 사회 문화적 맥락으로부터 분리하여 신화화하면 당시의 사회 문화를 총체적으로 이해할 수 없게 된다.

낯선 타 문화를 통해 자기 문화를 좀 더 객관적으로 바라볼 수 있듯이, 과거의 문화를 또 다른 낯선 문화로 봄으로써 전통의 실체를 올바로 인식할 수 있게 된다. 이러한 관점은 신화화된 전통의 실체를 폭로하려는 데에 궁극적 목적이 있는 것이 아니다. 오히려 과거의 문화를 타 문화로 인식함으로써 신화 속에 묻혀 버린 당시의 사람들을 문화와 역사의 주체로 복원하여, 그들의 입장에서 전통의 사회 문화적 맥락과 의미를 새롭게 조명하려는 것이다. 더 나아가 이러한 관점을 통해 우리는 현대 사회에서 전통이 지니는 현재적 의미를 제대로 이해할 수 있을 것이다.

1. 위 글을 짧게 요약해 보시오.

2. 위 글에 나오는 킬트와 유사한 사례를 생각해 보십시오.

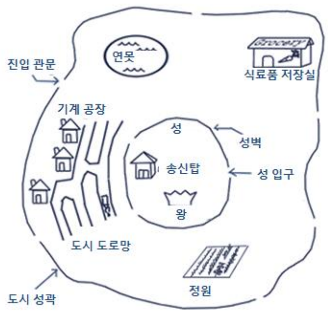
## Appendix B: Visual Analogy Generation Worksheet

<u>시각적 비유 만들기 활동지</u>

지금부터 두 가지 과학 개념을 배우게 될 것 입니다. 먼저 개념을 설명하는 지문을 읽고, 개념을 설명할 수 있는 비유를 그림으로 그려 보세요. 비유란 특정한 현상, 사물, 혹은 개념을 직접 설명하지 않고 비슷한 현상, 사물 혹은 개념에 빗대어 설명하는 것을 뜻합니다.

예를 들면 원자가 쪼개지지 않고 속이 찬 공 모양이라고 한 돌턴의 원자 모형은 딱딱한 구슬에 비유를 할 수 있습니다. 또 원자 안에 (+) 와 (–)전자가 골고루 퍼져 있는 톰슨의 원자 모형은 둥근 빵에 건포도가 골고루 퍼져 있는 모습 혹은 둥근 수박 속에 퍼져있는 수박씨의 모습에 비유를 할 수 있습니다. 아래는 비유를 그림으로 표시한 예입니다.

예시1. 세포 구조에 대한 시각적 비유




예시2. 포화 용액에 대한 시각적 비유


<엘리베이터 정원만큼 사람이 탔을 때>

예시3. 창의성 구성요소에 대한 시각적 비유

다음 지문을 읽은 후, 비유를 그림으로 표현해 보세요.

## 질량 보존의 법칙

얼음이 녹아 물이 되거나 설탕이 물에 용해되는 것과 같은 물리 변화에서는 물질의 상태나 모양이 변할 뿐 질량은 변하지 않는다. 이것은 물리 변화에서는 분자의 배열 상태는 변하지만 분자의 종류와 수는 변하지 않기 때문이다.

그러면 처음 물질과는 다른 새로운 물질이 생성되는 화학 변화가 일어날 때 질량은 어떻게 될까? 서로 다른 두 물질이 반응하여 앙금이 생기는 화학 변화가 일어날 때 질량은 어떻게 되는지 알아보자.

탄산나트륨 수용액과 염화칼슘 수용액이 만나면 탄산칼슘과 염화나트륨이 생성되는데 이 반응이 일어날 때 반응 전과 후의 질량에는 변화가 없다. 이 때 탄산나트륨 수용액과 염화칼슘 수용액의 반응에서 흰색 앙금이 생기는 것은 탄산칼슘이 물에 녹지 않기 때문이다.

탄산나트륨 + 염화칼슘 → 탄산칼슘 + 염화나트륨

$$Na_2CO_3 + CaCl_2 \rightarrow CaCO_3 + 2NaCl$$

화학 변화에서 반응 전과 후의 질량이 변하지 않는 이유는 무엇일까? 각 원자는 고유한 질량을 가진 입자이며, 화학 반응은 분자를 이루는 원자들의 사이의 결합이 끊어져 새로운 분자를 형성하는 변화이다. 화학 변화가 일어날 때 물질을 구성하는 원자들의 배열은 변하지만 원자의 종류나 수에는 변함이 없기 때문에, 변화 전후에는 물질들의 총 질량은 변함이 없이 일정하다.

여러 화학 변화를 조사해 보면 화학 변화에서는 이와 같이 반응 전과 후에 물질의 총 질량이 보존되는데, 이것을 질량 보존의 법칙이라고 한다.

(출처: 중학교 과학 3, 두산동아)

※ '소리내어 생각하기'를 하며 질량 보존의 법칙을 설명하는 비유를 그림으로 표현해 보세요.

예를 들어, "질량 보존의 법칙은 ______________________ 와(과) 같다"라고 비유를 생각하며 그림으로 표현해보세요. 필요하다면 제공된 종이에 그림을 그리거나 글을 써도 괜찮습니다.

최종적으로 선택한 비유는 5쪽에 그려주세요.

(잠시 휴식을 취해도 좋습니다.)

다음 지문을 읽은 후, 비유를 그림으로 표현해 보세요.

## 화학 결합

21세기에 들어와서 생명 과학의 중요성이 매우 커지고 있다. 생명의 기본은 세포이고, 세포 내에서의 모든 활동은 분자들에 의해서 이루어지고 있다. 만일, 원자가 결합하여 분자를 형성하지 않는다면 물과 공기 그리고 생명체도 존재하지 않을 것이다. 그러면 원자들이 결합하여 분자를 형성하는 까닭은 무엇일까?

소금의 주성분 물질은 염화나트륨(NaCl)이다. 염화나트륨 수용액에서 전류가 흐르는 것은 염화나트륨이 나트륨 이온(Na+)과 염화 이온(Cl-)으로 이온화하기 때문이다. 따라서 염화나트륨은 나트륨 이온과 염화 이온이 결합한 물질이라고 생각할 수 있다. 그러면 나트륨 이온과 염화 이온은 어떻게 형성되며, 이들은 어떻게 결합하는 것일까?

원자는 원래의 전자 배치보다 안정한 전자 배치를 이루기 위하여 화학 결합을 한다. 그러나 18족 원소인 비활성 기체는 가장 바깥 전자 껍질이 완성되어 있어 매우 안정하고 균형 잡힌 전자 배치를 이루고 있다. 따라서 쉽게 화학 결합을 형성하지 않는다.

18족 이외의 다른 원자들은 전자를 잃거나 얻어서 비활성 기체와 같이 가장 바깥 전자 껍질에 8개의 전자를 가져 안정해지려는 경향이 있는데, 이것을 옥텟(octet) 규칙이라고 한다. 그러면 이러한 원자들이 어떻게 안정한 전자 배치를 이루는지 알아보자.

일반적으로 금속 원자는 원자가전자(원자의 가장 바깥껍질에 있는 전자)를 잃고 비활성 기체와 같은 안정한 전자 배치를 이루어 양이온이 되려고 하고, 비금속 원소는 전자를 얻어 비활성 기체와 같은 전자 배치를 이루어 음이온이 되려고 한다. 예를 들어, 나트륨(Na) 원자는 전자 1개를 잃고 네온(Ne)과 같은 안정한 전자 배치를 이루는 나트륨 이온(Na+)으로 된다. 또, 염소(Cl) 원자는 전자 1개를 얻어 아르곤(Ar)과 같은 안정한 전자 배치를 이루는 염화 이온(Cl-)으로 된다.

그러면 이러한 이온들은 어떻게 결합을 형성하는 것일까? 전자를 잃기 쉬운 원자와 전자를 얻기 쉬운 원자가 서로 접근하면 전자를 서로 주고 받아 각각 양이온과 음이온으로 되면서 비활성 기체와 같은 안정한 전자 배치를 이루게 된다. 예를 들어, 나트륨 원자와 염소 원자가 만나면 서로 전자를 주고받아 나트륨 이온(Na+)과 염화 이온(Cl-)으로 된다. 이들 두 이온 사이에는 정전기적 인력이 작용하므로 서로 결합하여 염화나트륨을 형성한다.

이와 같이 양이온과 음이온 사이의 정전기적 인력에 의한 결합을 이온 결합이라고 하고, 이온 결합으로 이루어진 물질을 이온 결합 화합물 또는 이온 결합성 물질이라고 한다.

금속 원자와 비금속 원자가 서로 전자를 주고받아 생긴 양이온과 음이온이 결합하면 이온 결합 화합물이 만들어진다. 그러면 비금속 원자들 사이에는 어떤 결합이 형성될까?

수소 원자가 수소 분자를 형성할 때 수소 원자는 2개의 전자를 서로 공유하여 헬륨의 전자 배치와 같은 안정한 전자 배치를 이루게 된다. 이와 같이 두 원자가 각각 전자를 내놓고 전자쌍을 만들어 이 전자쌍을 서로 공유함으로써 형성되는 결합을 공유결합이라 하고, 공유 결합에 의해 만들어진 물질을 공유 결합 화합물 또는 공유 결합성 물질이라고 한다.

또 다른 예로 물 분자는 수소 원자 2개와 산소 원자 1개로 구성되어 있다. 각각의 수소 원자는 산소 원자와 2개의 전자를 공유하여 헬륨과 같은 전자 배치를 이루며, 산소 원자는 네온과 같은 전자 배치를 이룬다. 이 때 두 원자가 공유하는 전자쌍을 공유 전자쌍, 공유하지 않는 전자쌍을 비공유 전자쌍이라고 한다.

(출처: 고등학교 화학 I, 지학사)

※ '소리내어 생각하기'를 하며 화학 결합을 설명하는 비유를 그림으로 표현해 보세요.

예를 들어, "화학 결합은 ________________________________ 와(과) 같다"라고 비유를 생각하며 그림으로 표현해보세요. 필요하다면 제공된 종이에 그림을 그리거나 글을 써도 괜찮습니다.

최종적으로 선택한 비유는 10쪽에 그려주세요.

**Appendix C: Expert Review**

**시각적 비유 작성과정 구성요소에 대한 타당도 설문지**

연구 제목: Learner-generated Visual Analogy: Its Components and Process

본 연구에 사용될 '시각적 비유' 작성과정의 구성요소에 대한 타당도 설문에 참여해 주셔서 감사합니다. 본 연구는 학습자가 화학 결합에 대한 지문을 읽은 뒤 시각적 비유를 작성하는 과정을 밝히는 것을 목적으로 합니다. 시각적 비유의 작성 과정 분석 결과 도출된 구성요소를 7쪽에 제시된 양식에 따라 검토 부탁 드립니다.

감사합니다.

2013년 11월

서울대학교 대학원 교육학과 교육공학 전공

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**Coding scheme**

| Category | Subcategory | | Reference | Description |
|---|---|---|---|---|
| Understand-ing | Conceptualizing | Identifying attributes | Sternberg (1977) | Finding, defining, and describing any concepts, components, properties or principles |
| | | Stating Importance | | Stating the importance of certain content |
| | | Comparing attributes | Sternberg (1977) | Comparing similarities and differences between two or more concepts |
| | | Paraphrasing | | Restating concept in another form, mainly in learners' own words |
| | | Thinking of examples | | Providing learner-generated examples of the concept being learnt |
| | Rereading | | Heo (2006) | Reading aloud, Re-reading important information |
| | | | | Re-reading after confusion |
| Searching | Searching with thinking | | | Stopping think-aloud and thinking about ideas |
| | Searching with finding | | Heo (2006) | Searching for ideas by questioning or brainstorming while thinking aloud |
| | | | | Using paraphrases or personification to search for ideas |

*(table continues)*

| Category | Subcategory | | Reference | Description |
|---|---|---|---|---|
| Explaining | Matching | Matching components | Salih (2008) | Mapping components of the target concept onto the analogy |
| | | Matching principle | | Mapping principles of the target concept onto the analogy |
| | Describing analogy | | | Explaining the learner-generated analogy while or after visualization |
| Modifying | Modifying analogy | | Salih (2008) | Modifying and elaborating the learner-generated analogy |
| Evaluation | Evaluating analogy | | Backer et al (2011) | Checking completeness and/or correctness of the solution |
| | Deciding visualization | | Heo (2006) | Selecting the final analogy |
| Planning | Detecting task demand | | Backer et al (2011) | Reading task instructions, Identifying task |
| | Planning problem-solving approach | | | Developing reading plan, Developing action plan |
| Monitoring | Comprehension monitoring | | Backer et al (2011) | Noting lack of comprehension, Claiming understanding,<br>Demonstrating comprehension by repeating,<br>Demonstrating comprehension by elaborating |
| | Monitoring of progress | | | Reflecting on the quality of the progress made<br>Reflecting on strategy use |

*(table continues)*

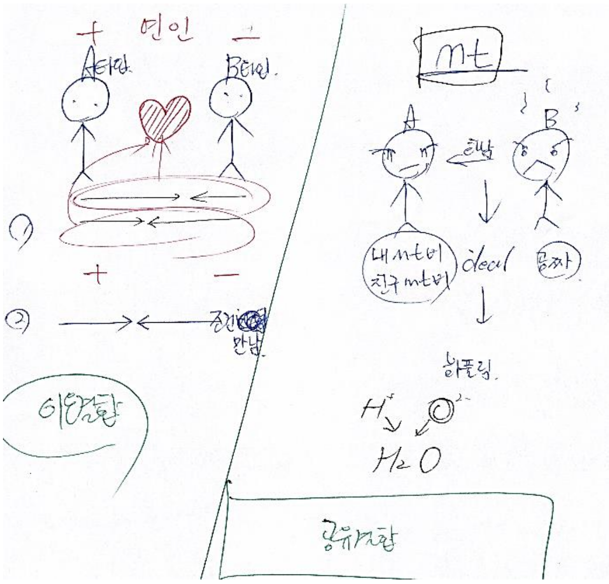
| Category | Subcategory | Reference | Description |
| --- | --- | --- | --- |
| Visualization | Simple visualizing | Heo (2006) | Visualizing without cognitive processing, such as writing down topics |
| | Appendant/assistant visualizing | | Confirming or highlighting what has already been visualized, such as underlining, circling, boxing, or drawing lines to show relationship |
| | Selective Visualizing | | Summarizing or transforming text while making sure of the content |
| | Visualizing with the conceptualization | | Visualizing and representing the text in a logical way |
| | Strategic visualizing with analogy and metaphor | | Visualizing analogy or metaphor |

다음 질문은 앞에서 제시한 구성요소의 타당성을 묻는 것입니다. 질문을 읽고 해당하는 곳에 체크하여 주시기 바랍니다.

| | | 전혀 그렇지 않다 | 그렇지 않다 | 보통이다 | 그렇다 | 매우 그렇다 |
|---|---|---|---|---|---|---|
| 설명력 | 구성요소는 학습자가 시각적 비유를 작성할 때 나타나는 인지적, 메타인지적 활동을 잘 설명하고 있다. | | | | | |
| 타당성 | 학습자가 시각적 비유를 작성할 때 나타나는 인지적, 메타인지적 구성요소로 타당하다. | | | | | |
| 적절성 | 구성요소는 유기적 관련성에 따라 적절하게 분류되었다. | | | | | |
| 보편성 | 구성요소는 보편적으로 적용될 수 있다. | | | | | |
| 이해도 | 구성요소는 쉽게 이해될 수 있도록 표현되었다. | | | | | |
| 기타 의견 | 구성요소에서 보완해야 할 점은 무엇입니까? | | | | | |

**Appendix D: Examples of Learner-generated Visual Analogies**

<Participant A>

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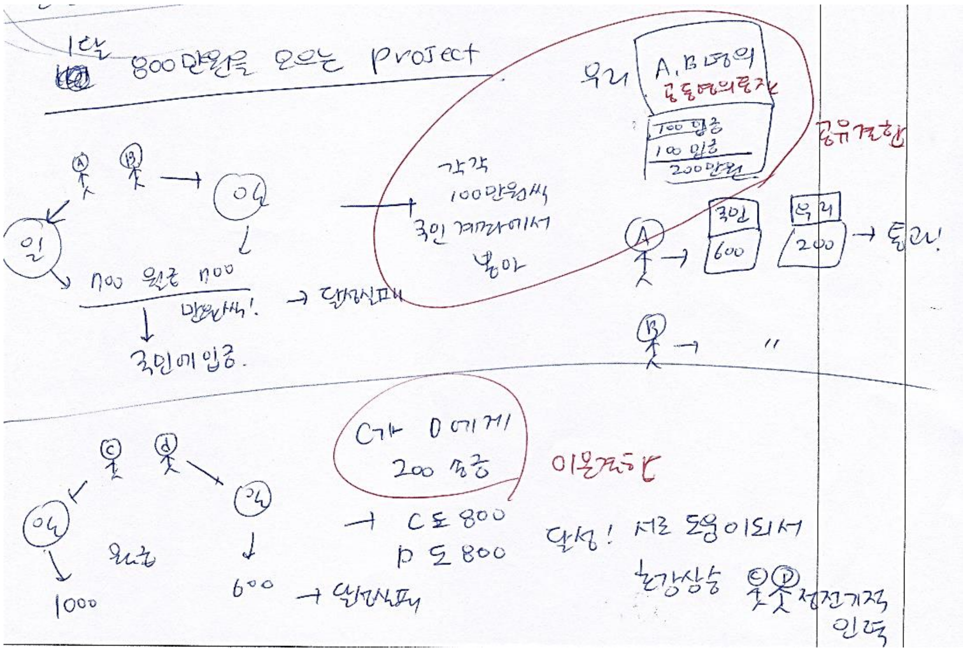

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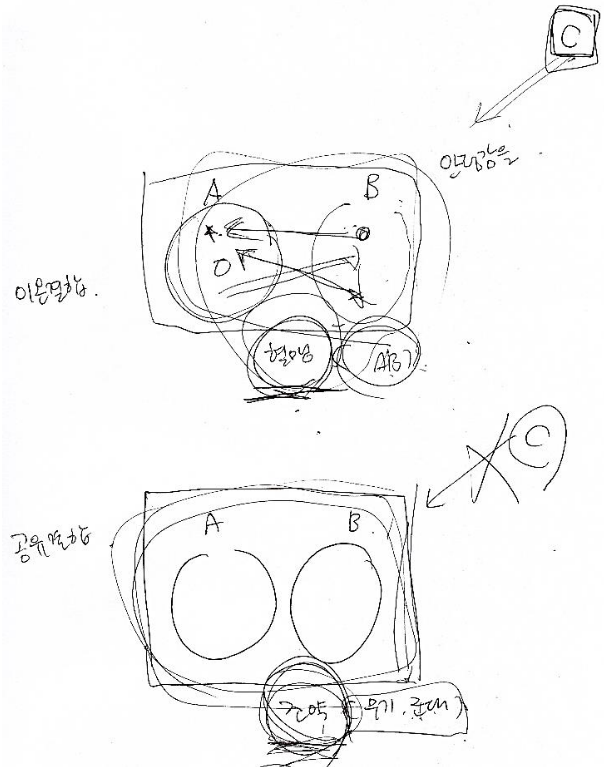
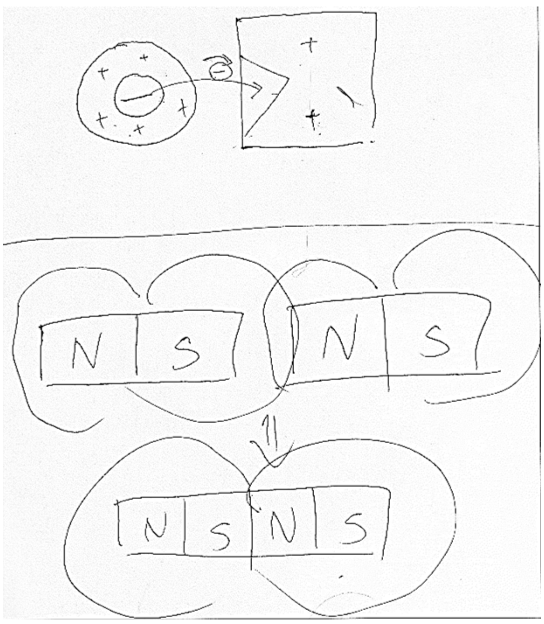



<Participant D>



## Appendix E: Learner Perception Survey Results

| | A | B | C | D | Mean (SD) |
|---|---|---|---|---|---|
| 1. Overall I am satisfied with the learning activity of generating a visual analogy. | 3.00 | 4.00 | 5.00 | 3.00 | 3.75(.96) |
| 2. It was easy to think of a visual analogy relevant to the chemical bonding. | 1.00 | 3.00 | 2.00 | 2.00 | 2.00(.82) |
| 3. The use of visual analogy helped me understand the concept of ionic bond. | 3.00 | 4.00 | 4.00 | 4.00 | 3.75(.50) |
| 4. The use of visual analogy helped me understand the concept of covalent bond. | 3.00 | 4.00 | 4.00 | 4.00 | 3.75(.50) |
| 5. The use of visual analogy helped me understand the relationship (similarity, difference) between ionic bond and covalent bond. | 3.00 | 5.00 | 5.00 | 4.00 | 4.25(.96) |
| 6. I could remember the chemical bonding easily using the analogy. | 2.00 | 4.00 | 3.00 | 4.00 | 3.25(.96) |
| 7. It was fun and novel experience using the visual analogy. | 4.00 | 5.00 | 4.00 | 5.00 | 4.50(.58) |
| 8. I gained confidence about chemical bonding using the visual analogy. | 2.00 | 5.00 | 2.00 | 3.00 | 3.00(1.41) |
| 9. My interest for chemical bonding increased using the visual analogy. | 3.00 | 5.00 | 3.00 | 4.00 | 3.75(.96) |
| 10. I would like to recommend using a visual analogy to a friend. | 4.00 | 4.00 | 5.00 | 5.00 | 4.50(.58) |
| Mean score | 2.80 | 4.30 | 3.70 | 3.80 | 3.65(.62) |

# 국문초록
# Abstract in Korean


## 학습자의 시각적 비유 작성 요소와 과정에 대한 탐색 연구



홍 서 연
서울대학교 교육학과
교육공학전공



비유는 개념 학습에서 활용되고 있는 효과적인 전략 중 하나로써 연구가 꾸준히 이루어지고 있다. 교수-학습에서 비유는 학습자에게 친숙하지 않은 개념과 친숙한 개념을 대응시켜 설명하는 전략으로 사용된다. 선행연구에 따르면 비유는 개념구조의 생성, 재구조화, 가시화를 통해 개념 이해에 긍정적인 효과를 가진다. 특히 시각적 비유는 비유물과 목표 개념의 대응 관계를 명확하게 제시한다. 한편, 이러한 비유 활용의 효과는 대응 관계에 대한 학습자의 이해와 비유물 자체에 대한 학습자의 친숙도에 따라 달라질 수 있다. 학습자가 비유물이나 대응관계를 이해하지 못 할 경우, 비유는 개념 이해에 긍정적인 영향을 미치지 못한다. 따라서 친숙도를 높이기 위해 학습자가 직접 비유를 생성하는 방법이 제안되었으나, 학습자의 시각적 비유 작성과정과 인식에 대한 연구는 부족한 실정이다.

따라서 본 연구의 목적은 학습자가 직접 시각적 비유를 작성할 때 구체적으로 어떠한 과정을 거치는지 살펴보고, 학습자 작성 시각적 비유 활용에 대한 인식을 밝히는 데에 있다. 이러한 연구 목적을 달성 하기 위해 20대의 성인학습자 4명을 대상으로 소리내어 생각하기 프로토콜 분석과 시각화 속성 분석을 통해 시각적 비유 작성 과정을 탐색하였다. 또한 인터뷰와 설문지를 통해 시각적 비유 활용에 대한 학습자 인식을 살펴보았다. 수집된 자료는 선행연구와 전문가 타당화를 바탕으로 개발된 코딩체계에 따라 분석하였다.

연구 결과 학습자는 계획, 개념 이해, 시각적 비유 탐색, 시각적 비유 정교화, 대응, 모니터링의 총 여섯 개의 단계를 걸쳐 시각적 비유를 작성하는 것으로 나타났다. 특히 학습자는 개념 이해와 시각적 비유 정교화 단계에 대부분의 시간을 할애하였는데, 개념 이해 단계에서 제시된 지문을 다시 읽어보고 주요 특성을 확인하며 특성 간 공통점과 차이점을 비교하였다. 시각적 비유 정교화 단계에서는 시각적 비유를 묘사하고 수정하였다. 시각화 속성에 따라 학습자가 생성한 시각화 자료를 분석한 결과, 학습자는 단순 시각화, 부가적 시각화, 선택적 시각화, 개념적 시각화, 전략적 시각화를 지속적으로 사용하였다. 학습자 인식으로는 자신이 작성한 시각적 비유가 각각의 하위 개념과 개념들간의 관계를 이해하는 데에 도움을 준다고 인식하였다. 시각적 표상을 하는 것에 대해서는 학습 과정과 시각적 비유 작성 과정을 모니터링하는 데에 도움이 된다고 인식하였다. 또한 시각적 비유 작성 활동이 학습 내용에 대한 흥미를 증진시킨다고 응답하였지만, 시각적 비유를 떠올리는 데에 어려움을 겪는다고 응답하였다.

연구결과를 바탕으로 학습자가 작성한 시각적 비유가 학습에서 갖는 두 가지 역할에 대하여 논의하였다. 첫째, 시각적 비유를 만들기 위하여 개념의 주요 특성을 확인하고 정교화하는 학습자의 활동은 선택적 부호화를 활성화하여 개념의 이해를 돕는 도구로 사용된다. 둘째, 시각적 비유를 작성하는 과제는 비유 자체만을 시각화하는 것에 제한되지 않고, 학습 내용을 시각화 하는 것을 촉진한다. 또한, 연구결과는 시각적 비유의 정확성에 대한 평가를 적게 하는 학습자에게 오개념과 부적절한 대응을 예방하기 위해 피드백을 제공하고 시각적 비유를 생성하는 데에 느끼는 어려움을 줄이기 위해서 다양한 언어적 및 시각적인 단서를 제시할 필요가 있음을 시사한다.

**주요어 : 시각적 비유, 학습자 작성 시각적 비유, 유추사고, 시각지능**
**학 번 : 2012-21334**

# AN EXPLORATORY STUDY ON THE COMPONENTS AND PROCESS OF LEARNER-GENERATED VISUAL ANALOGY

**By**

**SEOYON HONG**

Master's Thesis

Submitted to the Faculty of the Graduate School of
Seoul National University

In partial fulfillment of the requirements for the Degree of
Master's in Education

Major: Educational Technology

February 2014

# AN EXPLORATORY STUDY ON
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Seoyon Hong

Academic Advisor: Ilju Rha, Ph.D.

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December 2013

Approved by the Committee:

| | | |
|---|---|---|
| Chair | Dr. Cheolil Lim | ______________________ |
| Vice Chair | Dr. Young Hoan Cho | ______________________ |
| Committee | Dr. Ilju Rha | ______________________ |

# ABSTRACT

An Exploratory Study on the Components and Process of
Learner-generated Visual Analogy

Seo Yon Hong

Advisor: Dr. Ilju Rha
Degree: Master's Degree in Education
Major: Educational Technology

The ability to reason by analogy is an important feature of human cognition and creativity, which is pervasively used in both everyday life and expert thinking. In education, analogies are used to introduce a new concept by associating it with what learners already know. Previous research on instructional analogies has shown their positive effects on learning, and has hence proposed instructional models that incorporate them in teaching, such as Teaching With Analogies Model by Glynn (1989) and the General Model of Analogy Teaching by Zeitoun (1984). While valuable, this type of research only posits limited insight on how learners generate analogies and how they perceive the use of a visual analogy. Thus, the depth of insight into instructional strategies for effective and engaging activities is also limited.

The purpose of this study was to understand how learners generate visual analogies and perceive the use of visual analogies in learning by using think-aloud protocol analysis, visual task analysis, interview and survey. Four learners participated in this study to generate their own visual analogies about chemical bonding while thinking aloud. The collected protocol and visualization data were analyzed using the coding scheme developed from literature review.

The results showed that the learners were engaged in six stages: planning, understanding concept, searching for visual analogy, elaborating on visual analogy, matching, and monitoring. They spent the majority of time to understand the presented concept and to elaborate on their visual analogies. In *understanding concept*, the learners reread the excerpt, identified critical attributes, and compared attributes. In *elaborating on visual analogy*, they described and modified visual analogies. Nevertheless, the learners were hardly engaged in evaluating the limitations of their final visual analogy. In terms of visualization, the learners consistently used the following five types of visualization: simple, selective, appendant, conceptual and strategic visualizing. Moreover, the learners perceived the use of visual analogy as helpful for understanding the learning content and also enjoyable. Yet they found it challenging to come up with their own analogy.

Based on the findings, the following implications can be drawn. First, the process of generating visual analogy is not necessarily supported by visual cues. In this study, the learners tended to use verbs as cues to come up with analogies, which implies providing various verbal and visual cues for learners to facilitate the generation process when using learner-generated visual analogies. Second, the learners' minimal engagement in evaluating their visual analogies may explain the possible misconception caused by analogies, which thus suggests the need for providing feedback. Third, the use of learner-generated visual analogy is used as a tool for understanding abstract concept not only by associating it with a familiar concept, but also by selectively attending to the critical attributes of the concept learnt. Finally, the task of generating a visual analogy encourages visualization of both the analogy itself as well as the learning content, which can support learning.

Keyword: *visual analogy, learner-generated visual analogy, analogical reasoning, human visual intelligence*

Student ID: 2012-21334

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# I. INTRODUCTION

## 1. Background of the Study

Learning is largely associated with understanding a concept because concepts play essential roles in human reasoning (Jonassen, 2006). Concept learning serves as a foundation for principle and procedure learning as well as for higher order thinking (Gagné, 1968; Jonassen, 2006; Lim, 2012). Recognizing such importance of concept acquisition, educational researchers have explored various ways to introduce new concepts and to facilitate more effective concept learning. Some examples of these instructional strategies include providing an advance organizer, constructing a concept map, and presenting example and non-example cases (Ausubel, 1977; Driscoll, 2005; Merrill, 1983; Novak & Cañas, 2006).

In particular, Ausubel (1977) emphasized the importance of relating a newly learned concept to what learners already know, distinguishing meaningful learning from rote learning (Ausubel, 1977; Driscoll, 2005). To help learners connect the new concept and their prior knowledge, Ausubel suggested the use of advance organizer and anchoring idea. An advance organizer used at the beginning of learning activates learners' prior knowledge and presents a framework of materials to be learned. An anchoring idea refers to the specific, relevant idea already stored in learners' cognitive structure and it provides the entry points for new information to be connected (Driscoll, 2005). By suggesting these instructional strategies, Ausubel (1977) highlighted the importance of connecting the learning content to learners' prior knowledge in concept learning.

In a similar way, Reigeluth (1999) suggested the use of instructional analogies as to bridge the newly learned concept to the familiar concept. An analogy can be defined as "an explicit, non-literal comparison between two objects that describes their structural, functional, and/or causal similarities" (Gentner, 1983; Newby, Ertmer, & Stepich, 1995). Indicating a comparison between two objects, an analogy consists of the following form: "X is like, may be compared to, resembles, or works like Y" (Stepich & Newby, 1988a). In teaching-learning context, analogies have largely been used as explanatory devices or as discovery tools (Harrison & Treagust, 1993). The instructional analogy serves as a bridge between the new concept, also referred to as the target concept, and the familiar concept in learners' prior knowledge (Gentner, 1983). For instance, in explaining the structure of a cell structure, an instructor can use an analogy of a city and relate each component in the cell to the attributes of a city. The cell wall may be associated with the city border, the water vacuole with the water dam, and the atom with the government of the city.

The findings from previous research have demonstrated the effects of instructional analogies in enhancing conceptual understanding, retention, application of a new concept and motivation. Newby et al. (1995) conducted the experimental studies to examine the immediate and delayed effects of instructional analogy on learning physiological concepts. The results showed that the college students who received the instruction with the analogy performed significantly better than those who did not receive the analogy, both immediately and after a delayed time. Harrison and Treagust (1993) also found that using analogies which are familiar to learners and represent the shared attributes precisely can promote conceptual understanding. Furthermore, Venville and Treagust (1996) identified the key roles of analogies in conceptual change as a sense maker, a memory aid, a transformer, and a motivator.

The term analogical reasoning is used to describe the cognitive process of producing and interpreting an analogy. It involves the transfer of structural or relational information from the analogy to the target (Vosniadou & Ortony, 1989). Regardless of how remote the analogy and the target are, successful analogical reasoning depends upon the capability to perceive similarities and differences (Vosniadou & Ortony, 1989). When integrated in instruction, analogical reasoning requires learners to think about similarities and differences between the newly learned concept and their prior knowledge as well as integrate the new concepts into the existing schema.

Analogies can be delivered verbally, visually or using both verbal and visual representations. A verbal analogy is an analogy explained in written or spoken language whereas a visual analogy, also named a pictorial analogy, is presented in forms of a diagram or a picture. The studies that compare the effects of verbal analogy and visual analogy have shown the effectiveness of visual analogy in learning complex concepts (Noh, Yang, & Kang, 2010). This is because visual analogies convey the relation between the target concept and the analog more clearly (Bean, Searles, Singer, & Cowen, 1990). Furthermore, Curtis and Reigeluth (1984) explained that the use of analogy leads to recognize a relationship in terms of a visual while comparing and contrasting two concepts from different domains. This implies that analogies may cause visual thinking. Therefore, visual analogy which overtly depicts the relation between the target concept and the source concept can support conceptual understanding.

Among other determinants of the effectiveness of instructional analogies, research findings reveal that the familiarity of the analogies is crucial (Choi, 2012). To maximize the familiarity of the analogies, learner-generated analogies have been examined for their influence on learning (Noh et al., 2010). For instance, Lee, Kim, and Kim (2003) compared the effects of analogies generated by text developer, by instructor, and by students. The results showed that the student-generated analogies were more effective for simple concept learning, while the instructor-generated analogies were more effective in conveying complicated concepts. Since the essence of analogy is the comparison between the familiar concept and the unfamiliar concept, the learning effectiveness of analogy depends on how familiar the learners are with the analogy used. Therefore, if learners were to generate an analogy for themselves instead of being given an instructor-generated analogy, learners will be inclined to use familiar concepts which can thus promote conceptual understanding (Wong, 1993).

According to Noh et al. (2010), self-generated visual analogies were perceived as helpful to understand scientific concepts, to improve creative thinking, and to increase motivation and interest in science. Being given the opportunity to develop their own analogies, learners reported that they were able to translate the scientific concepts into familiar language. Compared to other types of learning activities, self-generated visual analogies were perceived as stimulating creativity more because the learners needed to make a comparison across seemingly unrelated concepts. Lastly, the learners felt that the process of analogy generation increased motivation since it was novel and interesting experience (Noh et al., 2010).

In addition, Wong (1993) conducted a qualitative study to examine the effects of learner-generated analogies as a learning task. He viewed the process of creating an analogy as a problem solving task, and thus, designed an analogy task according to the literature on analogical reasoning models and problem solving. The results showed that the use of learner-generated analogies not only enhanced the understanding of a scientific phenomenon, but also enabled the learners to correct misconceptions by validating the accuracy of their own analogies. Furthermore, Glynn (2007) also insisted that even when instructors provide an analogy, it may be helpful to ask learner to create their own analogies to verify that learners have not formed misconceptions.

While several researchers have proposed instructional models for instructors to incorporate verbal and visual analogies in teaching (Brown & Clement, 1989; Glynn, 1991; Kim, 1991; Zeitoun, 1984), there has been relatively little research on learner-generated visual analogies. Consequently, there is a need to develop a set of strategies to support learner-generated visual analogies for effective learning. Previous research on instructional models for instructors provide only limited insight on how learners generated analogies and how they perceive the use of visual analogies. The question of whether the process of learner-generated visual analogy differs from the process of analogical reasoning proposed by previous research is valuable to ask. Moreover, there is also a need to understand what difficulties the learners experience while generating a visual analogy.

Therefore, the purpose of this study was to examine the components and the process as well as the learner perception of learner-generated visual analogy in concept learning. Based on the results of this study, the process of learner-generated visual analogy, the role of learner-generated analogy in learning and the instructional implications were discussed.

## 2. Research Questions

The purpose of this exploratory study was to examine the components and the process of learner-generated visual analogy as well as the learner perception of the use of visual analogy. The components and the process of learner-generated visual analogy were examined by using think aloud method and protocol analysis. The learner perception was examined by the interview and the survey questionnaire. For these purposes, the following research questions were investigated in this study.

1. What are the components and process of generating a visual analogy by learners?

2. How do learners perceive the use of learner-generated visual analogy as learning activity?

# 3. Definition of Terms

## 3.1 Concept Learning

Concepts are “representations of classes of objects, symbols, or events” that share common properties or attributes (Jonassen, 2006; Merrill, 1983). Bruner, Goodnow, and Austin (1967) defined concept learning as “the search for and listing of attributes that can be used to distinguish exemplars from non-exemplars of various categories”. Concept learning in this study refers to learning not only the attributes of concepts, but also relationships among concepts (Jonassen, 2006).

## 3.2 Analogy

An analogy is defined as “an explicit comparison between two objects that describes their structural, functional, and/or causal similarities” (Gentner, 1983; Newby et al., 1995). An analogy consists of a target, an analog, and a connector (Gentner, 1983; Stepich & Newby, 1988b). In educational context, an analogy is used to introduce an unfamiliar concept by relating to a concept already familiar to learners. Hence, a target refers to the concept to be learned. An analogy is a familiar concept that learners already know. A connector reflects the relation between the target and the analog. Sometimes, more detailed explanations regarding both similarities and differences between the target and the analog may also be provided.

## 3.3 Learner-generated Visual Analogy

A learner-generated visual analogy in this study refers to an analogy that is formulated by learners and expressed mainly in visual form. It may be accompanied by labels and supplementary explanations in text, but the main mode of representation is visual. A learner-generated visual analogy contains the three elements of an analogy aforementioned (Gentner, 1983; Wong, 1993).

# II. LITERATURE REVIEW

## 1. Analogy

### 1.1 The Use of Analogies in Learning

In discussing the use and effects of analogy in learning, it is necessary to first review the definition of an analogy. Gentner (1983) defined an analogy as “an assertion that a relational structure that normally applies in one domain can be applied in another domain”. He also distinguished an analogy from other kinds of domain comparisons (Gentner, 1983). The four types of domain comparisons are literal similarity, analogy, abstraction, and anomaly. To understand the difference between each type of domain comparisons, a few preliminaries are necessary. First, there is an object-attribute shared between the target and the source. These object attributes include structural characteristics like color, size and shape. Then, there is relational predicate which is relations between objects. Let us take an atom and solar system for instance. The comparison of round shapes between an atom and the sun is shared object attributes. That the electron revolves around the nucleus like the plants do around the sun points to relational predicate.

The degree of attributional similarity and relational similarity between the source and the target differentiates each type of domain comparisons as shown in Figure II-1. According to Gentner and Markman (1997), *analogy* exhibits a high degree of relational similarity with little attribute similarity. At the opposite end of analogy is *mere-appearance* which exhibits a high degree of attribute similarity, but no relational similarity. *Anomaly* shares neither significant attribute nor relational similarities. *Metaphor* covers a wide range from relational comparisons to attribute comparisons.

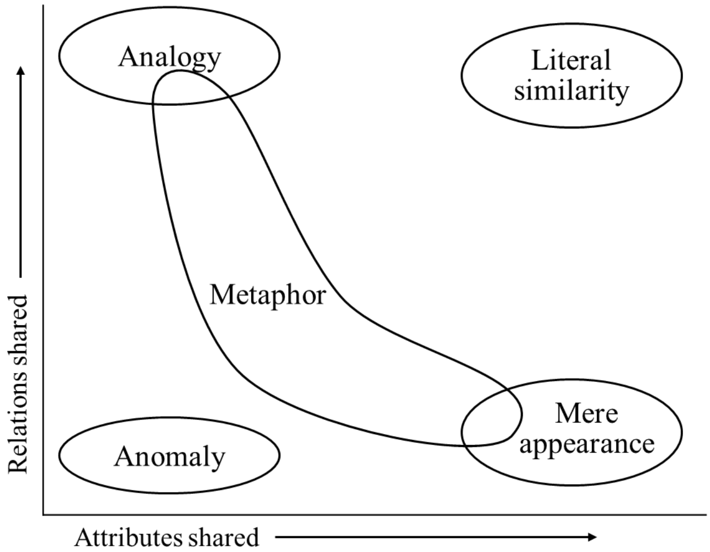



Figure II-1. Similarity Space (Gentner & Markman, 1997)

In teaching-learning context, analogies have largely been used as explanatory devices or as discovery tools by bridging a familiar concept and an unfamiliar concept (Gentner & Toupin, 1986; Harrison & Treagust, 1993). A familiar concept is what learners already know, also referred to as the source, the base domain, or schema already existing in memory (Vosniadou & Ortony, 1989). It serves as the analogy to which similarities and differences are transferred (Gentner, 1983). An unfamiliar concept is what learners need to learn, mostly called the target concept (Gentner, 1983). Many learning theories, such as

Ausubel's meaningful learning, constructivist learning theory, and Piaget's assimilation and accommodation, demonstrate the importance of creating connections between the new information and pre-existing knowledge (Pittman, 1999). And analogies act as cues to stimulate such connection.

In particular, the use of instructional analogies has been pervasive in science education because science is rich with concepts that are abstract and cannot directly be observed by senses (Vosniadou & Ortony, 1989). Analogies can help understanding concepts by visualizing the abstract concepts and by comparing the concept to the similarities of learner's real world (Duit, 1991; Thiele & Treagust, 1994). Curtis and Reigeluth (1984) analyzed analogies used in science textbooks, and concluded that analogies were most useful for complex and difficult concepts. They found that analogies based on structural relationship were used for easier, more concrete concepts while analogies based on functional relationship were used for more difficult and abstract concepts (Curtis & Reigeluth, 1984). Newby et al. (1995) conducted the experimental studies to examine the immediate and delayed effects of instructional analogy on learning physiological concepts. The control group received instruction without analogy while the experimental group received instruction with analogy. The results showed that college students who received instruction with analogy performed significantly better than those who did not receive analogy.

More recently, with the increased focus on constructive learner-centered learning, learner-generated analogies have been examined. Pittman (1999) insisted that the use of analogy may fail if the learners do not understand the analogy itself. Lee et al. (2003) examined the effect of analogies generated by textbook developers, instructors and learners. In this study, the analogies were either presented by the textbook developers or the instructors or generated by the learners in learning the concept of plate tectonics. The results showed that the instruction using the student-generated analogies was more effective than when the analogies were presented by textbook developers and instructors. However, the learners perceived that the analogies generated by textbook developers were more accurate than those generated by themselves. As evident in this study, the learner-generated analogy has shown to support learning.

### 1.2 Classifications of Analogy

Instructional analogies can be classified into various categories. In fact, several researchers have analyzed analogies used in instruction and in textbooks and attempted to present classification schemes of analogies (W. H. Choi, 2012; Curtis & Reigeluth, 1984; Pae & Chung, 2006; Thiele & Treagust, 1994; Venville & Treagust, 1996). Table II-1 summarized these classifications.

Analogical relationship refers to the nature of relationship between the target concept and the analog. The analogous relationship can be structural, functional, or both structural-functional. The presentation format refers to how the analogy is expressed verbally or visually. The condition of analogy refers to the content of the target concept and the analogy, and can be divided into three categories: concrete-concrete, abstract-abstract, and concrete-abstract. The position of analogy is the placement of analogy in terms of when the analogy is introduced to learners. Analogies can be introduced at the beginning of instruction, during the instruction and at the end of instruction. The level of enrichment is determined by how much explanation is presented. A simple analogy contains the target, the analog and the connector, whereas an enriched analogy states both the grounds for and the limitations of analogous relationship. The different roles of analogies identified by the educational researchers include a sense maker, a memory aid, a transformer, and a motivator.

Table II-1. Analogy Classification Schemes

| Curtis & Reigeluth (1984) | Thiele & Treagust (1994) | Venville & Treagust (1996) | Choi (2003) | Pae & Chung (2006) |
|---|---|---|---|---|
| Analogical relationship | | | Analogical relationship | |
| Presentation format | Format | | | Presentation |
| Condition | | | Condition | Condition |
| Position | | | | Placement |
| Level of enrichment | Level of enrichment | | Level of enrichment | Level of enrichment |
| | Analog explanation | | Description | Explanation |
| | Limitation | | | Limitation |
| | | Role of analogy | | Role of analogy |
| | | | Systemicity | |
| | | | Source of analogy | |

## 1.3 Visual Analogy

There are two major ways to communicate an analogy: verbal representation and visual representation. Visual analogies are also called pictorial analogies or graphic analogies (Issing, 1990; Spezzini, 2010). Previous studies have shown the effects of combining verbal and visual analogies. Verbal analogies stimulate learners to visualize an obscure, abstract concept (Bean et al., 1990). However, the shortcomings of verbal analogies are that the learners need to read and interpret the verbal description of the analogies, drawing the analogies in their mind. Depending on the learners' visual tendency and knowledge of the analogy content, they may not be able to visualize the analogy as intended, which can lead to misconception. In contrast, visual analogies can help learners' visualization by explicitly presenting the analogy and thus, enhance learners' understanding of a concept (Bean et al.,1990; Schwartz, 1993). They are, in other words, short-cuts to direct comparisons (Spezzini, 2010). Therefore, the visual analogies facilitate the visualization of verbally communicated analogies as well as restrict learners' arbitrary visualization, supporting more accurate comprehension of the analogy presented to the learners (Kim, 1991)

Researching findings have shown the effects of visual analogies in learning. Issing (1990) investigated the effects of visual analogies in a physics course. The results showed that the visual analogies supported learners' understanding of structural and functional concepts. Moreover, Salih (2008) also recommended the use of visual representation of the analogy, the target concept or both to assist the analogical reasoning and understanding. Sometimes, analogies may be represented both verbally and visually. Bean et al. (1990) studied the effects of visual analogies in high school biology class and found that the students who received both visual and verbal analogies showed better comprehension.

# 2. Analogy-related Reasoning

## 2.1 Case-based Reasoning

Case-based reasoning (CBR) is a model for problem that draws upon past experiences of a person (Aamodt & Plaza, 1994). Although CBR is largely used to understand and perform problem-solving, it can also help to understand the process of analogical reasoning since both of these cognitive process rely on previous experience and prior knowledge. CBR model explains that a problem is solved by finding a similar past case and reusing it in the new problem situation. In fact, in order to retrieve a similar case from long term memory, one is required to make a comparison and choose the most appropriate case. Therefore, both the analogical reasoning and CBR involve similar cognitive processes of forming a connection, applying and modifying the chosen object or case. The retrieved case which is used to solve the given problem can even be treated as intra-domain analogy. In this respect, CBR and analogy can be regarded almost as synonyms, and hence the discussion of CBR is relevant to this study.

Aamodt and Plaza (1994) insist that CBR utilizes specific knowledge of previously experienced, concrete problem situations which are referred to as *cases*. A case means a problem situation in CBR; a past case denotes a previously experience situation and a new or unsolved case is a new problem. Another important aspect of CBR is that it is an approach to “incremental and sustained learning” because each time a problem has been solved a new case is retained for future problem.

The CBR cycle has four major processes of retrieving, reusing, revising and retaining (Aamodt & Plaza, 1994). First, when a new case is defined, the most similar previous case is retrieved from the case library. During this process, matching of the new problem and the past case takes place. Secondly, the solution and knowledge from the retrieved case is reused to solve the new case. Then, the process of revising the proposed solution from the retrieved case takes place by applying it to the real life situation or evaluating the outcome. If failed to solve the new case, the proposed solution is revised. Finally, the case is retained as a new learned case or as a modified case. In this process of CBR, both general and specific knowledge plays a role. While specific knowledge is represented the retrieved case, general knowledge operates to support the overall processes. Figure II-2 below demonstrates the CBR cycle.

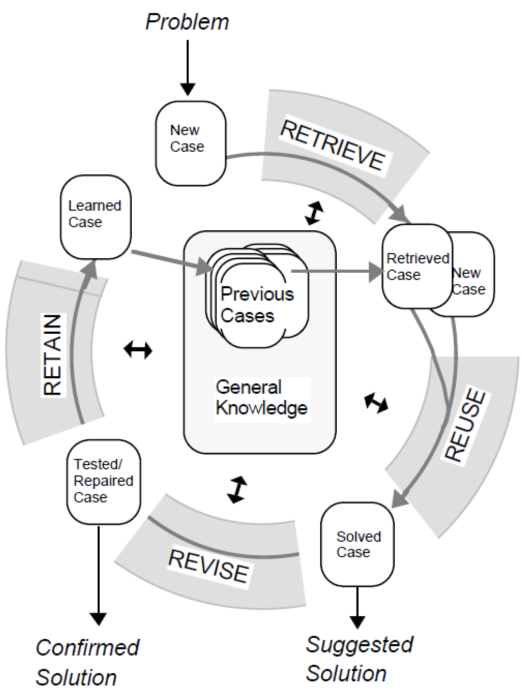



Figure II-2. Case-based Reasoning Model (Aamodt & Plaza, 1994)

So how does each process of retrieving, reusing, revising and retaining work? And what knowledge do we need in this process? To understand the CBR processes more in depth, it is necessary to look at tasks, methods employed, and knowledge needed for each process. These subordinate elements described what is required in order to practice CBR. Tasks are the goals for each process. Methods are applied to perform tasks. And to apply methods, respective knowledge is required. There may be several subtasks under the top-level task. For instance, in the retrieve process, one needs to identify relevant descriptors, search to find a past case, match the relevant descriptors to the past case and select the most similar case. The task decomposition of CBR is shown in Figure II-3. Tasks are written in bold letters, while methods are in italics. Straight lines represent the relation between tasks, and stippled lines the relation between tasks and methods.

Studies have shown empirical evidence for CBR, demonstrating the role of previous experiences in problem solving and learning. For instance, experts like fire commanders rely heavily on past experience than on abstract principles when making decisions with a high degree of uncertainty (Klein & Calderwood, 1988). Also in learning a new skill, people tend to use past experience (Aamodt & Plaza, 1994; Jonassen & Hernandez-Serrano, 2002). Recognizing such prevalent role of case, instructional designers have researched different strategies not only to engage learners' past experience in learning, but also to provide meaningful learning experience. Jonassen and Hernandez-Serrano (2002) suggested using narrative stories to offer learners indirect experiences. These stories provide much richer examples that they will serve a similar role in CBR as direct experience. Anchored instruction and goal-based scenarios also have similar approaches.

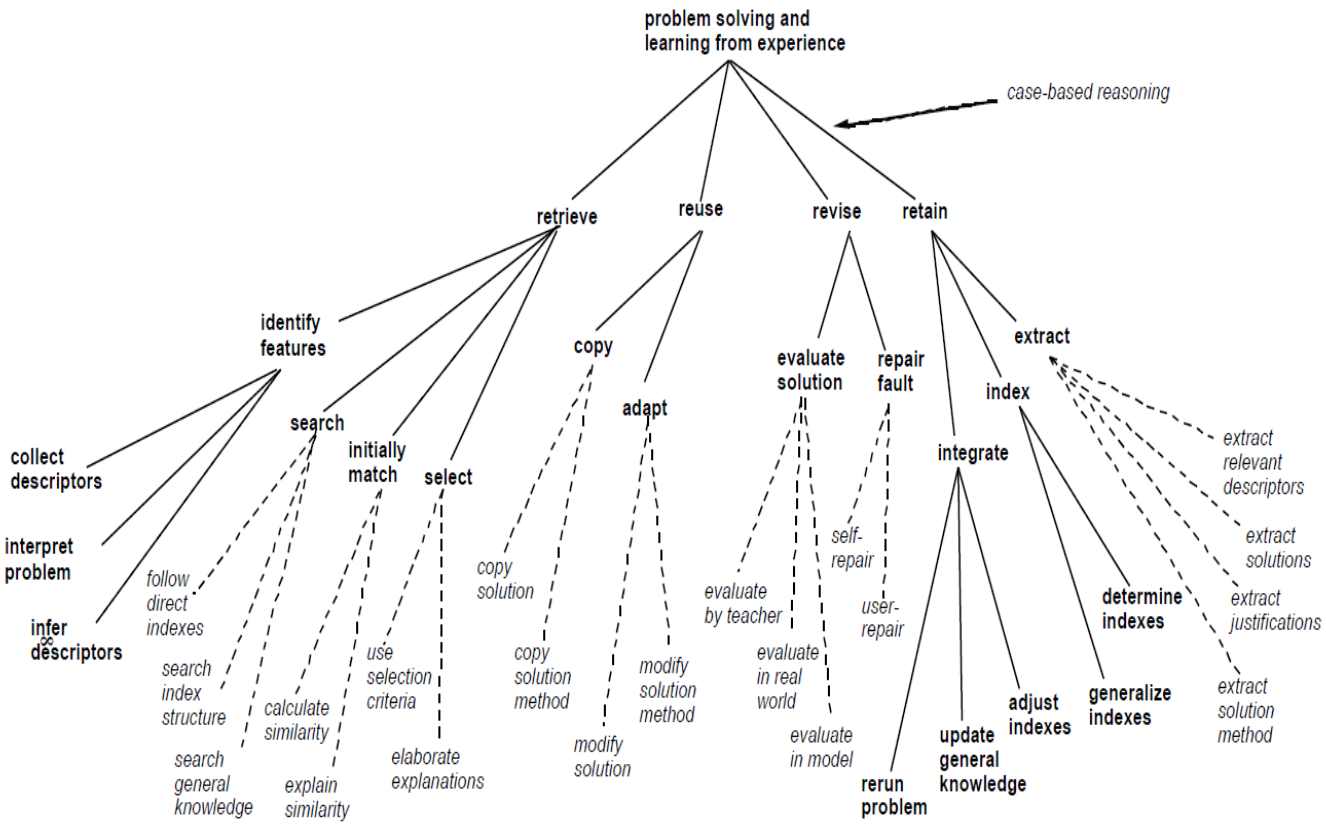



Figure II-3. Task Decomposition of CBR (Aamodt & Plaza, 1994)

## 2.2 Analogical Reasoning Models

Reasoning by analogy is pervasive in everyday way of thinking and speaking (Lakoff & Johnson, 1980; Sternberg, 1977a). When we try to explain something novel or make a decision in an unusual situation, we think based on what we know or have experienced from the past (Sternberg, 1977a). What is and what involves in such reasoning process? Rumelhart and Abrahamson (1973) distinguished analogical reasoning from remembering. In contrast to remembering which operates based on contents stored in memory, analogical reasoning operates based on the memory structure or relationships between concepts stored in memory. Therefore, following this definition of reasoning, Rumelhart and Abrahamson (1973) further explained that reasoning would involve judgment of the similarity or dissimilarity between concepts. In trying to understand the process of analogical reasoning, psychologists have presented models of analogical reasoning from different perspectives. In this section, few of these theories from information processing theory and componential theory will be briefly reviewed.

Coming from the perspective of information-processing theory, Spearman (1973) proposed three major principles (Sternberg, 1977b). These principles, in order, are apprehension of experience, eduction of relations, and eduction of correlates. The apprehension of experience involves encoding of the base concept and the presented analog. That is, the person first needs to understand basic characteristics of each. Based on such mental representation, the person then recognizes and draws out a relation between the base and the analog, inferring the relational rule between the two. According to Spearmen (1973), a relation refers to any attribute that mediates between two or more concepts. Finally, once the person recognizes the existence of relation between the base and the analog, the education of correlates takes place by applying the inferred rule to produce a new analog by associating (Sternberg, 1977b).

Shalom and Schlesinger (1972) also identified the selection rule and the connection formula in analogical reasoning (Sternberg, 1977b). The selection rule refers to the logical relationship among analogy terms. The connection formula means a particular formula employed by the individual to recognize the relationship among analogy terms. Analogical reasoning is the formation and application of the connection formula by the individual. According to Shalom and Schlesinger (1972), the person may go through a trial-and-error process before finding the final analogy.

Furthermore, Johnson (1962) insisted that analogical reasoning involves such problem-solving operations as inductive and deductive operations. During the inductive operation, the person will identify the specific attributes of the target and the analog and draw a relation between them. The deductive operation, then, corresponds to the process of applying the relation (Sternberg, 1977b).

Moreover, Sternberg (1977a, 1977b) proposed the componential theory of analogical reasoning. In this theory, the process of analogical reasoning is fragmented into three general categories under which six information-processing components exist. The three general categories of components are attribute identification, attribute comparison, and control. These components occur consecutively. The attribute identification involves forming an internal representation upon which further reasoning is based. The person first needs to identify attributes and values of the base term. The attribute comparison occurs by inferring the existence of relations, forming an analogous rule, applying the rule, and testing the validity of operations. Finally, the control component involves producing a response by identifying a new analog, and monitoring such selection. According to Sternberg (1977b), some components of analogical reasoning may repeat until the person had decided that he has reached an unique analogy solution.

Although the analogy related reasoning reviewed here stem from different theoretical background, they overlap in certain way. For instance, both Spearmen (1973) and Sternberg (1977b) recognized first understanding the base and the target term. Though being given different names, all of the aforementioned analogical reasoning models share the components of analogous relation inference and application. In general, the process of analogical reasoning seems to proceed in four major steps: encoding the target, inferring the relation, applying the relation, and responding to create an analog. In fact Sternberg (1977b) have compiled five of the analogical reasoning models to see the overlapping procedures of analogical reasoning and the resulting comparison is shown in Table II-2.

Table II-2. Literature on Analogical Reasoning (Sternberg, 1977b)

| | Johnson (1962) | Shalom & Schlesinger (1972) | Spearmen (1973) | Sternberg (1977b) |
|---|---|---|---|---|
| Encoding | | | Apprehension of experience | Attribute identification |
| Inference | Inductive | Forming a connection formula | Education of relations | Attribute comparison |
| Application | Deductive | Applying the connection formula | Education of correlates | |
| Response | | | | Control |

## 2.3 Learner-Generated Analogical Reasoning Model

Most of analogical reasoning models examined the process of finding an analogy when given a set of the base term, the analog, and the target as they are based on an analogy test. Although it still involves formulating a new analogy, it is different from the process of learner-generated analogy in that the learner needs to establish an analogical relation on his or her own instead of having to identify and apply the relation decided externally.

Salih (2008) proposed the model of learner-generated analogical reasoning which involves three phases: reception phase, interaction phase, and emergent phase. In the reception phase, the learner is exposed to the target concept that is to be learnt, and establishes understanding of the concept. In the interaction phase, the learner tries to create an analog by repeatedly comparing and modifying it to best represent the target concept. Salih (2008) insisted that in this phase, learner's analogy generation process is affected by learners' emotion, presented stimulus, and recall. Learners need to be motivated in order to engage in analogy generation process. Stimulus refers to key words and structural features of the target concept that facilitated the generation of analogies. Recall refers to remembering the attributes of both the target and the analog concepts. Learners need to reserve the access to both of these concepts in order to generate analogies. Salih (2008) also insisted that learners will go through several steps of matching, evaluating, modifying and creating analogies until they are settled with the final analogy. In the emergent phase, the final analogy is produced and expressed either verbally or visually. Figure II-4 illustrates the self-generated analogical reasoning model.

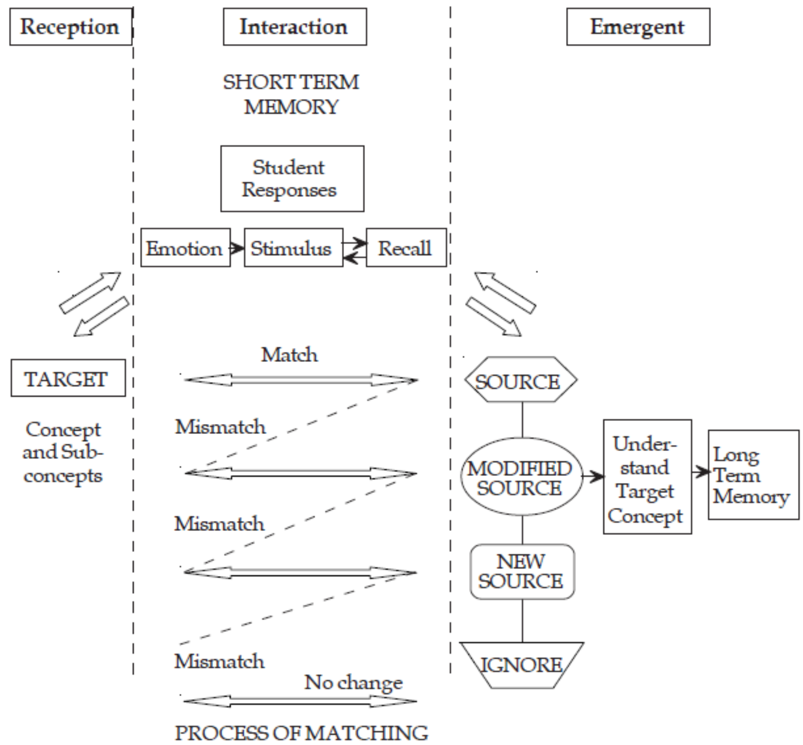



Figure II-4. Self-generated Analogical Reasoning Model (Salih, 2008)

Salih's self-generated analogical reasoning model shares commonalities with the models described in Table II-2 to some extent. For instance, both Sternberg (1977b) and Salih (2008) stated that one may repeat the process of producing, validating, modifying or creating analogies several times. Another similarity is that the models include a stage or phase of understanding the target concept, identifying its attributes and matching the target concept and the generated analogy.

## 2.4 Analogy and Visual Intelligence

In this section, the concept of visualization and visual intelligence will be briefly reviewed in relation to analogy and analogical reasoning. Analogy and visual intelligence have been thought to be related to each other. Curtis and Reigeluth (1984) insisted that the use of analogies causes visual thinking to occur. By visual thinking, they refer to mental images or models that are formed while comparing and contrasting the target concept and the analogy. The use analogies, according to Curtis and Reigeluth (1984), leads to see a relationship in terms of a picture

Heo (2006) presented three perspectives of visualization depending on how it is defined and used in different fields of study. The first perspective sees visualization as phenomenalizing. It is external representation like an image or an illustration. Visualization is treated only as a physical output. Therefore, from this perspective, visualization and visual materials used in education are judged by their effectiveness to deliver learning content. The second perspective, however, understands visualization as internal representation and mental imagery. Visualization in itself is seen as thinking process. Finally, the third perspective views visualization as one type of cognitive system. Similar to Gardner (1983)' theory of multiple intelligence, this perspective accepts the concept of 'visual intelligence'. It focuses on ability to use visual intelligence to reproduce external knowledge or information in a meaningful way.

Winn (1982) differentiated visualization used in education into two: visualization in learning and visualization in instruction. According to him, visualization in learning refers to visualization as an internal cognitive processing by learners. For instance, Rha's and Stevick's definition of visualization falls into this category. According to Rha (2007) and Stevick (1986), visualization is a mental process for explaining, expecting, operating, and creating objects, processes or events through imagery formats. In contrast, visualization in instruction is about supporting strategies. For instance, Gilbert's definition of visualization belongs to this category; he defined visualization as "the systematic and focused visual display of information in the form of stables, diagrams, and graphs" (Gilbert, 2005).

Zeitoun (1984) specified visual imagery as one of the elements that are thought to be related to analogical reasoning performed by learners. His statement is also supported by Winn (1982) who insisted that analogy involves visual processes. The process of recognizing attributes and forming a structural relation between the target concept and the analogy necessarily involves visualization either internally or externally (Winn, 1982). Which part of human visual intelligence is involved in analogical reasoning? To answer this question, it is necessary to first review the human visual intelligence theory.

Rha (2003, 2010) stated that human visual intelligence involves three dimensions: interpretation, operation, and creation. The interpretation dimension involves understanding the external physical environment. Very naturally, human beings tend to interpret and react to what they see through their vision. We judge height, distance and existence in reacting to physical world that we live in. Secondly, human beings can operate visual representations inside their brain. For example, when we make visualizations of how to get to a certain restaurant, we are operating physical objects visually. Another example can be found in imagery training. Imagery training is widely used in sport by visualizing mental rehearsal. Tiger Woods once said that he always visualized before the swing. In addition to physical objects, visual operation also can apply to conceptual objects, and this visual operation in fact is involved in analogical reasoning partially, if not unavoidably. Finally, the third operation of human visual intelligence is creation. Creation is rather unrealistic and mystic aspect of visual intelligence. For instance, dreams, futuristic visualization, and illusions are affiliated with creation operation. At this point, it is limited to understand creative capacity of human visual intelligence.

# III. METHODS

## 1. Research Procedure

The purpose of this study was to examine the components and process of learner-generated visual analogy and to investigate learner's perception and satisfaction of using visual analogy as learning activity. For this purpose, the study used think-aloud protocol analysis, interview and survey. The overview of the research procedure is shown in Figure III-1.

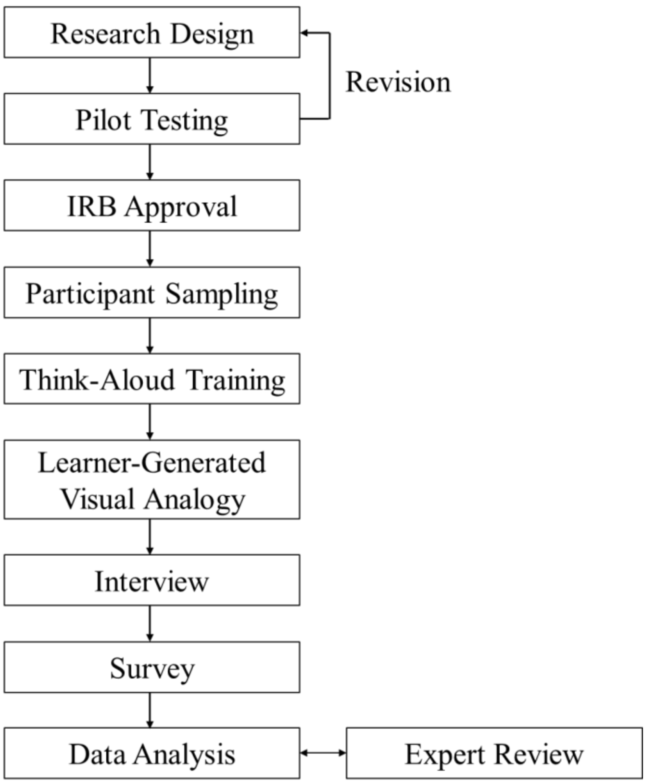



Figure III-1. Research Procedure

First, literature review on analogical reasoning, analogy, visualization, and think-aloud protocol was conducted to develop the think-aloud training material and the visual analogy generation task. The think-aloud training material was adopted from Cho (2005) who used the think-aloud method to examine the analogical transfer process in problem solving. The training material included solving visual problems, summarizing a text, and thinking of a case related to the text. In order to prepare a reading passage for visual analogy, an excerpt from the high school chemistry textbook was used. The concept of chemical bonding was chosen for the study since it consists of two sub-concepts of ionic bond and covalent bond, which therefore asks the participants not only to understand individual attributes, but also to compare and contrast between the two sub-concepts.

Then, the pilot study was conducted with a graduate student with major in education to improve the developed passages and instructions for learner-generated visual analogy. After the pilot study, he suggested that the participants should be briefly introduced to what a visual analogy is and given some examples. He also mentioned giving enough time for the participants to think about and generated a visual analogy. Revisions were made to include a brief introduction to what a visual analogy is and some examples of visual analogies. One practice question on generating a visual analogy about the law of conservation of mass was added so that the participants will be familiarized to the task.

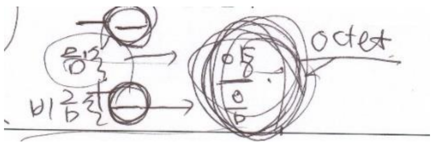
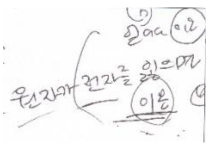
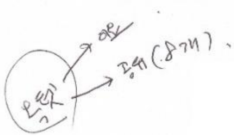
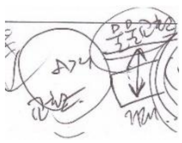
Four learners participated in the study individually, and the whole process took approximately two hours. First, the participants were trained in the think-aloud method for 30 minutes. The researcher explained the background and the application of the think-aloud method and showed a demonstration. Then, the participants were given problem solving questions to practice think-aloud. During the practice, the researcher intervened only to help the participants to continue thinking aloud. After the think-aloud training, the researcher explained the definitions of an analogy and a visual analogy used in teaching and learning and some examples of visual analogies.

After the think-aloud training, the participants completed the visual analogy generation task for two science concepts: the law of conservation of mass and the chemical bonding. The entire process was audiotaped and observed by the researcher. The researcher did not interfere except when the participants stopped thinking aloud for more than ten seconds. Only if then, the researcher encouraged the participants to continue to think aloud. The researcher recorded non-verbal data such as hand gestures and body movements as well as visualization activities. The experiment was finished when the participants decided they had generated the analogies that sufficiently explained the concepts.

When the participants finished generating the visual analogies, the researcher conducted a follow-up interview. In order to clarify the participants' thinking and reasoning process and strategies, the researcher asked the participants to reflect upon their process of making an analogy. The researcher also asked about why the participants had come up with such analogies, what difficulties they experienced, how they thought about visualizing an analogy and if they had used analogies to study before. The interview was audiotaped. In addition to the interview, the participants completed the survey questionnaire and rated each item on a 5-point Likert scale.

Consequently, in this study, two types of data were collected: verbal protocol and visualization data. Verbal protocol refers to the verbal data collected from the think-aloud method (Van Someren et al., 1994). Visualization data includes visualizations, such as notes, diagrams, and visual analogies, generated by the participants during the task. For analysis, raw verbal protocol was transcribed into text with timestamps. Following the guidelines for analyzing think-aloud data, verbal data was segmented at points where there was a sentence break or a pause for more than three seconds (Ericsson & Simon, 1993; Van Someren et al., 1994). Secondly, visualization data was scanned as digital images, fragmented into smaller coherent pieces and given id numbers as shown in Table III-1. Finally, the collected data was coded independently by two researchers.

Table III-1. Examples of Fragmented Visualization Data

| Data ID | Visualization |
|---|---|
| C-1 |   |
| C-2 |  |
| C-3 |  |
| C-4 |  |

## 2. Participants

Data was collected from four participants, two males and two females aged between 23 and 27. Three of the participants were college students and one graduate students. The major of three participants was not related to science and thus had very little background in science. Only one participant had high prior knowledge in science. All of the participants were from Seoul, South Korea. Though different institutions, they all attended institutions located in Seoul. The demographics of the participants are shown in Table III-2.

Similar to other qualitative research methods, the think-aloud method seeks rich data from a small sample (Fonteyn, Kuipers, & Grobe, 1993). This non-random convenience sample was used because the task of generating a visual analogy while practicing think-aloud required certain level of cognitive ability. According to Piaget (1964), the fourth developmental stage called formal operational stage from adolescence through adulthood is when theoretical and abstract thinking as well as inductive and deductive reasoning start to develop. In addition to the task of generating a visual analogy, the participants were also asked to think-aloud. Although research has shown that the think-aloud method does not interfere with thought and regulation process (Van Someren, Barnard, & Sandberg, 1994), it can still cause working memory overload. Therefore, it was necessary to select participants who would be able to handle such cognitive process.

Moreover, this particular sample was selected because of the verbalization skills that were necessary for collecting think-aloud protocol data. According to Van Someren et al. (1994), verbalization skill is one of the important properties to consider when selecting participants for a think-aloud study. While there may be individual differences, young children usually find it difficult to engage in thinking aloud (Van Someren et al., 1994). Therefore, college or graduate students who would be more capable of thinking aloud were selected for this study.

Table III-2. Participant Demographics

| Participant | Age | Gender | Major |
|---|---|---|---|
| A | 25 | Male | Economics |
| B | 23 | Female | Science |
| C | 27 | Female | Education |
| D | 26 | Male | Korean History |

# 3. Data Collection and Instruments

## 3.1 Think-aloud Method

Initially, the think-aloud method was developed from the introspection in psychological research (Van Someren et al., 1994). The introspection assumed that a researcher can observe internal events occurring in one's consciousness as one can observe events in the outside world. With the wave of behaviorism, however, the introspection method received criticisms for its limitations in scientific, objective analysis. Variations of introspective methods followed by using verbal reports as data. With verbal reports, the researchers could avoid subjective interpretation. Moreover, while retrospective interview or survey may be inconsistent with the participant's cognitive and metacognitive processes during the task, the think-aloud verbal data is more likely to be complete and consistent with the participant's thinking (Fonteyn et al., 1993).

The think-aloud method is being used to investigate a variety of research topics in both psychological and educational research. It is used to investigate expert knowledge, problem solving process, reading comprehension, usability testing for online or computer-mediated learning environment, and visualization process (Davey, 1983; Eveland Jr & Dunwoody, 2000; Heo, 2006; Van Den Haak, De Jong, & Jan Schellens, 2003). While the aforementioned research uses think-aloud as research methodology, other educational research has also shown that the think-aloud method in itself can be applied as an instructional or learning strategy. For instance, Baumann, Seifert-Kessell, and Jones (1992) showed that the think-aloud instruction promoted elementary students' comprehension monitoring abilities.

With the instructions for think-aloud and some practice tasks, the think-aloud method is expected not to interfere with one's thinking (Ericsson & Simon, 1998; Van Someren et al., 1994). The verbal protocol, which is the verbal reports collected from the think-aloud method, consists of rather incomplete sentences or phrases because the participants do not monitor their verbalization process. Also, the verbal protocol often provides a relatively incomplete record of complex cognitive processes which can be complemented by conducting a follow-up interview. Moreover, using analysis methods with high inter-coder reliability, it is possible to explore many aspects of cognitive and meta-cognitive processes from the think-aloud verbal protocol (Ericsson & Simon, 1998).

## 3.2 Visual Analogy Generation Task

The visual analogy generation task consisted of two parts: reading an excerpt on a science concept and generating a visual analogy. Nonetheless, prior to generating their own visual analogies, the participants needed to understand what a visual analogy is and to get used to thinking about a visual analogy. Therefore, several examples of visual analogies were presented, for each of which the researcher also provided oral explanation.

Two science concepts, the law of conservation of mass and chemical bonding, were selected from Korean middle school and high school science textbooks. Since the textbooks are authorized by the Ministry of Education, the excerpts from the science textbooks were used without editing. However, all visual diagrams were removed. This was to reduce possible influence of visual cues on the participants' analogies since visual representations can serve as an anchoring to structural analogies. As a result, only the textual information was presented to the participants, which might have hindered deeper understanding of chemical bonding. Following the excerpt, the task instruction was given to the participants as follows: "Please draw an analogy that can explain chemical bonding while thinking aloud. For example, you can think about what chemical bonding is like, and visualize your analogy. You may write or draw on the scratch paper provided". The participants were given blank papers and a four-color pen.

Since the law of conservation of mass was an easier concept adopted from a middle school science textbook, it was expected that the participants had already learned the concept. Hence, it was used as a practice question for the participants to get used to generating their own visual analogies and performing the think-aloud method. Consequently, the visual analogies for the law of conservation of mass were not included in the analysis for this study. Only the visual analogies pertaining to the chemical bonding was analyzed.

The topic of chemical bonding was selected for the following reasons. First, it was complex enough with two subordinate principles of ionic bonding and covalent bonding. The participants were expected not only to identify two different types of chemical bonding, but also to compare and contrast between the two. Second, chemical bonding is generally a difficult and yet basic topic for those students who do not have much prior knowledge in chemistry.

## 3.3 Interview

When the participants finished generating visual analogies, a follow-up interview was conducted to further clarify the process of learner-centered visual analogy generation and to investigate the learner satisfaction and perceived helpfulness. The interview was semi-structured. The interview questions were prepared prior to the experiment, consulting to the previous research (Noh et al., 2010). First, the researcher asked the participants to reflect on and explain the steps in which they made the analogies and some thoughts they had while making the analogies. They were also asked why they came up with such analogies, if they had any previous experience of using analogies, if they were satisfied with their own analogies, and how visualizing an analogy had helped their learning. Table III-3 shows the interview questions.

Table III-3. Interview Questions

1. Please explain your own analogy. Why did you choose this as your final analogy?
2. Can you recall and explain the steps you took to create the analogy?
3. Why do you think you made this analogy? (E.g. similar shape or size, recent experience, etc.)
4. What were the difficulties you experienced during making your own analogy?
5. How did making an analogy help you learn the concept of chemical bonding?
6. How did drawing an analogy help you learn the concept of chemical bonding?

*(table continues)*

7. How did drawing an analogy help you make your own analogy?
8. How well does it represent the concept of chemical?
9. Have you used your own analogy or heard a teacher's analogy before for your study? If so, please explain the learning content and the analogy.
10. In your past experience, how did the analogy help you learn?

## 3.4 Survey Questionnaire

The survey was conducted to measure learner perception and satisfaction. Learner perception is an important construct to examine particularly for learner-centered learning activity (Chung & Lim, 2000). It provides meaning insights for instructional designers to decide if an instructional strategy or learning activity will be reused and how it can be further improved. In this study, the questions were adopted from the study by So and Brush (2008) and Lim (1999). So and Brush (2008) examined perceived learner satisfaction in a blended learning environment. They constructed ten items, and the Cronbach's alpha coefficients were .85. Lim (1999) explored factors affecting learner satisfaction in the web-based online discussion, and the Cronbach's alpha coefficients were .93. The total of ten items were constructed to examine overall satisfaction with the learner-centered visual analogy generation activity. The participants were asked to rate each item on a scale from 1 (strongly disagree) to 5 (strongly agree).

## 4. Data Analysis

### 4.1 Protocol Analysis

Protocol analysis is a technique for analyzing qualitative verbal data collected from the think-aloud method which avoids bias and subjectivity. Protocol analysis is used predominantly for the study of cognitive processes (Van Someren et al., 1994). Previous research using the think-aloud method examined the problem solving process, the metacognitive activities, the visualization process, and the analogical transfer process (Cho, 2005; De Backer, Van Keer, & Valcke, 2012; Heo, 2006). Transcribed verbal protocols are coded with a coding scheme and sometimes for further analysis, are aggregated into episodes which correspond to a single element in the propose model (Van Someren et al., 1994). In this study, the purpose of protocol analysis was to examine the cognitive and metacognitive components and process during the visual analogy generation task. The analysis process is shown in Figure III-2 below.

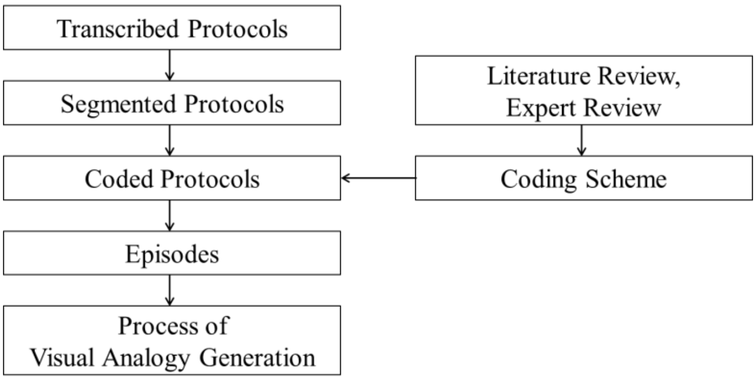



Figure III-2. Protocol Analysis Process

The first version of coding scheme was developed from literature review. Relevant researches were found using such keywords as ‘self-generated analogy’, ‘think-aloud’, and ‘visualization’. The coding scheme was mainly based on three studies on the visualization process of verbal information; the learners’ metacognitive knowledge; and the learner-generated analogical reasoning model (De Backer et al., 2012; Heo, 2006; Salih, 2008). Then, two researchers made revisions by analyzing the verbal protocol from the pilot study using the first version of coding scheme. The second version of coding scheme was then reviewed by three experts, one Ph.D. in educational technology and two doctoral candidates in educational technology. The experts reviewed the components and rated on a 5-point Likert scale regarding explicability, validity, appropriacy, generality, and comprehensibility. The mean scores for each criteria were 5.00 for explicability, 5.00 for validity, 4.00 for appropriacy, 4.67 for generality, and 4.67 for comprehensibility. Revisions were made after reviewing experts’ comments. The final protocol coding scheme is shown in Table III-4.

Table III-4. Protocol Coding Scheme

| Category | Subcategory | Description | Coding code |
| --- | --- | --- | --- |
| Understanding concept | Identifying attributes | Finding, defining, and describing any concepts, components, properties or principles | UIA |
| | Identifying critical attributes | Stating the importance of certain content | UIC |
| | Comparing attributes | Comparing similarities and differences between two or more concepts | UC |
| | Paraphrasing | Restating concept in another form, mainly in learners' own words | UP |
| | Thinking of examples | Providing learner-generated examples of the concept being learnt | UE |
| | Rereading | Reading aloud; Re-reading important information; Re-reading after confusion | UR |
| Searching for analogy | Searching with thinking | Stopping think-aloud and thinking about ideas | ST |
| | Brainstorming | Searching for ideas by questioning or brainstorming while thinking aloud; Using paraphrases or personification to search for ideas | SB |
| Matching | Matching components | Mapping components of the target concept onto the analogy | MC |
| | Matching principle | Mapping principles of the target concept onto the analogy | MP |

*(table continues)*

| Category | Subcategory | Description | Coding code |
|---|---|---|---|
| Elaborating analogy | Describing analogy | Explaining the learner-generated analogy while or after visualization | ElD |
| | Modifying analogy | Modifying and elaborating the learner-generated analogy | ElM |
| Evaluating analogy | Evaluating analogy | Checking completeness or correctness of the analogy | EvA |
| | Deciding final analogy | Selecting the final analogy | EvD |
| Planning | Detecting task demand | Reading task instructions; Identifying task | PD |
| | Planning problem-solving approach | Developing reading plan; Developing action plan | PA |
| Monitoring | Comprehension monitoring | Noting lack of comprehension; Claiming understanding; Demonstrating comprehension by repeating; Demonstrating comprehension by elaborating | MoC |
| | Progress monitoring | Reflecting on the quality of the progress made; Reflecting on strategy use | MoP |

Two researchers, both master's students in educational technology, analyzed the segmented verbal protocols independently using the coding scheme after practicing coding with the data collected from the pilot study. Once the researchers finished analyzing the segmented verbal protocols, they discussed to resolve differences in coding. The inter-coder reliability was substantial (Kappa = .88). The coded protocol was aggregated into episodes which represented one category in the coding scheme. Following the method used by Cho (2005) and Heo (2006), segmented protocols were aggregated into one episode if three or more protocols were coded as the same category consecutively. Until another episode appeared, it was assumed that the previous episode continued.

Once all episodes were identified, individual participant's process was examined by analyzing how episodes were related to each other. Then, the general process of learner-generated visual analogy was schematized based on most frequently observed episodes and stages. The final process of learner-generate visual analogy was presented after investigating the percentages of time spent for each episodes.

## 4.2 Visualization Analysis

The verbal protocol collected from the think-aloud method heavily contains information regarding the participants' thinking process during the visual analogy generation and relatively little regarding the visualization process. Thus, in order to examine the visualization process, it was necessary to analyze visualization data, including notes, diagrams, and visual analogies made by the participants. The visualization analysis used the five categories of visualization presented by Heo (2006). Originally Heo (2006) suggested six categories of visualizing according to the visual attributes; however, the sixth category–visualization with rehearsal for teaching– did not appear in this study and thus, not included in the final coding scheme (see Table III-5).

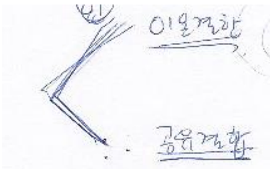
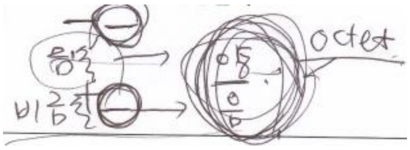
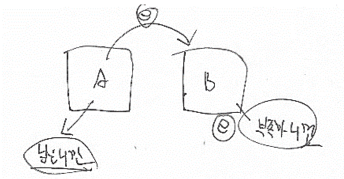
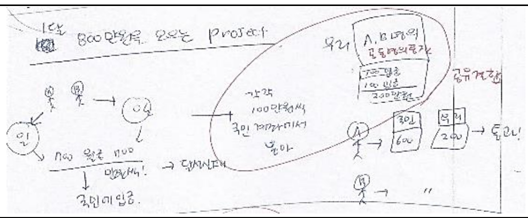
Table III-5. Visualization Coding Scheme

| Category | Description |
|---|---|
| Simple visualizing | Visualizing without cognitive processing, such as writing down topics |
| Appendant visualizing | Confirming or highlighting what has already been visualized, such as underlining, circling, boxing, or drawing lines to show relationship |
| Selective Visualizing | Summarizing or transforming text while making sure of the content |
| Conceptual Visualizing | Visualizing and representing the text in a logical way |
| Strategic Visualizing | Visualizing analogy or metaphor |

The first category is simple visualizing which involves visualizing without much cognitive processing. Examples of simple visualizing are copying down titles, subtitles, or concept names. The second category is appendant visualizing which is confirming or highlighting what has already been visualized, such as underlining, circling, boxing, or drawing lines to show relationship. The third category is selective visualizing. It is summarizing or writing down a certain part of text that the learner has selected while reading text. Selective visualizing is different from simple visualizing in that the learner verifies the content and transforms the original text that he or she chooses to summarize or pay attention to. The fourth category is conceptual visualizing. It refers to visualizing and representing information by the learner's own logical way, including diagrams, graphs and tables. In this study, the term was modified to conceptual visualizing. Finally, the fifth category is strategic visualizing. Whereas the former categories involves visualizing the incoming information, strategic visualizing with analogy and metaphor associates the incoming information with concepts or objects from a different domain for effective learning. Table III-6 shows examples for each visualization category.

The fragmented visualization data was combined with corresponding verbal protocol. This was to understand the context of visualization. Using the five categories of visualization, two researchers independently analyzed segmented visualization data. The inter-coder reliability was substantial (Kappa = .98). The results from visualization coding were combined with the protocol analysis results and represented in the process of learner-centered visual analogy generation.

Table III-6. Categories and Examples of Visualization

| Category | Example |
|---|---|
| Simple visualizing |   |
| Appendant visualizing |   |
| Selective visualizing |  |
| Conceptual visualizing |   |
| Strategic visualizing |  |

# IV. Results

## 1. Process of Visual Analogy Generation

The first research question in this study was to examine components and process of learner-centered visual analogy generation. For this purpose, patterns of learner-centered visual analogy generation were analyzed using the verbal protocol, visualization data and interview.

### 1.1 Analogy Generation Process

#### A. Patterns of Analogy Generation

In this section, the commonly observed patterns of visual analogy generation by learner are discussed. After the protocol analysis, segmented protocols were aggregated into episodes which represent the subcategories in the process of generating a visual analogy. The patterns for each participant were schematized by following the order of coded episodes. Figure IV-1 reveals the process of each participant's visual analogy generation.

The results from episode analysis showed that learners were engaged in six different stages while generating a visual analogy. On average, they went through 12.5 episodes (*SD* = 3.1). Participant A had exceptionally small number of episodes compared to three other participants with only eight episodes. All the other participants ranged between 13 and 15 episodes.

Such episodes as *describing analogy* and *matching principle* were observed from all four participants with the highest frequencies. The frequencies of metacognitive episodes like *evaluating,* and *monitoring* varied. In fact, *evaluating* did not emerge as an episode. Moreover, the overall process did not differ with the level of prior knowledge, except that the participant with high prior knowledge in chemistry was able to use relevant examples like chemical formulas.

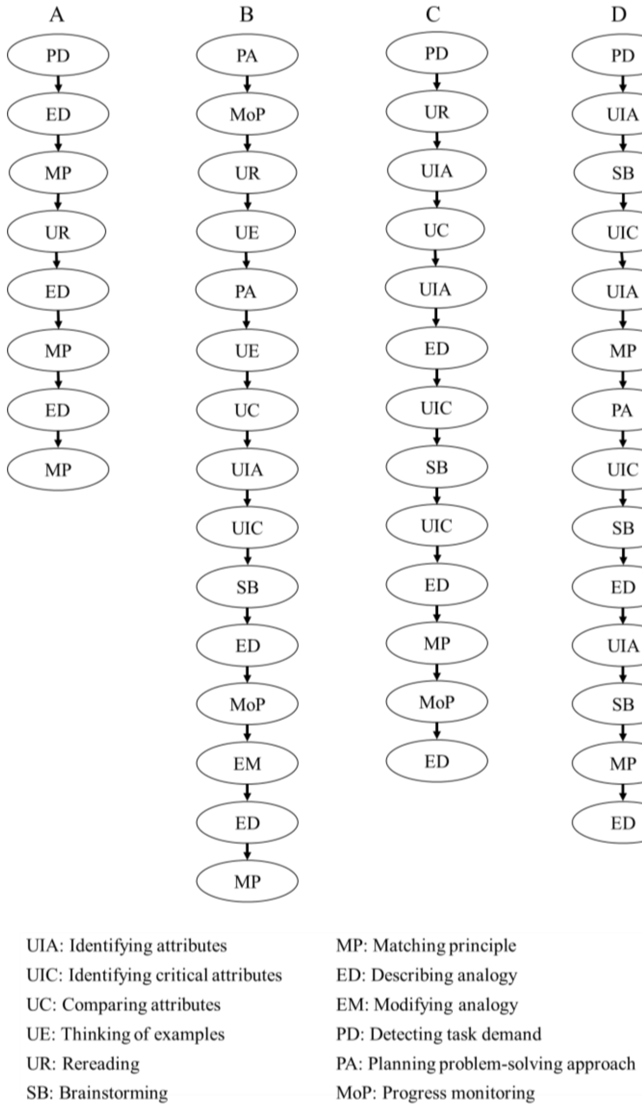



Figure IV-1. Analogy Generation Process by Participants

The following common patterns were observed among the four participants. First, they all began the process of visual analogy generation with planning either by detecting the visual analogy task or by setting up a problem-solving approach to accomplish the task. To detect the visual analogy task, they read the instruction and checked the materials provided to them. For example, participant C, after reading the task instruction, turned the pages to find that she was given blank scratch papers and the last page reserved for the final visual analogy. Planning approach at the beginning of the task involved verifying what should be done first before making a visual analogy. For instance, participant B planned to “look at the definition first”. Participant C also explicitly stated that she “needed to understand this so that [she] can make an analogy”.

Secondly, after planning, the participants proceeded to build understanding of chemical bonding. Understanding repeatedly involved identifying attributes of chemical bonding, identifying critical attributes, comparing the two types of chemical bonding, and rereading the provided excerpt. Understanding began by rereading the excerpt. After reading the excerpt, the participants paraphrased the concepts of ionic bond and covalent bond in their own words in order to comprehend the concepts. The role of paraphrasing may have played an important role in searching for an analogy since some participants used personification to explain using less academic and livelier expressions. For example, participant B explained ionic bond as being “unkind” because it transfers electrons completely from one atom to the other and covalent bond as being “nice” because it shares an electron pair. The participants also used onomatopoeia to describe the process of bonding, using sound expression like “jjak-jjak”. This may be seen as the participants' attempts to understand the unfamiliar concept expressed in formal academic language by using familiar expressions.

Since there were two types of chemical bond, the participants highlighted the difference and the similarity between ionic and covalent bond. In comparing the two concepts, the participant eliminated auxiliary information and focused on what they thought was the key idea. As a result, they recognized the importance of certain attributes, such as the atoms' tendency to have eight electrons, the total transfer of electron from one atom to another, and the sharing of electrons. All of the participants were able to discern the differences between ionic and covalent bond which were represented in the analogies; however, the similarity–satisfying the octet rule– was represented only in two analogies. Only one participant with high prior knowledge was able to elaborate the similarity and difference using an example. Figure IV-2 demonstrates how the subcategories of understanding concept are related.

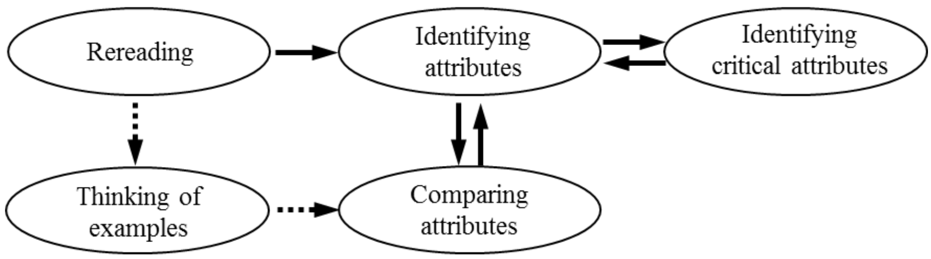



Figure IV-2. Subcategories of Understanding Concept

From the understanding stage, participants tended to either search for an analogy or directly proceed to elaborate on their analogies. In searching for an analogy, participants repeated the critical attributes of concepts identified by themselves earlier. More particularly, they tended to focus on verbs which describe the principle of chemical bonding. Anchored on verbs, such as ‘share’, ‘transfer’, and ‘give and take’, they tried thinking of analogies by replacing the subjects, such as electrons and atoms.

> “Sharing...what’s there that shares something...” (Participant B)
> “Gain electron, gain electron…hmm” (Participant C)
> “Military? Something that forms stability...” (Participant C)
> “They need to transfer…transfer…” (Participant D)

Elaborating on the created analogy was consisted of two elements: describing the analogy and modifying the analogy to the learning content. In this stage, the participants identified components of their own analogies and described the analogy.

> “There is a person with personality type A and another person with personality type B. Personality type A is very relaxed and…type A person met type B person. They fell in love. When they fall in love…um…when they are in a relationship, one person has to take a step back to be considerate for the other. So they try to adjust their relationship by stepping back and forth.” (Participant A)

> “Let’s say there is a goal to save ten million won within a year. It’s like a bet. You have to save up one million won within a year in this project. And few people applied to this project. So there are two people, A and B. Person A earned eight million alone and B also earned eight million. And there is this job which A and B have to work together and they get two million. They can get divide two million and each get one million. Or if they don’t want to get one million won separately, they can together make one bank account

> under with name and put two million there. So this two million won is now both A and B's." (Participant B)

As shown in the verbatim, some participants described the analogy in a way of storytelling. In most of the analogies generated, the atoms were represented as people. Participant A's analogy was explicitly about interpersonal relationship. Participant B's analogy was about how two pairs of people can achieve the set amount of money in different ways analogous to chemical bonding. Participant C used two villages forming different types of alliances by either sending married people to one village or sharing armies and land together. While participant D's analogy for ionic bond included person, his analogy for covalent bond was comprised of magnetic fields which were not at all related to interpersonal relationship.

Moreover, three of the participants used the same analogous situation to explain ionic and covalent bond. To explain two different principles of chemical bond which have the same condition of satisfying octet rule, the participants adjusted sub-elements of the analogy while maintaining the overall analogous situation. Participant A, B, and C used the same analogous situation to explain ionic bond and covalent bond as follows:

> "For example, there are only A, B, C, and D in this project team. C had only D to give and D only has C to receive from. So they are satisfied. So C has ten million but gives two million…now C has eight million to achieve the goal. For D, six million plus two million…has earned eight million…so they are very satisfied because they both benefited. So electrostatic attraction has formed because they helped each other. In conclusion, all four satisfied

> octet rule, but covalent bonding is they may sacrifice a little bit but make a shared bank account together to achieve the goal and in this case C complete gives money away to D to satisfy the octet rule." (Participant B)
>
> "We can think that there are two villages. This is Africa and there are villages in Africa. There is village A and village B, and there is common enemy C. Village A and B are different families…fighting against enemy C to maintain stability. In case of ionic bond, males in one village find females in the other village to get married. They need to get married, males in village B and females in village A so it's blood alliance. So from now on they are allied by blood and new village AB is formed. But in case of covalent bond, they just say 'let's live together'. Our village has this many males and your village has that many males so we just make a treaty and live together. So they can share weapons and armies." (Participant C)

Participant D, however, used two completely distinct analogies. In his analogy for ionic bond, he used a person, which represents a nonmetallic element, consuming only the yolk of an egg, which represents an electron in a metallic element, to explain ionic bond. For covalent bond, he used the analogy of magnetic fields.

Finally, the four participants performed metacognitive activities, such as monitoring and evaluation, consistently throughout the process of visual analogy generation. Since most of metacognitive activities appeared in only one or two segmented protocols, only few metacognitive episodes were included in the analysis result. The monitoring statements was made in the middle of understanding stage and explanation stage, which implies that the participants were monitoring consistently throughout the visual analogy generation task. The participants monitored the process in two aspects. First, they monitored their understanding of chemical bonding. Because the participant has little background knowledge in chemistry, they made sure they understood the content correctly. Monitoring comprehension included questioning themselves about accuracy of their understanding and clarifying parts that they had trouble understanding. For example, during the interview conducted after the task, participant C claimed that she “checked if [she] was thinking consistently”. After making such monitoring assertions, they usually went back to the understanding stage to reread the excerpt or identify attributes. Secondly, the participants monitored the strategies and the process of visual analogy generation. This included reflecting on the creativeness of analogies, deliberating on how to express visual analogies and explaining what he or she was doing. Some examples of monitoring statements are as follows:

> “There can be more analogies than this one but…” (Participant A)
> “I thought about the definition while reading.” (Participant B)
> “I understood up to here.” (Participant C)

In contrast to monitoring, evaluation judged the quality of analogy in terms of its correctness and completeness in explaining the chemical bonding. While evaluation appeared in coded segments of verbal protocol, it did not appear as an episode. In most cases, participants made brief evaluation and continued to search for an analogy or describe an analogy.

Thus far, the process and patterns of generating a visual analogy were examined. The overall process of generating a visual analogy can be concluded by integrating the commonly observed patterns among the participants as illustrated in Figure IV-3. The direction of arrow indicates the sequence of stages in the process. The thickness of arrow signifies the number of observed course of generation process. The thinnest line represent courses that appeared only one or two times among the participants, while the thickest line represent courses appearing more than five times. Therefore, the general process of visual analogy generation is demonstrated with the moderately thick lines and the thickest lines. The thinnest lines show subsidiary stages.

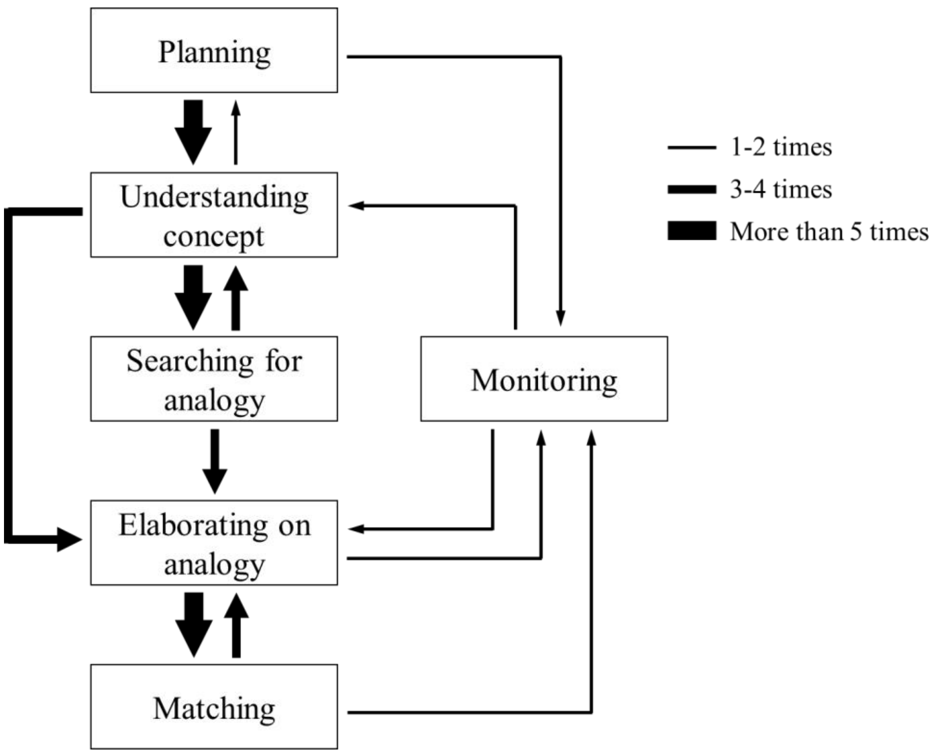



Figure IV-3. Process of Generating an Analogy

## B. Time Used for Analogy Generation

Because the patterns of visual analogy generation do not represent how much time was allotted for each stage, it was necessary to examine the amount of time spent for each stage. The analysis of time use can be carried out either by using the absolute value of time measured in second or by examining the percentages of time used. In this study, because the total amount of time was different for the participants as shown in Table IV-1, the percentage of time was analyzed to examine the time use and to compare the patterns among the participants. As shown in Table IV-1, the average time spent for generating a visual analogy is 855.5 second (*SD* = 334.3). Participant B was engaged in the task for the longest time.

Table IV-1. Total Amount of Time Used

| | Total time (sec) |
|---|---|
| A | 532.0 |
| B | 1262.0 |
| C | 990.0 |
| D | 638.0 |
| Mean | 855.5 |

The percentage of time spent for each stage by individual participants is shown in Table IV-2 and Figure IV-4. Participant A spent nearly 40 percent of the time in describing an analogy and less than five percent for searching, evaluating, and monitoring. Participant B spent 70 percent of the time in identifying attributes and thinking of examples to understand concept as well as describing the analogy.

This result was interesting since participant B had the highest prior knowledge in chemistry and yet had invested as much time as 30 percent in identifying attributes and thinking of examples in understanding stage. Participant C used more than half of the time to understand the concept. Similarly, participant D also spent most time in understanding.

Table IV-2. Percentage of Time Spent by Participants

| | P | U | S | El | M | Mo | Ev |
|---|---|---|---|---|---|---|---|
| A | 1.7 | 24.2 | 3.6 | 40.6 | 21.6 | 3.9 | 4.3 |
| B | 2.3 | 33.8 | 4.6 | 37.0 | 11.6 | 3.6 | 7.1 |
| C | 8.0 | 54.3 | 6.3 | 15.3 | 5.5 | 8.6 | 2.1 |
| D | 7.7 | 33.7 | 26.2 | 13.0 | 13.9 | 1.3 | 4.2 |

**Notes.** P: Planning, U: Understanding concept, S: Searching for analogy, El: Elaborating analogy, M: Matching, Mo: Monitoring, Ev: Evaluating analogy

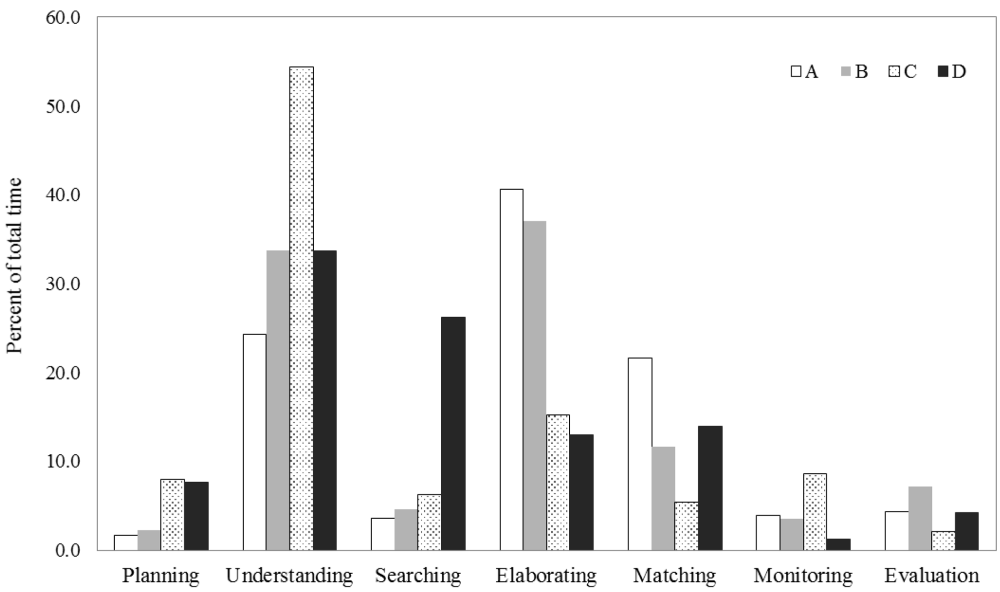



Figure IV-4. Percentages of Time Spent by Participants

It was thus evident that the participants spent the majority of time to understand the presented concept and to elaborate their analogies. While understanding the concept, they reread the excerpt or identified the concept by paraphrasing for the most of the time. Describing the analogy accounted for more than 15 percent of the total time. In contrast, the participants spent relatively little time modifying the analogy. Moreover, monitoring comprehension and progress showed very small percentage of time. Since monitoring involves one's metacognition, it may not have been reflected in the think-aloud. The average time in second is shown in Table IV-3 and the percentages are shown in Figure IV-5.

Table IV-3. Average Time for Each Stage

| | P | U | S | El | M | Mo | Ev | Total |
|---|---|---|---|---|---|---|---|---|
| Mean | 41.5 | 327.0 | 76.5 | 229.3 | 101.3 | 39.8 | 40.3 | 855.5 |
| SD | 29.9 | 188.0 | 63.4 | 167.5 | 39.4 | 33.8 | 33.3 | 334.3 |

**Notes.** P: Planning, U: Understanding concept, S: Searching for analogy, El: Elaborating analogy, M: Matching, Mo: Monitoring, Ev: Evaluating analogy

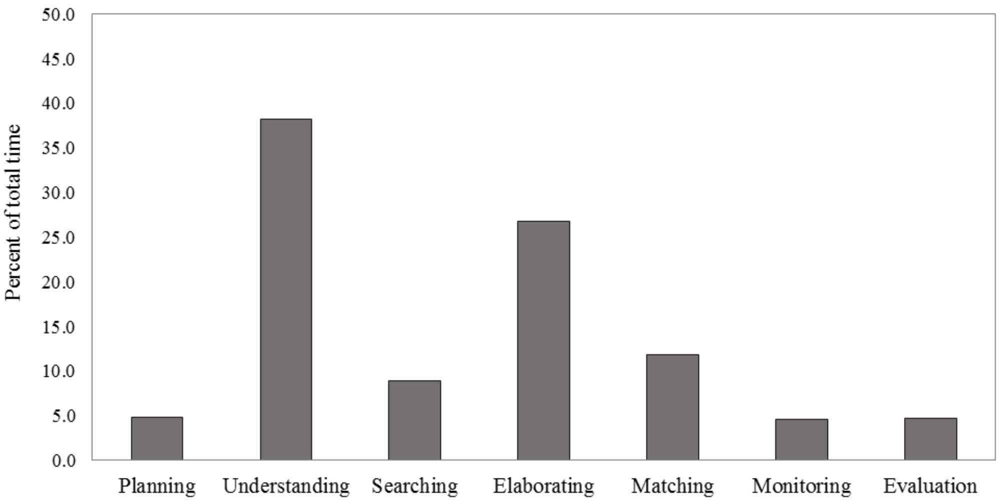



Figure IV-5. Percentages of Average Time for Each Stage

## 1.2 Visualization Process

### A. Patterns of Visualization

The visualization data was analyzed according to visual attributes suggested by Heo (2006). After the analysis, the coded visualization data was connected to corresponding analogy generation episode. The amount of time spent for visualization was also analyzed. Participant A, as shown in Figure IV-6, used two types of visualization: conceptual visualizing and strategic visualizing. He visualizing only during elaborating analogy and matching principle. He used strategic visualizing for 66.7 percent of the time he was describing the analogy. After he had made the analogy for covalent bond, he used conceptual visualizing to match the analogy to the concept of covalent bond which accounted for 8.7 percent of time. He used visualization for 28.9 percent of the total time.

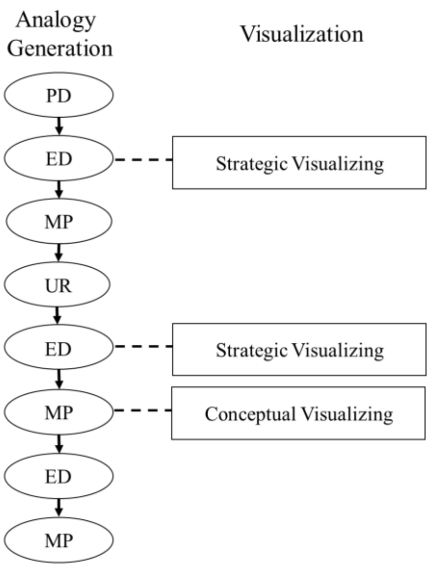



Figure IV-6. Visualization Process for Participant A

As evident in Figure IV-7, participant B made four types of visualizations: simple visualizing, appendant visualizing, conceptual visualizing and strategic visualizing. While understanding concept, participant B used conceptual visualizing for 15.7 percent, simple visualizing for 4 percent, and appendant visualizing for 2.8 percent of the time. While describing the analogy, the participant visualized the analogy for 57.4 percent of the time. In total, participant B visualized 32.1 percent of the time she was generating the visual analogy.

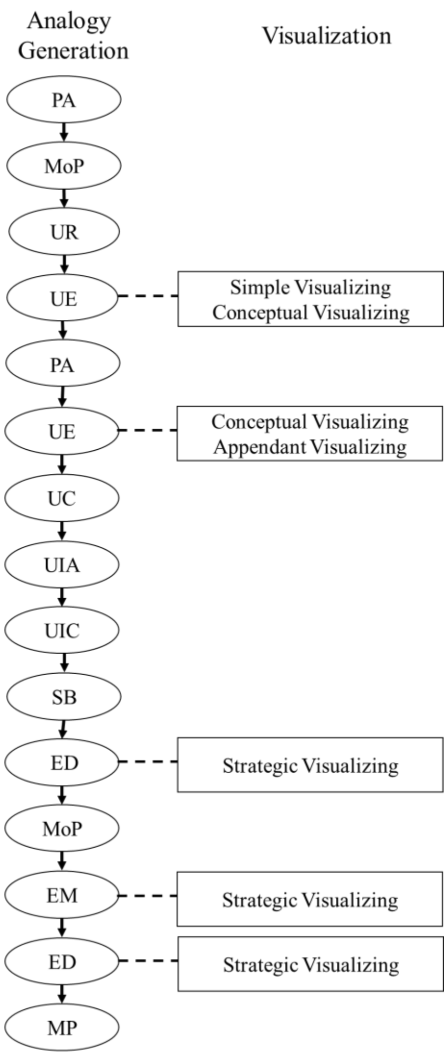



Figure IV-7. Visualization Process for Participant B

Participant C used all five types of visualizations as shown in Figure IV-8. Out of the total time, the participant visualized for 34.1 percent. While rereading the excerpt, the participant wrote down phrases like ionic bond, covalent bond, and losing the outermost electrons. To identify attributes and particularly critical information, she used conceptual and appendant visualizing. Simple visualizing was used to brainstorm ideas for an analogy. Finally, similar to other participants, she used strategic visualizing for 43.7 percent of the time while describing the analogy.

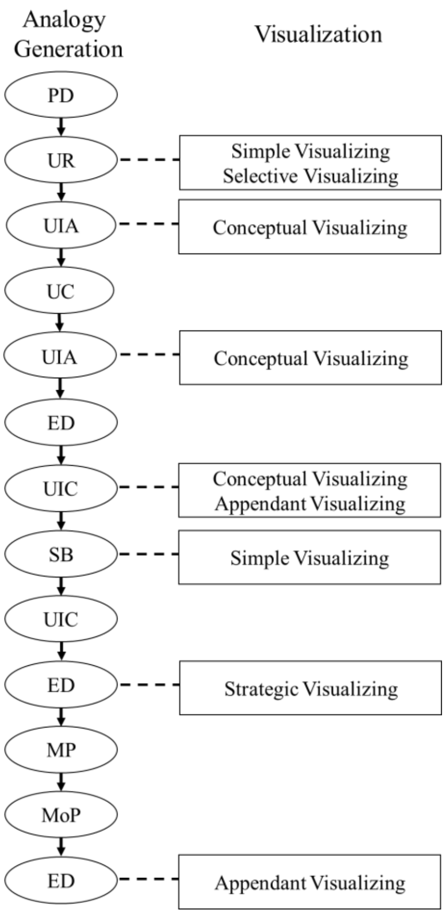



Figure IV-8. Visualization Process for Participant C

Participant D exercised three types of visualizations as shown in Figure IV-9. Conceptual visualizing was used while understanding the concept. Strategic visualizing was used while describing the analogy and matching the concept and the analogy. Appendant visualizing was also used while describing the analogy. In total, participant D used visualization for 21 percent of the times, which was the least amount of time for visualization among the four participants.

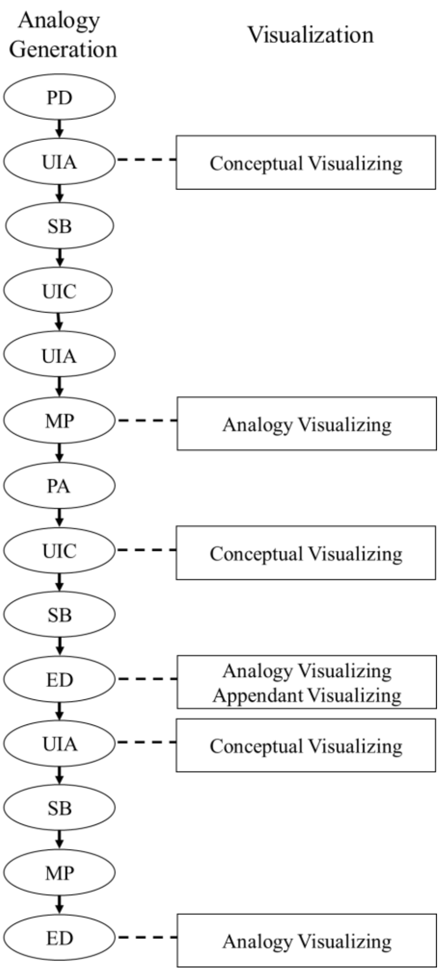



Figure IV-9. Visualization Process for Participant D

## B. Time Used for Visualization

On average, the participants used 3.5 types of visualizations for 257.8 seconds (*SD* = 134.2). In other words, the participants visualized for 30.1 percent of the total time. All participants used conceptual and strategic visualizing. Conceptual visualizing was most frequently used while identifying attributes, whereas strategic visualizing was most frequently used to describe an analogy. In contrast, metacognitive stages did not involve any visualization. Table IV-4 shows what percentage of time in each stage the participants visualized.

Table IV-4. Percentages of Time Used to Visualize in Each Stage

| | Understanding concept | Searching for analogy | Elaborating | Matching |
|---|---|---|---|---|
| Participant A | | | | |
| Conceptual | | | | 8.7 |
| Strategic | | | 66.7 | |
| Participant B | | | | |
| Simple | 4.0 | | | |
| Appendant | 2.8 | | | |
| Conceptual | 15.7 | | | |
| Strategic | | | 57.4 | |
| Participant C | | | | |
| Simple | 5.6 | 29.0 | | |
| Appendant | 2.2 | | 19.2 | |
| Selective | 2.6 | | | |
| Conceptual | 16.4 | | | |
| Strategic | | | 43.7 | |
| Participant D | | | | |
| Appendant | | | 2.4 | |
| Conceptual | 23.7 | | | |
| Strategic | | | 56.6 | 14.6 |

## 1.3 Process of Visual Analogy Generation

### A. Process of Visual Analogy Generation

The results described thus far be integrated to demonstrate the overall process of visual analogy generation as shown in Figure IV-10. The overall process integrates the two dimensions, analogy generation and visualization, into one process. As discussed earlier, the analogy generation dimension contains six stages: planning, understanding concept, searching for visual analogy, elaborating on visual analogy, matching and monitoring. Though included in the coding scheme, evaluation was excluded from the final process as it did not appear as an episode during the analysis. The arrows in the figure denote the direction of progress. The relative size of each box implies the amount of time learners spent during each stage. Since the participants invested the majority of time in *understanding concept* and *elaborating on visual analogy* stages, the progression of sub-processes were also demonstrated. The portion below the dotted line in each stage shows the type of visualizing used for each stage. As noted, *planning* and *monitoring* stages did not involve visualizing.

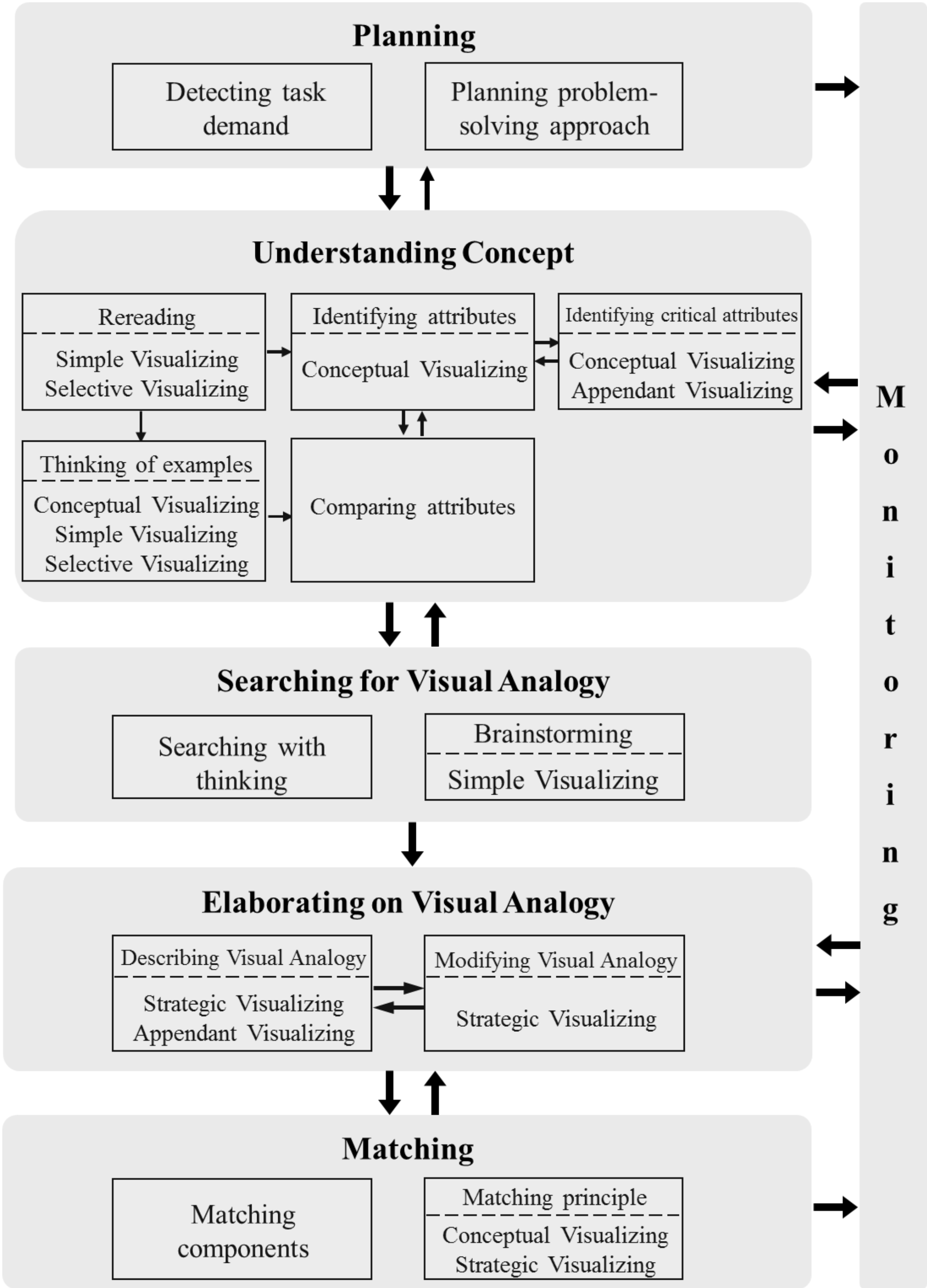



Figure IV-10. Final Process of Visual Analogy Generation

B. Strategies for Generating a Visual Analogy

When the participants were asked to describe how they came about in generating the visual analogies, there were two strategies commonly used by the participants. First, the participants identified the critical attributes of each type of chemical bonding and concentrated on these attributes to search for and elaborate their visual analogies. Some participants answered that they wanted to represent as much detail as possible, but in the end concentrated on key concepts.

> "I gave up on describing every detail and focused on expressing only what is important." (Participant A)
>
> "The difference was that here electrons are shared and here electrons are completely given away to another part. So I took this as the central premise." (Participant B)
>
> "When I thought of an analogy, I tried looking for the key point. (Participant C)
>
> "Instead of conveying everything, I took part that's most important." (Participant D)

All of the participants focused on the differences between ionic and covalent bond, and conveyed the difference in their analogies.

> "It took me some time to find what it is, but the octet rule was the key and these were two different ways to obtain eight electrons." (Participant C)

> "I wanted to emphasize the difference, so here, I focused on the transfer of electron and here I wanted to represent commonly shared component." (Participant D)

For most of the participants, the atoms were replaced with such analogs, as people, organism, or magnetics, and the electrons were depicted as love, friendship, money, land, army, and magnetic fields. The underlying principle of transferring or sharing electrons was represented in the final visual analogies. In all analogies, combination of some kind was illustrated analogously, three of which was also related to certain purpose. For instance, in participant A's analogy to go camping together was the purpose of friendship while participant C's analogy depicted the stability as the purpose of alliance between two villages. Participant B's analogy portrayed the octet rule as the amount of money that people had to earn to win a bet. Although the extent to which attributes were represented analogously differs among the participants, all of them contained the key principles of chemical bonding.

Secondly, as shown by the protocol analysis, the participants also insisted in the interview that they contemplated on the verbs that describe the key attributes in searching for visual analogies.

> "I thought like something has to share or something is given away to fit into some standard. I think I tried to replace the objective with something abstract." (Participant B)

> "Exchanging for something good is similar to what happens between people or friends." (Participant A)

Although it may be due to the nature of concept used in this study, the participants showed tendency to concentrate more on functional features than structure of atom or chemical bonds. Therefore, they used verbs that describe these functional aspects as cues. Because the participants attempted to think of an analogy that involves exchanging and sharing, they often came across analogies that are related to human being either directly or indirectly. Friendship, exchange of money, and village alliances described in three analogies all occur between persons or groups of people.

## 2. Learner Perception

In this study, learners' perception of the use of visual analogy was examined using the survey questionnaire and the interview. The survey to measure learner perception and overall satisfaction included ten items for which the participants rated on a 5-point Likert scale. The participants were generally satisfied with the use of learner-generated visual analogy with the mean score of 3.65. For further investigation, the participants were interviewed regarding their scores and the mean scores for each questionnaire item were calculated. The survey results are included in the Appendix E.

The participants perceived the activity of generating their own visual analogy as fun and novel experience which they would like to recommend to others. In the follow-up interview, Participant D said that he had "never used an analogy to study, but it seems helpful". In contrast, two other participants had previously encountered the use of analogy either of their own or an instructor's. Participant A acknowledged that analogies are used in teaching and learning, mostly for science subjects. Despite the difference in previous experience of using analogies in learning context, the participants agreed that the use of visual analogy was fun and novel and that their interest for the topic increased by using the visual analogy.

Furthermore, the participants showed positive response with the mean score of 4.25 (*SD* = .96) to helpfulness of using a visual analogy in understanding the relationship between the two types of chemical bond. In addition to enhancing the comprehension of the relationship, the participants also responded with the mean score of 3.75 (*SD* = .50) that the use of visual analogy helped understand each type of chemical bond.

In the follow-up interview, the participants perceived that the use of learner-generated visual analogy was helpful for the following reasons. First, because in order to generate an analogy, they needed to understand the concept. In doing so, they reread the excerpt several times and turned their attention to identifying the key attributes, which helped them understand the concept. Secondly, the participants perceived that visualizing an analogy was useful since visualization helped represent the concept more clearly than verbal descriptions of the analogy. Visualization by explicitly depicting the connection between the concept and the analogy was perceived to help both understanding the chemical bonding and monitoring the analogy generation process.

> "Expressing it as a drawing made me to try to understand the process correctly. To know the difference between a covalent bond and an ionic bond, the drawings have to be different. Also I can see from my own drawing what parts are missing." (Participant D)

Lastly, the participants also responded that learner-generated visual analogies helped clarify confusion. To create a visual analogy, the participants needed to select attributes, usually two to three, to represent. In most cases, these attributes were critical to understanding the presented scientific concept. In one case of participant C, the attributes portrayed in the final visual analogy also included the attribute that the participant had difficulty understanding. Participant C said she could not understand why the atoms had to bond with each other. As she kept rereading the excerpt, trying to follow the logic and thought about the chemical phenomenon, she was eventually able to grasp the purpose of chemical bonding. The purpose of chemical bonding–achieving stability by having eight electrons– was then represented in her visual analogy as the two allied villages' stability against the other village. Likewise, the learners depicted what they thought was most important or what they initially had trouble understanding in their visual analogies, which they perceived to be useful for their understanding.

> "The analogy I made is organized around what I might be confused with. For example, I couldn't understand why they had to bond together. So I kept thinking about it while making my own visual analogy." (Participant C)

The item regarding the difficulty of creating a visual analogy received the lowest mean score of 2.00 (*SD* = .82). The participants found it difficult to come up with a visual analogy on their own for two reasons. First, they wanted to be creative in formulating the visual analogy. Therefore, they tried to think of funny or unique analogies which however was difficult. The participant B, after seeing the examples of visual analogies provided by the researcher, tried to come up with a groundbreaking visual analogy, but she could only come up with visual analogies that are rather mundane.

> "I tried my best to think creatively." (Participant A)

> "It was difficult to come up with an analogy easily because I felt like I had to make an analogy that was completely different situation." (Participant B)

Moreover, the participants responded that visualizing made the process of generating an analogy difficult. Producing a coherent drawing of a visual analogy was not easy for the participants because they kept modifying the visual analogy or placing additional lines, circles or boxes while describing the visual analogy verbally. One participant also said that it was difficult to visualize what he intended. This had to more do with the participants' drawing skills to express the intended analogy and less with the difficulty of coming up with a visual analogy.

> "I wanted to express as many things as possible." (Participant D)

> "It was difficult to draw like the examples shown here, as one complete, well-arranged diagram." (Participant A)

# V. Discussion

## 1. Process of Learner-generated Visual Analogy

The process of learner-generated visual analogy presented in this study did not differ largely from those processes of analogical reasoning proposed by previous research. Sternberg (1997b) suggested that there were four stages commonly mentioned by the literature on analogical reasoning: encoding, inference, application and response. Similar to his description, the process consisted of encoding of the learning concept in *understanding concept*, inference and application in *searching for visual analogy*, and *matching*, and response in *elaborating on visual analogy*.

Compared to the previous research, the process of learner-generated visual analogy presented in this study differed in two aspects. First, the learners in this study tended to use verbs as textual cues. By using the verbs that describe the chemical bonding, the learners were able to draw functional relationships between the target concept and the analogy beyond comparing surface features.

The tendency to use verbal cues observed is inconsistent with Gentner (1983)'s structure mapping process. According to the structure mapping process, analogical mapping occurs from text to text or from visual to visual conditions. However, in this study the learners tended to generate a visual analogy based on the textual information. Although the learners produced various visualizations during the process, there was no significant evidence found in this study to suggest that visualizations were the cues for generating a visual analogy. Instead, the visualizations made during the learning were used to organize the learning content and help the learners understand the presented concept. This may be due to the fact that most of the learners did not have enough prior knowledge in chemistry. Without sufficient prior knowledge, they might not have been able to visualize the structure of ionic or covalent bonding that could contribute to the generation of a visual analogy. Had they been able to construct a diagram for chemical bonding processes, visual cues may have affected the visual analogies as suggested by Gentner (1983).

Secondly, the learners showed minimal engagement in evaluating their final visual analogies. Compared to the amount of time spent to understand the presented concept and elaborate on the analogies, the learners in this study spent less time evaluating the quality of analogy and examining the limitations of analogies. The learners also tended to become fixated on one or two analogies instead of trying to come up with several visual analogies and choosing the most appropriate one.

This finding draws contrasts with the results from Wong's research (1993) where the learners validated their own analogies to correct misconceptions. This may be due to the different orientation of the tasks. Wong (1993) used the learner-generated analogies to evaluate learners' explanations of a scientific concept. The learners were asked not only to create and apply the analogy to explain the given concept, but also modify their analogy. In this study, the learners were only asked to create a visual analogy that can explain for chemical bonding. Therefore, the engagement in evaluation can differ depending on how the task is presented to the learners, and when not required, the learners will be less likely to explain the limitations of their visual analogies which can potentially lead to incorrect or excessive mapping.

## 2. Roles of Learner-generated Visual Analogy in Learning

While the use of learner-generated visual analogy supports learning in general, two specific roles of learner-generated visual analogies can be discussed based on the results of the study. First, the learner-generated visual analogy is used as a tool to help understand the structure of a concept. The process of generating a visual analogy revealed that the learners selected and focused on essential information. For instance, in the final visual analogies, such attributes as transferring and sharing electrons were explicitly represented while electron shells or atoms were omitted. In order to make an analogy, the learners needed to not only understand the concept, but also be able to distinguish critical attributes. To distinguish critical attributes, they reread the excerpt several times thoughtfully and identified the structure and relationship between the properties of the presented concept.

Mayer (1993) referred to this process of recognizing and concentrating on the critical attributes as selecting which is one of the three cognitive processes supported by an analogy. In Mayer's framework for metaphoric aids in learning, three possible cognitive processes can be supported by the use of instructional analogy: selecting, organizing, and integrating. The findings in this study suggest that a learner-generated visual analogy facilitates selecting by directing learners' attention toward key information, organizing by using the familiar concept as the framework, and integrating by relating the presented concept and the visual analogy.

Previous research suggested that an analogy in learning serves as an explanatory device or a discovery tool (Gentner & Toupin, 1986; Harrison & Treagust, 1993). In a similar way, the learners in this study used the visual analogies as explanatory devices to understand the new concept. This finding is consistent with the finding presented by Noh et al (2010); learner-generated visual analogies were perceived as helpful to understand scientific concepts.

Lastly, the task of generating a visual analogy encourages the learners to use various visualizing strategies throughout the learning process. The learners did not restrict using visualization to elaborate on a visual analogy, but also used visualization while understanding the presented concept as well as searching for a visual analogy. The learners also used different types of visualizations including simple visualizing, selective visualizing, appendant visualizing, conceptual visualizing, and strategic visualizing.

Previous research on visualizing demonstrated the positive relationship between visualizing and comprehension as they help accommodate and remember incoming information effectively (Cohen & Johnson, 2012; Kulhavy & Swenson, 1975; Sung, Leem, & Kim, 2010). The act of visualizing is also thought to expand one’s thinking and facilitate creative thinking (Rha, 2010). Many educational researchers have recognized that visualizing a particular object or concept is an important cognitive ability to improve performance and maximize learning by organizing knowledge (Clark & Lyons, 2004; Kulhavy & Swenson, 1975; Sung et al., 2010). The findings in this study suggest that the use of learner-generated visual analogy can encourage the visualization of learning content, which can support learning.

## 3. Instructional Implications

Based on the findings of this study, the following instructional implications can be drawn. First, it is necessary to provide feedbacks to learners' visual analogy. The learners in this study paid less attention to examining the limitations of their visual analogies. While generating a visual analogy and formulating the connection between the new concept and the familiar concept can facilitate learning, inadequate or excessive mapping can result in misconception. Depending on their previous knowledge and understanding of the concept, learners may also leave out critical information. In fact, the results in this study showed that the learners' visual analogies represented the properties of concept to different extent. Therefore, the learners should be given opportunities to validate their final visual analogies.

Providing feedback can prevent inadequate or excessive mapping since feedback provides explanatory and corrective information regarding the learner performance and the learning process (Choi, 2008; Hattie & Timperley, 2007). An instructor may provide feedback about the quality and limitations of the learner's visual analogy. Feedbacks can also be given by peers. For instance, Pittman (1999) used peer feedback to allow the learners discuss various analogies with others and evaluate their own analogies.

Secondly, when using the learner-generated visual analogy, an instructor needs to guide the generation process to reduce the difficulty of coming up with an analogy. When using the learner-generated analogy, Petrie and Oshlag (1993) highlighted the importance of providing examples of visual analogy. Since learners will most likely be inexperienced in creating a visual analogy, the guidelines regarding the definition and examples of visual analogies can support learners..

In addition to presenting examples, an instructor can provide various cues including both verbal and visual. An instructor should consider presenting different verbal and visual cues because the relationship between the types of cues and analogy mapping is yet to be verified. While previous research has shown that the visual representation of the target concept may trigger an analogy generation (Gentner, 1983; Salih, 2008), the findings in this study showed that the learners were also able to generate a visual analogy from verbal cues. Therefore, an instructor can provide various verbal and visual cues to help learners generate visual analogies.

# VI. Conclusion

The purpose of this exploratory study was to examine the components and the process of learner-generated visual analogy in concept learning, and learner perception of the use of the learner-generated visual analogy. For this purpose, the think-aloud protocol, the visualization data, the interview responses and the survey results analyzed to answer the following research questions:

1. What are the components and process of generating a visual analogy by learners?
2. How do learners perceive the use of learner-generated visual analogy as learning activity?

To examine the process of generating a visual analogy, four learners participated in the study. The participants met with the researcher individually to receive think-aloud training and generate a visual analogy. They were given a text-based excerpt from a Korean high school chemistry textbook about chemical bonding to produce a visual analogy. The entire process was recorded and observed by the researcher. Upon the completion of visual analogy generation, the participants completed the questionnaire followed by the semi-structured interview. The think-aloud protocol was transcribed and coded by two researcher independently using a coding scheme. The coded protocols were aggregated into episodes for further analysis. The visualizations made by the participants were also analyzed according to their visual attributes. Finally, analysis results were integrated to propose the overall process of generating a visual analogy.

The results showed that the learners were engaged in six stages: planning, understanding concept, searching for visual analogy, elaborating on visual analogy, matching, and monitoring. The progression of stages was not in a linear fashion since the learners repeatedly went through understanding concept, searching for visual analogy, elaborating on visual analogy, and matching. The learners spent the majority of time to understand the presented concept and to elaborate on their visual analogies. Throughout the process, the learners also monitored their understanding of the presented concept and the progress of visual analogy generation.

While generating a visual analogy, the learners consistently practiced the five types of visualization: simple, selective, appendant, conceptual and strategic visualizing. In *understanding concept* stage, simple, selective, appendant, and conceptual visualizing were used. In *searching for visual analogy* stage, simple visualizing was occasionally used. In *elaborating on visual analogy* stage, analogy and appendant visualizing was used. Among the five types of visualization, conceptual visualizing and strategic visualizing were used most frequently. The results suggest that the use of visual analogy encourages using visualization through the process.

In terms of learner perception, the learners were generally satisfied with the use of learner-generated visual analogy as learning activity. They perceived the use of visual analogy as helpful and enjoyable, and yet found it challenging to come up with their own visual analogy. By generating a visual analogy, they were able to comprehend the properties of each type of chemical bonding as well as the relationship between the two bonding. Visualizing an analogy was useful to represent and understand their relationship more clearly. Nevertheless, some participants felt pressure to be creative in their analogies and found it difficult to visualize every detail of analogy they produced.

This study used qualitative methodology with a relatively small sample and therefore is limited in providing generalizable results. Considering the findings and limitations of this study, future research is suggested as follows. First, the effects of using a visual analogy should be further examined. Glynn and Takahashi (1998) had previously shown the positive influence of visual analogies presented in the science textbook on learners' recall of the target concept both immediately after the study and after two weeks. Nevertheless, there is insufficient evidence found in this study to conclude that the learner-generated visual analogy supports learner's memory. Therefore, future research can investigate the effects of a visual analogy on learning achievement and retention as well as the comparison between a learner-generated visual analogy and an instructor-generated visual analogy.

Second, future research can investigate the role of visualization in the generation of visual analogies. In this study, learner's visualizations did not directly influence their visual analogies. Instead, the visualizations helped the learners organize and understand the learning content written in text. The mapping seemed to occur between verbal cue and the visual analogy, which was inconsistent with previous research on the structure mapping process (Gentner, 1983). The role of visualization in generating a visual analogy should further be researched which will help comprehend the process of generating a visual analogy more deeply.

Third, the influence of learner characteristics on learner-generated visual analogy can be studied. The scope of this study was limited to examine what learner characteristics affect the process of generating a visual analogy and the properties of learner's visual analogy. The research on such learner characteristics as field dependency and visual tendency, will provide insightful understanding and implications to enhance the use of learner-generated visual analogy.

Lastly, the use of visual analogy in various tasks and domains of learning can be further studied. A majority of research on the use of analogy in learning has concentrated on science since scientific concepts are abstract and unobservable. However, the use of analogy can be explored in various domains and for different learning tasks such as comprehension of text, problem-solving and creative thinking.

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# APPENDIX

## Appendix A: Think-aloud Training Material

<u>'소리내어 생각하기 (Think Aloud)' 설명</u>

◆ '소리내어 생각하기'란?

'소리내어 생각하기'는 1900년대 초의 내성법에 기반을 두고 있습니다. 내성법은 바깥 세상을 관찰하듯이 의식에서 일어나는 일들을 관찰할 수 있다는 아이디어에서 출발하였으며 과제수행 중간에 자신이 어떠한 생각을 하였는지를 설명하도록 합니다.

'소리내어 생각하기'는 문제를 해결하는 동안 머리 속에 떠오르는 모든 생각을 말하도록 합니다. 이 때 다른 사람이 개입하거나 질문을 하지 않으며, 다만 '소리내어 생각하기'를 중단했을 때는 계속 생각을 말하도록 유도합니다. '소리내어 생각하기'는 과제를 수행하는 동안 말하는 것은 거의 자동적으로 이루어지기 때문에 생각의 흐름을 많이 방해하지는 않습니다.

◆ '소리내어 생각하기'의 활용 영역

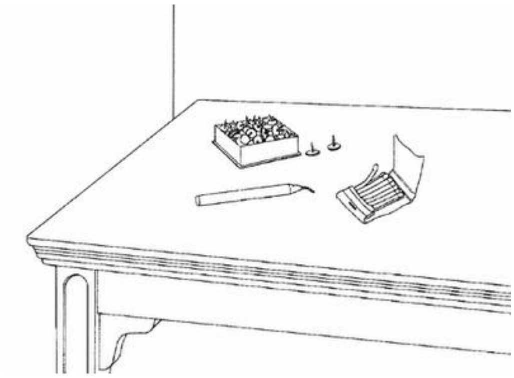
'소리내어 생각하기'는 다양한 연구분야에서 많이 사용되고 있습니다. 교육공학에서는 과제분석을 하거나 사용편의성 검사를 할 때 사용됩니다. 과제분석은 무엇을 가르칠 것인가를 결정할 때 실시하는데 전문가가 실제 과제를 수행할 때 어떤 지식을 사용하는지를 알아야 할 필요가 있습니다. 사용편의성 검사는 학습자가 컴퓨터로 만들어진 교육자료를 손쉽게 사용할 수 있는 지를 검사하는 것으로서 학습자에게 과제를 제공하고 그 과제를 해결하는 과정에서 '소리내어 생각하기'를 하도록 함으로써 교육자료의 문제점을 발견합니다.

또한, 독서교육에서는 '소리내어 생각하기'를 통해서 읽기과정을 직접적으로 관찰할 수 있기 때문에 학생들의 읽기능력을 평가하는 방안으로도 활용되고 있습니다.

◆ '소리내어 생각하기' 연습

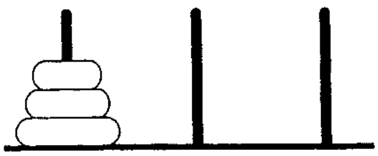
아래 문제를 해결하면서 자신의 머리 속에 떠오르는 생각들을 모두 말로 표현해 보십시오. 생각을 최대한 많이 말로 표현하는 것이 중요합니다. 문제해결에 필요하다면 종이에 그림을 그리거나 글을 써도 괜찮습니다.

**문제 1)** 아래 그림을 보면 책상 위에 압정이 든 상자, 성냥, 초가 있습니다. 이들 도구들을 이용하여 초를 벽에 부착해 보시오.

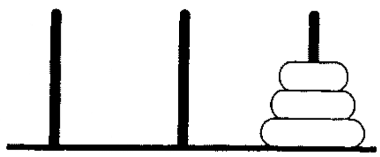


**문제 2)** 아래 그림을 보고 <처음 상태>에 있는 둥근 원판들을 <목표상태>로 옮겨 놓으십시오. 단, 큰 원판이 그 보다 작은 원판 위에 올라갈 수 없으며, 한 번에 하나의 원판만을 옮겨 놓을 수 있습니다. 필요하다면 뒤에 제공된 종이에 그림을 그리거나 글을 써도 괜찮습니다.

<처음상태>



<목표상태>



**문제 3)** 다음 글을 읽고 물음에 답하시오.

인간은 성장 과정에서 자기 문화에 익숙해지기 때문에 어떤 제도나 관념을 아주 오래 전부터 지속되어 온 것으로 여긴다. 나아가 그것을 전통이라는 이름 아래 자기 문화의 본질적인 특성으로 믿기도 한다. 그러나 이런 생각은 전통의 시대적 배경 및 사회 문화적 의미를 제대로 파악하지 못하게 하는 결과를 초래한다. 여기에서 과거의 문화를 오늘날과는 또 다른 문화로 보아야 할 필요성이 생긴다.

홉스봄과 레인저는 오래된 것이라고 믿고 있는 전통의 대부분이 그리 멀지 않은 과거에 '발명'되었다고 주장한다. 예컨대, 스코틀랜드 사람들은 킬트(kilt)를 입고 전통 의식을 치르며, 이를 대표적인 전통 문화라고 믿는다. 그러나 킬트는 1707 년에 스코틀랜드가 잉글랜드에 합병된 후, 이곳에 온 한 잉글랜드 사업가에 의해 불편한 기존의 의상을 대신하여 작업복으로 만들어진 것이다. 이후 킬트는 하층민을 중심으로 유행하였지만, 1745 년의 반란 전까지만 해도 전통 의상으로 여겨지지 않았다. 반란 후, 영국 정부는 킬트를 입지 못하도록 했다. 그런데 일부가 몰래 집에서 킬트를 입기 시작했고, 킬트는 점차 전통 의상으로 여겨지게 되었다. 킬트의 독특한 체크무늬가 각 씨족의 상징으로 자리 잡은 것은, 1822 년에 영국 왕이 방문했을 때 성대한 환영 행사를 마련하면서 각 씨족장들에게 다른 무늬의 킬트를 입도록 종용하면서부터이다. 이때 채택된 독특한 체크무늬가 각 씨족을 대표하는 의상으로 자리를 잡게 되었다.

킬트의 사례는 전통이 특정 시기에 정치.사회적 목적을 달성하기 위해 만들어지기도 한다는 것을 보여 준다. 특히 근대 국가의 출현 이후 국가에 의한 '전통의 발명'은 체제를 확립 하는 데 큰 역할을 담당하기도 하였다. 이 과정에서 전통은 그 전통이 생성되었던 시기를 넘어 아주 오래 전부터 지속되어 온 것이라는 신화가 형성되었다. 그러나 전통은 특정한 시공간에 위치하는 사람들에 의해 생성되어 공유되는 것으로, 정치.사회.경제 등과 밀접한 관련을 맺으면서 시대마다 다양한 의미를 지니게 된다. 그러므로 전통을 특정한 사회 문화적 맥락으로부터 분리하여 신화화하면 당시의 사회 문화를 총체적으로 이해할 수 없게 된다.

낯선 타 문화를 통해 자기 문화를 좀 더 객관적으로 바라볼 수 있듯이, 과거의 문화를 또 다른 낯선 문화로 봄으로써 전통의 실체를 올바로 인식할 수 있게 된다. 이러한 관점은 신화화된 전통의 실체를 폭로하려는 데에 궁극적 목적이 있는 것이 아니다. 오히려 과거의 문화를 타 문화로 인식함으로써 신화 속에 묻혀 버린 당시의 사람들을 문화와 역사의 주체로 복원하여, 그들의 입장에서 전통의 사회 문화적 맥락과 의미를 새롭게 조명하려는 것이다. 더 나아가 이러한 관점을 통해 우리는 현대 사회에서 전통이 지니는 현재적 의미를 제대로 이해할 수 있을 것이다.

1. 위 글을 짧게 요약해 보시오.

2. 위 글에 나오는 킬트와 유사한 사례를 생각해 보십시오.

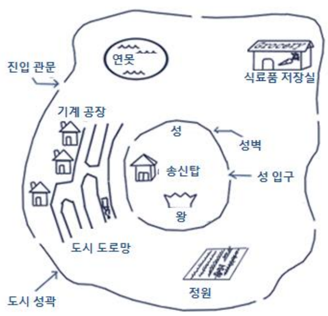
## Appendix B: Visual Analogy Generation Worksheet

<u>시각적 비유 만들기 활동지</u>

지금부터 두 가지 과학 개념을 배우게 될 것 입니다. 먼저 개념을 설명하는 지문을 읽고, 개념을 설명할 수 있는 비유를 그림으로 그려 보세요. 비유란 특정한 현상, 사물, 혹은 개념을 직접 설명하지 않고 비슷한 현상, 사물 혹은 개념에 빗대어 설명하는 것을 뜻합니다.

예를 들면 원자가 쪼개지지 않고 속이 찬 공 모양이라고 한 돌턴의 원자 모형은 딱딱한 구슬에 비유를 할 수 있습니다. 또 원자 안에 (+) 와 (–)전자가 골고루 퍼져 있는 톰슨의 원자 모형은 둥근 빵에 건포도가 골고루 퍼져 있는 모습 혹은 둥근 수박 속에 퍼져있는 수박씨의 모습에 비유를 할 수 있습니다. 아래는 비유를 그림으로 표시한 예입니다.

예시1. 세포 구조에 대한 시각적 비유




예시2. 포화 용액에 대한 시각적 비유


예시3. 창의성 구성요소에 대한 시각적 비유

다음 지문을 읽은 후, 비유를 그림으로 표현해 보세요.

## 질량 보존의 법칙

얼음이 녹아 물이 되거나 설탕이 물에 용해되는 것과 같은 물리 변화에서는 물질의 상태나 모양이 변할 뿐 질량은 변하지 않는다. 이것은 물리 변화에서는 분자의 배열 상태는 변하지만 분자의 종류와 수는 변하지 않기 때문이다.

그러면 처음 물질과는 다른 새로운 물질이 생성되는 화학 변화가 일어날 때 질량은 어떻게 될까? 서로 다른 두 물질이 반응하여 앙금이 생기는 화학 변화가 일어날 때 질량은 어떻게 되는지 알아보자.

탄산나트륨 수용액과 염화칼슘 수용액이 만나면 탄산칼슘과 염화나트륨이 생성되는데 이 반응이 일어날 때 반응 전과 후의 질량에는 변화가 없다. 이 때 탄산나트륨 수용액과 염화칼슘 수용액의 반응에서 흰색 앙금이 생기는 것은 탄산칼슘이 물에 녹지 않기 때문이다.

탄산나트륨 + 염화칼슘 → 탄산칼슘 + 염화나트륨

$$Na_2CO_3 + CaCl_2 \rightarrow CaCO_3 + 2NaCl$$

화학 변화에서 반응 전과 후의 질량이 변하지 않는 이유는 무엇일까? 각 원자는 고유한 질량을 가진 입자이며, 화학 반응은 분자를 이루는 원자들의 사이의 결합이 끊어져 새로운 분자를 형성하는 변화이다. 화학 변화가 일어날 때 물질을 구성하는 원자들의 배열은 변하지만 원자의 종류나 수에는 변함이 없기 때문에, 변화 전후에는 물질들의 총 질량은 변함이 없이 일정하다.

여러 화학 변화를 조사해 보면 화학 변화에서는 이와 같이 반응 전과 후에 물질의 총 질량이 보존되는데, 이것을 질량 보존의 법칙이라고 한다.

(출처: 중학교 과학 3, 두산동아)

※ '소리내어 생각하기'를 하며 질량 보존의 법칙을 설명하는 비유를 그림으로 표현해 보세요.

예를 들어, "질량 보존의 법칙은 ____________________ 와(과) 같다"라고 비유를 생각하며 그림으로 표현해보세요. 필요하다면 제공된 종이에 그림을 그리거나 글을 써도 괜찮습니다.

최종적으로 선택한 비유는 5쪽에 그려주세요.

(잠시 휴식을 취해도 좋습니다.)

다음 지문을 읽은 후, 비유를 그림으로 표현해 보세요.

## 화학 결합

21세기에 들어와서 생명 과학의 중요성이 매우 커지고 있다. 생명의 기본은 세포이고, 세포 내에서의 모든 활동은 분자들에 의해서 이루어지고 있다. 만일, 원자가 결합하여 분자를 형성하지 않는다면 물과 공기 그리고 생명체도 존재하지 않을 것이다. 그러면 원자들이 결합하여 분자를 형성하는 까닭은 무엇일까?

소금의 주성분 물질은 염화나트륨(NaCl)이다. 염화나트륨 수용액에서 전류가 흐르는 것은 염화나트륨이 나트륨 이온(Na+)과 염화 이온(Cl-)으로 이온화하기 때문이다. 따라서 염화나트륨은 나트륨 이온과 염화 이온이 결합한 물질이라고 생각할 수 있다. 그러면 나트륨 이온과 염화 이온은 어떻게 형성되며, 이들은 어떻게 결합하는 것일까?

원자는 원래의 전자 배치보다 안정한 전자 배치를 이루기 위하여 화학 결합을 한다. 그러나 18족 원소인 비활성 기체는 가장 바깥 전자 껍질이 완성되어 있어 매우 안정하고 균형 잡힌 전자 배치를 이루고 있다. 따라서 쉽게 화학 결합을 형성하지 않는다.

18족 이외의 다른 원자들은 전자를 잃거나 얻어서 비활성 기체와 같이 가장 바깥 전자 껍질에 8개의 전자를 가져 안정해지려는 경향이 있는데, 이것을 옥텟(octet) 규칙이라고 한다. 그러면 이러한 원자들이 어떻게 안정한 전자 배치를 이루는지 알아보자.

일반적으로 금속 원자는 원자가전자(원자의 가장 바깥껍질에 있는 전자)를 잃고 비활성 기체와 같은 안정한 전자 배치를 이루어 양이온이 되려고 하고, 비금속 원소는 전자를 얻어 비활성 기체와 같은 전자 배치를 이루어 음이온이 되려고 한다. 예를 들어, 나트륨(Na) 원자는 전자 1개를 잃고 네온(Ne)과 같은 안정한 전자 배치를 이루는 나트륨 이온(Na+)으로 된다. 또, 염소(Cl) 원자는 전자 1개를 얻어 아르곤(Ar)과 같은 안정한 전자 배치를 이루는 염화 이온(Cl-)으로 된다.

그러면 이러한 이온들은 어떻게 결합을 형성하는 것일까? 전자를 잃기 쉬운 원자와 전자를 얻기 쉬운 원자가 서로 접근하면 전자를 서로 주고 받아 각각 양이온과 음이온으로 되면서 비활성 기체와 같은 안정한 전자 배치를 이루게 된다. 예를 들어, 나트륨 원자와 염소 원자가 만나면 서로 전자를 주고받아 나트륨 이온(Na+)과 염화 이온(Cl-)으로 된다. 이들 두 이온 사이에는 정전기적 인력이 작용하므로 서로 결합하여 염화나트륨을 형성한다.

이와 같이 양이온과 음이온 사이의 정전기적 인력에 의한 결합을 이온 결합이라고 하고, 이온 결합으로 이루어진 물질을 이온 결합 화합물 또는 이온 결합성 물질이라고 한다.

금속 원자와 비금속 원자가 서로 전자를 주고받아 생긴 양이온과 음이온이 결합하면 이온 결합 화합물이 만들어진다. 그러면 비금속 원자들 사이에는 어떤 결합이 형성될까?

수소 원자가 수소 분자를 형성할 때 수소 원자는 2개의 전자를 서로 공유하여 헬륨의 전자 배치와 같은 안정한 전자 배치를 이루게 된다. 이와 같이 두 원자가 각각 전자를 내놓고 전자쌍을 만들어 이 전자쌍을 서로 공유함으로써 형성되는 결합을 공유결합이라 하고, 공유 결합에 의해 만들어진 물질을 공유 결합 화합물 또는 공유 결합성 물질이라고 한다.

또 다른 예로 물 분자는 수소 원자 2개와 산소 원자 1개로 구성되어 있다. 각각의 수소 원자는 산소 원자와 2개의 전자를 공유하여 헬륨과 같은 전자 배치를 이루며, 산소 원자는 네온과 같은 전자 배치를 이룬다. 이 때 두 원자가 공유하는 전자쌍을 공유 전자쌍, 공유하지 않는 전자쌍을 비공유 전자쌍이라고 한다.

(출처: 고등학교 화학 I, 지학사)

※ '소리내어 생각하기'를 하며 화학 결합을 설명하는 비유를 그림으로 표현해 보세요.

예를 들어, "화학 결합은 ________________________________ 와(과) 같다"라고 비유를 생각하며 그림으로 표현해보세요. 필요하다면 제공된 종이에 그림을 그리거나 글을 써도 괜찮습니다.

최종적으로 선택한 비유는 10쪽에 그려주세요.

## Appendix C: Expert Review

**시각적 비유 작성과정 구성요소에 대한 타당도 설문지**

연구 제목: Learner-generated Visual Analogy: Its Components and Process

본 연구에 사용될 '시각적 비유' 작성과정의 구성요소에 대한 타당도 설문에 참여해 주셔서 감사합니다. 본 연구는 학습자가 화학 결합에 대한 지문을 읽은 뒤 시각적 비유를 작성하는 과정을 밝히는 것을 목적으로 합니다. 시각적 비유의 작성 과정 분석 결과 도출된 구성요소를 7쪽에 제시된 양식에 따라 검토 부탁 드립니다.

감사합니다.

2013년 11월

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**Coding scheme**

| Category | Subcategory | | Reference | Description |
|---|---|---|---|---|
| Understand-ing | Conceptualizing | Identifying attributes | Sternberg (1977) | Finding, defining, and describing any concepts, components, properties or principles |
| | | Stating Importance | | Stating the importance of certain content |
| | | Comparing attributes | Sternberg (1977) | Comparing similarities and differences between two or more concepts |
| | | Paraphrasing | | Restating concept in another form, mainly in learners' own words |
| | | Thinking of examples | | Providing learner-generated examples of the concept being learnt |
| | Rereading | | Heo (2006) | Reading aloud, Re-reading important information<br>Re-reading after confusion |
| Searching | Searching with thinking | | Heo (2006) | Stopping think-aloud and thinking about ideas |
| | Searching with finding | | | Searching for ideas by questioning or brainstorming while thinking aloud<br>Using paraphrases or personification to search for ideas |

*(table continues)*

| Category | Subcategory | | Reference | Description |
|---|---|---|---|---|
| Explaining | Matching | Matching components | Salih (2008) | Mapping components of the target concept onto the analogy |
| | | Matching principle | | Mapping principles of the target concept onto the analogy |
| | Describing analogy | | | Explaining the learner-generated analogy while or after visualization |
| Modifying | Modifying analogy | | Salih (2008) | Modifying and elaborating the learner-generated analogy |
| Evaluation | Evaluating analogy | | Backer et al (2011) | Checking completeness and/or correctness of the solution |
| | Deciding visualization | | Heo (2006) | Selecting the final analogy |
| Planning | Detecting task demand | | Backer et al (2011) | Reading task instructions, Identifying task |
| | Planning problem-solving approach | | | Developing reading plan, Developing action plan |
| Monitoring | Comprehension monitoring | | Backer et al (2011) | Noting lack of comprehension, Claiming understanding, Demonstrating comprehension by repeating, Demonstrating comprehension by elaborating |
| | Monitoring of progress | | | Reflecting on the quality of the progress made Reflecting on strategy use |

*(table continues)*

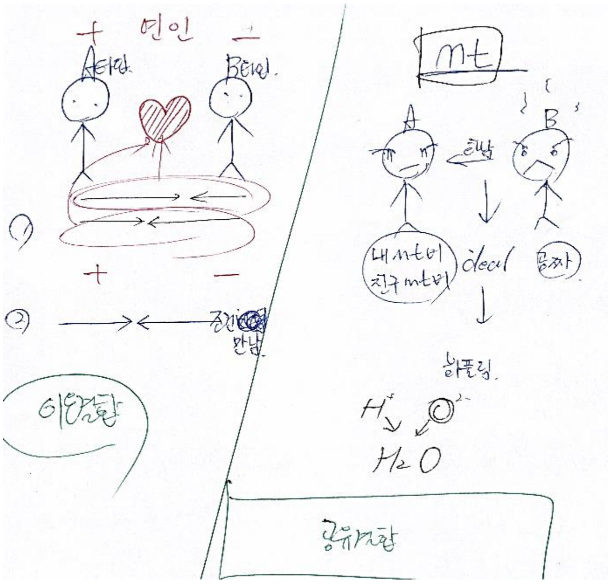
| Category | Subcategory | Reference | Description |
|---|---|---|---|
| Visualization | Simple visualizing | Heo (2006) | Visualizing without cognitive processing, such as writing down topics |
| | Appendant/assistant visualizing | | Confirming or highlighting what has already been visualized, such as underlining, circling, boxing, or drawing lines to show relationship |
| | Selective Visualizing | | Summarizing or transforming text while making sure of the content |
| | Visualizing with the conceptualization | | Visualizing and representing the text in a logical way |
| | Strategic visualizing with analogy and metaphor | | Visualizing analogy or metaphor |

다음 질문은 앞에서 제시한 구성요소의 타당성을 묻는 것입니다. 질문을 읽고 해당하는 곳에 체크하여 주시기 바랍니다.

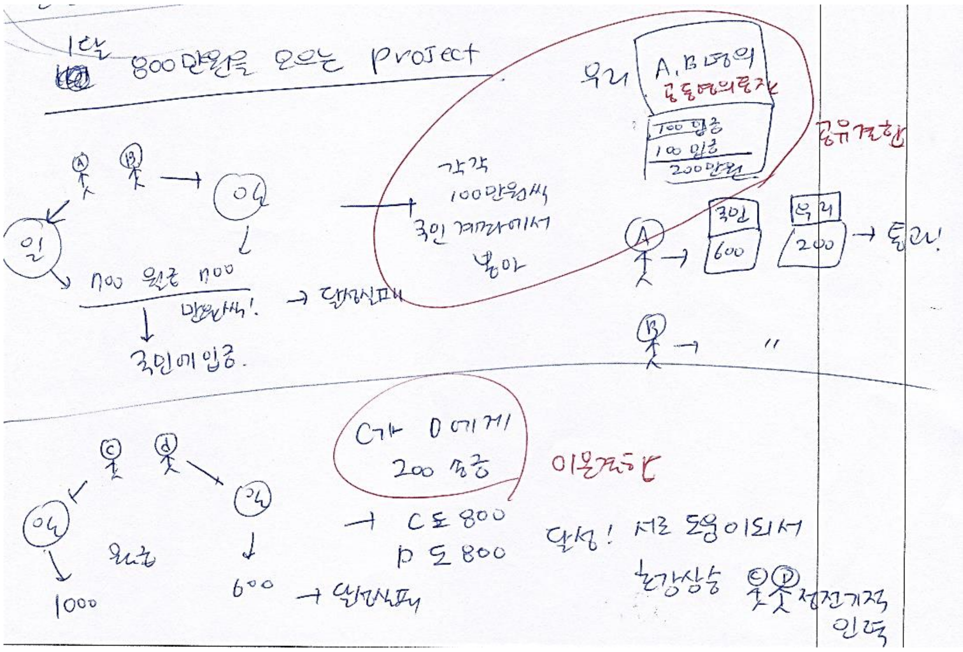
| | | 전혀 그렇지 않다 | 그렇지 않다 | 보통 이다 | 그렇다 | 매우 그렇다 |
|---|---|---|---|---|---|---|
| 설명력 | 구성요소는 학습자가 시각적 비유를 작성할 때 나타나는 인지적, 메타인지적 활동을 잘 설명하고 있다. | | | | | |
| 타당성 | 학습자가 시각적 비유를 작성할 때 나타나는 인지적, 메타인지적 구성요소로 타당하다. | | | | | |
| 적절성 | 구성요소는 유기적 관련성에 따라 적절하게 분류되었다. | | | | | |
| 보편성 | 구성요소는 보편적으로 적용될 수 있다. | | | | | |
| 이해도 | 구성요소는 쉽게 이해될 수 있도록 표현되었다. | | | | | |
| 기타 의견 | 구성요소에서 보완해야 할 점은 무엇입니까? | | | | | |

## Appendix D: Examples of Learner-generated Visual Analogies

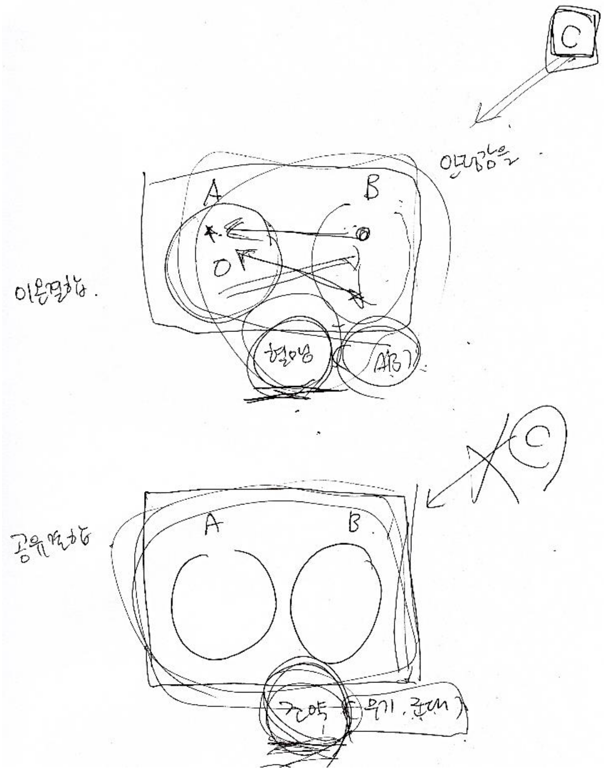
<Participant A>



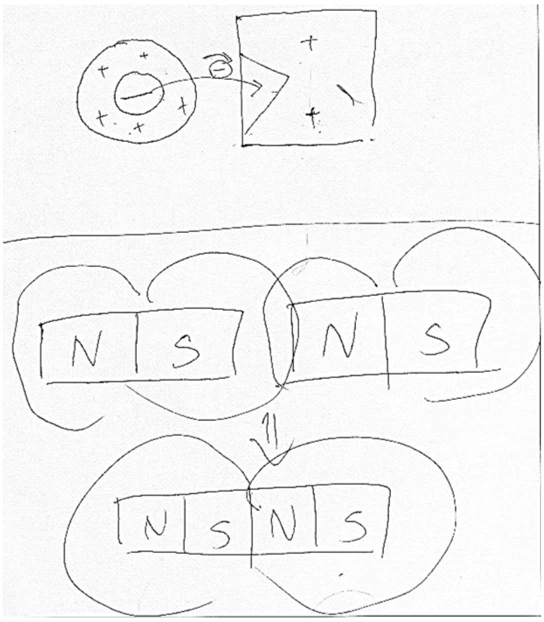

<Participant B>



<Participant C>




<Participant D>



**Appendix E: Learner Perception Survey Results**

| | A | B | C | D | Mean (SD) |
|---|---|---|---|---|---|
| 1. Overall I am satisfied with the learning activity of generating a visual analogy. | 3.00 | 4.00 | 5.00 | 3.00 | 3.75(.96) |
| 2. It was easy to think of a visual analogy relevant to the chemical bonding. | 1.00 | 3.00 | 2.00 | 2.00 | 2.00(.82) |
| 3. The use of visual analogy helped me understand the concept of ionic bond. | 3.00 | 4.00 | 4.00 | 4.00 | 3.75(.50) |
| 4. The use of visual analogy helped me understand the concept of covalent bond. | 3.00 | 4.00 | 4.00 | 4.00 | 3.75(.50) |
| 5. The use of visual analogy helped me understand the relationship (similarity, difference) between ionic bond and covalent bond. | 3.00 | 5.00 | 5.00 | 4.00 | 4.25(.96) |
| 6. I could remember the chemical bonding easily using the analogy. | 2.00 | 4.00 | 3.00 | 4.00 | 3.25(.96) |
| 7. It was fun and novel experience using the visual analogy. | 4.00 | 5.00 | 4.00 | 5.00 | 4.50(.58) |
| 8. I gained confidence about chemical bonding using the visual analogy. | 2.00 | 5.00 | 2.00 | 3.00 | 3.00(1.41) |
| 9. My interest for chemical bonding increased using the visual analogy. | 3.00 | 5.00 | 3.00 | 4.00 | 3.75(.96) |
| 10. I would like to recommend using a visual analogy to a friend. | 4.00 | 4.00 | 5.00 | 5.00 | 4.50(.58) |
| Mean score | 2.80 | 4.30 | 3.70 | 3.80 | 3.65(.62) |

# 국문초록
# Abstract in Korean

학습자의 시각적 비유 작성 요소와 과정에 대한
탐색 연구

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비유는 개념 학습에서 활용되고 있는 효과적인 전략 중 하나로써 연구가 꾸준히 이루어지고 있다. 교수-학습에서 비유는 학습자에게 친숙하지 않은 개념과 친숙한 개념을 대응시켜 설명하는 전략으로 사용된다. 선행연구에 따르면 비유는 개념구조의 생성, 재구조화, 가시화를 통해 개념 이해에 긍정적인 효과를 가진다. 특히 시각적 비유는 비유물과 목표 개념의 대응 관계를 명확하게 제시한다. 한편, 이러한 비유 활용의 효과는 대응관계에 대한 학습자의 이해와 비유물 자체에 대한 학습자의 친숙도에 따라 달라질 수 있다. 학습자가 비유물이나 대응관계를 이해하지 못 할 경우, 비유는 개념 이해에 긍정적인 영향을 미치지 못한다. 따라서 친숙도를 높이기 위해 학습자가 직접 비유를 생성하는 방법이 제안되었으나, 학습자의 시각적 비유 작성과정과 인식에 대한 연구는 부족한 실정이다.

따라서 본 연구의 목적은 학습자가 직접 시각적 비유를 작성할 때 구체적으로 어떠한 과정을 거치는지 살펴보고, 학습자 작성 시각적 비유 활용에 대한 인식을 밝히는 데에 있다. 이러한 연구 목적을 달성 하기 위해 20대의 성인학습자 4명을 대상으로 소리내어 생각하기 프로토콜 분석과 시각화 속성 분석을 통해 시각적 비유 작성 과정을 탐색하였다. 또한 인터뷰와 설문지를 통해 시각적 비유 활용에 대한 학습자 인식을 살펴보았다. 수집된 자료는 선행연구와 전문가 타당화를 바탕으로 개발된 코딩체계에 따라 분석하였다.

연구 결과 학습자는 계획, 개념 이해, 시각적 비유 탐색, 시각적 비유 정교화, 대응, 모니터링의 총 여섯 개의 단계를 걸쳐 시각적 비유를 작성하는 것으로 나타났다. 특히 학습자는 개념 이해와 시각적 비유 정교화 단계에 대부분의 시간을 할애하였는데, 개념 이해 단계에서 제시된 지문을 다시 읽어보고 주요 특성을 확인하며 특성 간 공통점과 차이점을 비교하였다. 시각적 비유 정교화 단계에서는 시각적 비유를 묘사하고 수정하였다. 시각화 속성에 따라 학습자가 생성한 시각화 자료를 분석한 결과, 학습자는 단순 시각화, 부가적 시각화, 선택적 시각화, 개념적 시각화, 전략적 시각화를 지속적으로 사용하였다. 학습자 인식으로는 자신이 작성한 시각적 비유가 각각의 하위 개념과 개념들간의 관계를 이해하는 데에 도움을 준다고 인식하였다. 시각적 표상을 하는 것에 대해서는 학습 과정과 시각적 비유 작성 과정을 모니터링하는 데에 도움이 된다고 인식하였다. 또한 시각적 비유 작성 활동이 학습 내용에 대한 흥미를 증진시킨다고 응답하였지만, 시각적 비유를 떠올리는 데에 어려움을 겪는다고 응답하였다.

연구결과를 바탕으로 학습자가 작성한 시각적 비유가 학습에서 갖는 두 가지 역할에 대하여 논의하였다. 첫째, 시각적 비유를 만들기 위하여 개념의 주요 특성을 확인하고 정교화하는 학습자의 활동은 선택적 부호화를 활성화하여 개념의 이해를 돕는 도구로 사용된다. 둘째, 시각적 비유를 작성하는 과제는 비유 자체만을 시각화하는 것에 제한되지 않고, 학습 내용을 시각화 하는 것을 촉진한다. 또한, 연구결과는 시각적 비유의 정확성에 대한 평가를 적게 하는 학습자에게 오개념과 부적절한 대응을 예방하기 위해 피드백을 제공하고 시각적 비유를 생성하는 데에 느끼는 어려움을 줄이기 위해서 다양한 언어적 및 시각적인 단서를 제시할 필요가 있음을 시사한다.

**주요어 : 시각적 비유, 학습자 작성 시각적 비유, 유추사고, 시각지능**
**학 번 : 2012-21334**