

Summoning Prior Knowledge Through Metaphorical Graphics: An Example in Chemistry Instruction

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ABSTRACT. The present investigation was designed to determine if the learning benefits of metaphors and graphics could be combined into one instructional device—a metaphorical graphic—to aid in the acquisition of difficult concepts of chemistry. The authors further sought to determine if metaphorical graphics could foster greater retention of the basic properties of chemical elements when compared to verbal descriptions of those properties or traditional graphical representations of elements commonly seen as orbital diagrams in chemistry textbooks. The findings revealed that metaphorical graphics helped learners to develop a deeper understanding of the behavior and reactivity, but not physical properties, of the features of fifteen selected chemical elements.

Keywords: chemistry instruction, learning, metaphorical graphics

Instructional adjuncts to text can enhance students' comprehension of instructional material when compared to text alone (Corkill, 1992; Kulhavy, Stock, & Kealy, 1993; Robinson, 1998; Winn, Li, & Schill, 1991). Researchers have investigated the effects on learning of graphics as adjuncts consisting of maps, diagrams, charts, and pictures (Bower, Karlin, & Dueck, 1975; Rieber & Parmley, 1995; Schnotz, 2002; Schwartz, 1997; Schwartz & Collins, 2008; Verdi & Kulhavy, 2002; Winn, 1994; Wright, Milroy, & Lickorish, 1999). In general, graphic adjuncts increase the comprehension of text if the graphics facilitate cognitive activity during the encoding process (Kintsch, 1994). Similarly, metaphors have also been used as accompaniments to text, rendering comprehension levels significantly higher with their use. That is, investigations of metaphors generally reveal that metaphors enhance comprehension of related text because they prime learners to attend to the emergent features—features not present within the structure of the metaphor (Britton & Graesser, 1996; Gineste, Indurkha, & Scart, 2000; Schwartz, Stroud, Lee, Scott, & McGee, 2006).

When emergent features of a metaphor match essential elements of a text, learners use the metaphor to map meaning onto the target textual material for comprehension (Allbrit-

ton, McKoon, & Gerrig, 1995). However, there has been little empirical research regarding the facilitative effects of metaphors and graphics on learning when the two referents are combined instructionally, with or without text. This investigation was designed specifically for this purpose.

The investigation was designed to determine if metaphors and graphics can be integrated into a single adjunct instructional device—a metaphorical graphic—and whether this device can foster greater comprehension of the target material. A metaphorical graphic is a spatially based display, depicting a metaphorical representation of a concept (Schwartz & Maguire, 2003). In the present study, the efficacy of a metaphorical graphic, without the accompaniment of text, was tested in the instructional domain of chemistry.

Chemistry was chosen as a domain because the subject matter involves many concepts that are difficult for students to learn (Katz, 1996). Students have trouble learning chemistry because its concepts are abstract, microscopic, difficult to relate to, and hard to visualize. Katz contends that common methods of chemistry instruction fail to account for these problems due to the material being delivered via abstract concepts and complex diagrams. Metaphorical graphics, on the other hand, have the potential to make chemistry concepts more comprehensible to students by allowing the learner to summon relevant prior knowledge from which meaning of abstract chemistry concepts can be derived. Likewise, metaphorical graphics have the capability to combine spatially relevant features of chemistry concepts into familiar patterns of relationships that can be visualized by learners. Metaphorical graphics can thus provide an advantage to learners by combining the positive affects both graphics and metaphors have on learning. Present theoretical models of both metaphors and graphics provide some insights as to how metaphorical graphics may provide such an important aid to learners with respects to the acquisition of new concepts.

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Theoretical Foundation

Paivio's (1986) dual-coding theory attempts to explain how graphics facilitate the acquisition of new concepts. This theory proposes that information is represented in two fundamentally distinct systems: one pertaining to verbal information, such as words, sentences, the content of conversations, and stories, and the other pertaining to nonverbal information, such as pictures, sensations, and sounds (Paivio, Clark, & Lambert, 1988). Increased learning occurs when information can be coded into both systems, whereas information coded only into one is comparatively poorly recalled. Paivio explained that nonverbal components of memory are generally stronger than memories that are verbal. However, he further suggested that although the two systems function independently, they also "contribute additively to memory performance" (p. 226).

Dual-coding theory can be discussed in conjunction with Baddeley's (1986) model of working memory. According to Baddeley, information is organized in a short-term store through three separate systems: a central executive system and two subordinate systems: (a) the visuospatial sketchpad and (b) the phonological loop. The central executive acts as the attention-controlling system, whereas the two subordinate systems operate as subservient processors. The visuospatial sketchpad processes images, whereas the phonological loop processes verbal information. Because working memory has a limited capacity (Miller, 1956), new information competes for space with other information held, including knowledge retrieved from long-term memory during processing. When the system is taxed with volumes of information exceeding its capacity, information is lost—a problem of cognitive load (Chandler & Sweller, 1990; Mousavi, Low, & Sweller, 1995; Sweller, 1994). As cognitive load increases, information entering the system is degraded and sometimes lost. Graphics provide a useful tool for dealing with this problem, in that one graphic can represent a substantial amount of information while only consuming a fraction of working memory space.

Graphics

Larkin and Simon (1987) explained that relevant information is processed together as a whole chunk when presented via a graphic display. Cognitive load is reduced rendering more working memory space available for encoding or making problem solving inferences. More working memory space provides for more information from prior knowledge and additional information from to-be-learned material. In fact, according to Schnotz (2002), when a learner views information in the form of a graphic, prior knowledge of graphic-relevant information is summoned from long-term memory and attached to the graphic to yield a stronger dual code. Moreover, Schnotz (1993) contended that graphics are processed in both the verbal and the nonverbal systems. Thus, when combined with the propositions and images

from both the internal and external information sources, rich dual codes can be formed, leading to optimal conditions for learning.

When discussing graphics by themselves, it is not always clear what information they convey and may not be sufficiently specific as an adjunct to teach difficult, abstract concepts such as those in chemistry. Kulhavy, Lee, and Caterino (1985) contended that graphics serve a conjoint retention function during learning. That is, graphics serve to organize new incoming information during encoding by providing a nonverbal image into which learners can associate verbal propositions at specific locations in the image itself (Schwartz, 1997). According to the conjoint retention theory, during retrieval learners summon the image of the graphic into working memory and use it to decode the relevant verbal information (Robinson, Katayama, & Fan, 1996). However, although the theory is robust in its ability to explain the way graphics and verbal information are coded together and used during encoding, storage, and retrieval, the theory fails to account for the way internally represented information—information that is already known—is summoned and linked to the external information—new information to be learned.

In short, Schnotz (2002) suggested that graphics enhance both the nonverbal and verbal codes of both internal and external information. Stock, Kulhavy and Peterson (1995) identified the process by which internal and external information is cognitively combined. However, neither Schnotz, Kulhavy et al. (1985), nor Schwartz (1997) addressed the nature of graphics' ability to summon internal information. It is expected that metaphorical graphics may serve to summon this internal information and organize incoming external information. Not only do metaphorical graphics take advantage of the learning benefits of graphics, but metaphorical graphics may also contain semantic relationships within the graphic that yield a strong learning device. It is these semantic relationships that allow the graphic to act as a metaphor combining the learning benefits of graphics with that of metaphors.

Metaphors

Metaphors are relational structures of knowledge that represent features and relationships among features between two seemingly different but related knowledge domains (Glucksberg & Boaz, 1993). In the metaphorical literature, a metaphor consists of two components—a topic and a vehicle. A topic is a main idea—a familiar or unfamiliar concept to be learned—whereas a vehicle is a separate concept with similar structural properties that is entirely unrelated to the topic (Glucksberg, McGlone, & Manfredi, 1997; Kintsch, 2000; Lakoff & Johnson, 1980). Metaphors allow for a learner to map the properties of the vehicle onto the topic, attributing similar properties to each. Thus, a metaphor allows for large amounts of information to be transferred from the vehicle to the topic (Paivio, 1979).

When a learner is presented with a metaphor, prior knowledge of the vehicle is summoned from the learner's long-term memory store and brought into working memory (Wolfe, 2001). Once in working memory, the properties of the vehicle are mapped onto the topic, creating a packet of new information regarding the previously unknown material. In essence, the prior knowledge of the vehicle provides a framework for understanding the topic. Thus, metaphors help learners understand unfamiliar concepts because the vehicle serves as an effective template that learners can use to overlay new information, allowing them to comprehend the unfamiliar concept.

Consider the metaphor "my lawyer is a shark" (Glucksberg, Newsome, & Goldvarg, 2001). In this example, the metaphor topic is *lawyer* and the metaphor vehicle is *shark*. When viewed from a literal standpoint, the sentence does not make sense. However, when the properties of a shark—vicious, aggressive, and tenacious—are mapped onto the topic of lawyer, a deeper understanding is attained. And yet certain properties of sharks cannot be mapped onto properties of lawyers. That is, "my lawyer is a shark" cannot be taken to mean that the lawyer is a skilled swimmer with gills. Glucksberg et al. referred to these nonmappable properties as metaphor-irrelevant information.

Metaphor-irrelevant information is important to consider because it sets boundaries on the prior knowledge summoned by a vehicle. Thus, when given the lawyer–shark metaphor, a learner need only summon the metaphor relevant information into working memory in order to yield a deeper understanding of the topic. Metaphors can be valuable in conveying concepts only when a vehicle shares similar properties with the topic and are constrained when dealing with abstract concepts due to the unavailability of appropriate concepts to act as vehicles.

Metaphors are not commonly used in chemistry because of the difficulty in finding appropriate vehicles that share similarities with abstract concepts of chemistry. We believe that visual codes exist that can act as appropriate vehicles for concepts of chemistry.

Limitations in Chemistry Instruction

In traditional instructional methods of chemistry, learners typically develop verbal codes of concepts in the absence of visual codes since chemistry instructors tend to explain new concepts verbally (cf. Katz, 1996). Thus, learners store verbal codes in memory as isolated units with few meaningful attachments to prior knowledge. Likewise, when learners develop nonverbal codes in the presence of the kinds of diagrammatic graphics widely used in chemistry instruction, learners have difficulty summoning prior knowledge as well.

Because standard graphics are unfamiliar to learners within the domain of chemistry, they may be stored as single nonverbal codes with little or no prior knowledge attached. Learners have difficulty forming strong dual codes because of the lack of the ability of the learner to attach

meaningful prior knowledge to the incoming abstract information. In short, verbal and nonverbal codes stored in this manner as isolated, restricted clusters in memory are extremely difficult for learners to derive meaning and later retrieve. Metaphorical graphics may aid in the solving of this problem by integrating incoming verbal and nonverbal information with prior knowledge relevant to the metaphorical graphic to form a strong dual code.

Metaphorical Graphics

As mentioned previously, a *metaphorical graphic* is defined as a spatially based display depicting a metaphorical representation of a concept in which the combined configuration of the graphic's spatial features serves as the vehicle for the topic. If the principles of metaphors and graphics function effectively, then a learner should be able to use a metaphorical graphic to map the information depicted in the graphic onto the concept of the topic to be learned. Because metaphorical graphics combine both metaphors and graphics into a single unit of information via a dual code it is expected that the combination may yield an effective device for learning. Moreover, metaphorical graphics occupy limited space in working memory and work to combine unfamiliar new information relevant to the topic with familiar prior knowledge relevant to the vehicle. As a result, the combination serves to bridge the gap between the unfamiliar domain and the familiar concepts and propositions. Information stored in this manner can be retrieved more efficiently than an isolated image or a single set of articulated propositions because dual codes are linked in multiple ways. Thus, it was the aim of this investigation to develop effective metaphorical graphics to enhance student learning of basic properties of chemical elements. Specifically, we hypothesized that metaphorical graphics would foster greater comprehension of basic properties of chemical elements when compared to conditions in which these properties are (a) described verbally without the benefit of either a metaphor or a graphic and (b) shown in the type of nonmetaphorical graphics commonly depicted in standard textbooks of chemistry.

Present Investigation

In the present investigation, metaphorical graphics were created for individual chemical elements in order to convey information regarding the behavior and reactivity of each element. The cognitive theory of multimedia learning discusses the interactive processes involved in learning material presented through multiple modalities (Mayer, 2005; Mayer & Moreno, 2002). The model suggests that the best conditions for learning are when information can be easily organized into cognitive structures in working memory, through focusing attentional resources on the most relevant information. With respect to material presented as both graphics and text, learning suffers when attention is drawn away from the pertinent portions of the information to be learned

(Mayer & Johnson, 2008). This coincides with a vast body of research that has revealed conditions in which too much information, in the form of redundant text-based content, may actually hinder learning. This principle lead to what is referred to as the redundancy effect (Kalyuga, Chandler & Sweller, 1998, 1999; Mayer, 2001; Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2002). In other words, complementary verbal information is most useful to learners when it is presented in a manner that does not consume valuable attentional resources and cognitive demand. However, Mayer and Johnson demonstrated that if textual information is presented in concise statements, within spatially relevant locations, learning is enhanced. In the present study we aimed to integrate the relevant to-be-learned information through the relationships ascribed by the graphics themselves so that redundant textual information may be avoided. We expected this to result in additional cognitive resources available for the integration of the unfamiliar content with prior knowledge in working memory. Fifteen elements were sampled from the 108 naturally occurring elements on the periodic table of elements. The experimental sample of elements was selected in order to represent the periodic table as a whole with an equal proportion of main group elements, transition metals, and gases.

While adhering to the structure of a metaphor discussed previously, the unfamiliar topic of chemistry was presented by way of a familiar vehicle—human characters. Each graphic was a drawing of a human figure with characteristics representing the behavior, reactivity, and physical properties of the element being portrayed. When the graphic was viewed, it was expected that the semantic relationships between each part of the graphic would serve to summon prior knowledge of human behavior from long-term memory in order to map that information onto the properties of chemical elements. By accessing prior knowledge of human behavior based on generalities of social experience, learners would be able to use that information as a template for characteristics of the chemical elements.

Blasko and Briehl (1997) suggested that as a metaphor becomes more familiar, information processing speeds up as previous experience narrows possible nuances of interpretation, strengthening links between relevant concepts in semantic memory. This experimental presentation type was contrasted with two other depictions of chemical elements—orbital diagrams and verbal descriptions—expecting that learners would perform better when presented with the metaphorical graphics.

Orbital diagrams were utilized because these types of graphics are traditionally used in standard textbooks of chemistry. Each diagram depicted an element in graphical form conveying two types of information about the element: the number of electrons present and the number of electrons in the outer shell of that element. Finally, to serve as a control group, elements were presented as verbal descriptions including all the necessary information from the other two conditions only without graphics.

If the metaphorical graphics designed in this investigation contained, as a whole, the correct spatial information and semantic relationships of the chemical elements, then those relationships would provide for a more elaborated understanding of the characteristics of the elements. However, results should show up in certain kinds of outcomes and not others. For instance, on simple isolated facts about elements such as the element's physical property, elaborated semantic relationships are unnecessary, and, thus, we hypothesized that the recall of these facts would not differ based on presentation type.

On the other hand, if learners are required to make inferences and predictions about the element's behavior and reactivity, then learners viewing metaphorical graphics should have an advantage over the other traditional presentations of chemical elements. Furthermore, it is believed that it is these types of behavioral predictions and inferences that would become eminently important in further learning about the interactions and reactions between chemical elements. In sum, we hypothesized that learners exposed to the metaphorical graphics would make better predictions and inferences regarding the behavior and reactivity of chemical elements when compared to the other two groups.

Finally, the investigation was designed to determine whether prior instruction in chemistry would hinder or assist in the acquisition of basic properties of chemical elements relative to the metaphorical graphic displays. We hypothesized that participants with prior instruction in chemistry would perform better on predictive questions of chemical elements behavior when compared to participants without previous instruction in chemistry. This is because the metaphorical graphics used in this investigation should allow learners to summon prior knowledge of chemistry relevant to the metaphor that cannot be summoned by the graphics traditionally used to teach chemistry.

Method

Design

Two factors, Presentation Type and Previous Chemistry Instruction, were combined factorially to yield six experimental cells. The resulting design was a 3×2 (Presentation Type [metaphorical graphic versus orbital diagram vs. verbal description] \times Previous Chemistry Instruction [1 year vs. none]) fixed analysis of variance (ANOVA). Both factors were manipulated as between-subjects variables.

Participants

Participants were 132 students randomly sampled from a midsized university in the western portion of the United States. Of the sample, 20 were men and 112 were women, with an average age of 21.2 ($SD = 1.49$) and 21.5 ($SD = 1.17$) years for each group, respectively. All participants received extra credit from their instructor for participating in

the study. All participants were primarily English-speaking and free of any observable sensory, physical, or learning challenges that would compromise their ability to perform in the investigation. Of the full sample, the majority declared a major of psychology (39.4%), with the remaining 60.6% distributed across a number of social and physical science majors with a proportionate distribution in those categories at 34.9% and 14.6%, respectively. The remaining 9.1% reported a major of "undeclared." Participants reported an average GPA of 2.74 on a standard 4-point scale. Forty-one participants (32.0%) reported no previous high school chemistry instruction and 87 (68%) participants reported 1 year of previous high school chemistry instruction.

Materials

The materials used in this investigation consisted of three different presentations of chemical elements derived from the periodic table of elements. The presentations depicted the chemical elements as metaphorical graphics, standard orbital diagrams, or written verbal descriptions.

Fifteen elements were selected for this study from the 108 natural elements appearing on the periodic table of elements. These 15 experimental elements were selected as accurate representations of the periodic table as a whole. The sample included approximately the same proportion of metals and nonmetals as well as the same proportion of main group elements to transition metals. A complete list of the elements is contained in Table 1.

Metaphorical graphics. The metaphorical graphics depicted each experimental chemical element as an individual with various characteristics consistent with the behavior, reactivity, and physical properties of the elements being portrayed. Specific human characteristics were derived in

order to metaphorically depict key features of the elements themselves. These key features were based on two types of characteristics. One type was the properties of the chemical elements as they would be described in a standard chemistry textbook and the other type was characteristics of the elements if they were metaphorically viewed from the aspect of popular culture.

The physical properties of chemical elements shown in standard chemistry textbooks include the element's atomic number, chemical symbol, oxidation state, and ionic charge. These three properties were labeled in the borders of the metaphorical drawings. Each graphic was drawn in front of a chromatic background that represents the element's physical appearance and the class in which the element belongs. For example, the number of valence electrons was represented as either the beads on the women's necklaces or buttons on the men's coats.

In order to facilitate the understanding of the physical properties of each experimental element, an interpretive key was provided for each participant to use while viewing. The key consisted of a generic drawing of a man and a woman describing the specifics of the metaphorical graphic and the significance of the numbers contained in the borders.

In order to determine the extent to which the characteristics were taken from popular culture, a list of concepts, terms, and words associated with each element was created based on educational Web sites, chemistry textbooks, and familiar states and conditions of the elements in everyday life. For example, because copper is commonly associated with copper wire, the metaphorical graphic of copper was shown as a woman dressed in a copper-colored gown and adorned with conspicuous copper jewelry. Further, the copper figure was shown wearing a necklace with two red balls representing copper's two valence electrons. The background of the drawing was metallic blue to represent the transition metals, the class to which copper belongs.

In a second example, a woman of upper class status represented the element carbon with a large diamond ring on her hand representing a familiar state of carbon in its purest form. The background of carbon was solid blue, signifying a nonmetal solid, the class to which carbon belongs. Helium is part of a group of elements called the noble gases. Noble gases do not bond with any of the other elements and noble gases have no charge. Therefore, the character for helium appears with his arms crossed and his nose in the air giving the impression that he would have considerable disinterest in interacting with others. Helium had two buttons on his coat to represent the two valence electrons. The background of helium was an orange gas that represents the noble gases. For an example of a metaphorical graphic, see Figure 1 for an achromatic rendition of helium.

Orbital diagrams. Three separate chemistry textbooks (Brown, Lemay, & Bursten, 1997; Ebbing, 1996; Seese & Daub, 1988) were used to derive the appearance of the orbital diagrams for each element. Orbital diagrams convey

TABLE 1. List of Elements Sampled from the Periodic Table of Elements

Element	Properties
Hydrogen	Nonmetal, gas
Helium	Nonmetal, noble gas
Carbon	Nonmetal, solid
Oxygen	Nonmetal, gas
Fluorine	Nonmetal, gas
Magnesium	Metal, main group
Argon	Nonmetal, noble gas
Calcium	Metal, main group
Iron	Metal, transition
Copper	Metal, transition
Silver	Metal, transition
Tin	Metal, transition
Cesium	Metal, main group
Tungsten	Metal, main group
Uranium	Metal, inner-transition



FIGURE 1. An achromatic rendition of the metaphorical graphic for helium.

two pieces of information regarding the element: the number of electrons (atomic number) and the amount of electrons in the outermost shell (the number of valence electrons). Each element's charge and physical appearance was written in the border surrounding a diagram of the orbitals in exactly the same fashion as they appeared in the borders of the metaphorical graphics. An interpretive key was provided for the participants in this condition with a generic drawing of an orbital diagram describing the important relevant information. For example, carbon has an atomic number of 6 with four valence electrons represented as green balls. Carbon also carries a charge of +4 and can appear physically as

a nonmetal solid. For an example of an orbital diagram, see Figure 2 for an achromatic rendition of carbon.

Verbal descriptions. Each element was also described verbally. The verbal descriptions included short, bulleted statements about each element. The statements conveyed the following information: the element's name, symbol, atomic number, number of valence electrons, oxidation state, and relative weight. A key accompanied the verbal descriptions with bulleted statements describing the information that would appear on each slide. An example of a verbal description is as follows: Fluorine has an atomic number of 9. Fluorine has seven valence electrons and carries a charge of -1 . Fluorine appears as a gas and is a nonmetal. For an example of a verbal description for fluorine, see Figure 3.

Dependent Measures

Three chemistry textbooks and a professor of chemistry were consulted to determine the appropriateness of the dependent measures. Four sets of dependent measures were designed for this investigation: a free-recall question, inference and predictive questions, a cued-recall question, and comprehension questions.

Free-recall question. One question was designed to test participants' retention of the experimental material. The question required participants to write down everything they could remember about the elements they studied. Participants had a blank sheet of lined paper to record their answer with no prompts or designated formats.

Scenario cued-recall questions. Thirteen completion questions were written for this section requiring participants to assign an element given a scenario. Eight questions had only one correct answer and five questions had multiple possible answers. Each of the 15 elements was included in at least one question.

The scenario cued-recall test consisted of two types of questions: predictive and inference. Seven predictive questions required participants to make predictions about the elements, whereas six inference questions required participants to make inferences about the elements metaphorically. An example of a prediction question is: Which of the elements you studied would you predict would not bond with any of the other elements? An example of an inference question is: Metaphorically speaking, which of the elements that you studied would have the most dangerous personality?

Element cued-recall question. One question was composed for this section. Participants were given five elements to describe each as if the element was a person. That is, participants were asked to describe characteristics of the element physically, behaviorally, emotionally, or socially as if they



FIGURE 2. An achromatic rendition of the orbital diagram for carbon.

had the opportunity to meet the element in a social setting. The following elements were given with room to describe each: cesium, helium, hydrogen, uranium, and tungsten.

Comprehension questions. Five questions were composed for this section. The first question required participants to rank the nonmetal elements in order of reactivity. The second question required the participants to indicate the number of electrons in the outer shell for each of the elements that were given. The third question required participants to

arrange the elements into groups of similar properties. Five groups were listed: gases, inner-transition metals, nonmetals, regular metals, and transition metals. The fourth question required participants to indicate the maximum oxidation number for five elements. The elements were: copper, iron, tin, uranium, and tungsten. The fifth question required participants to name and write compounds. Three examples were given and a description on how each example was solved. The fifth question consisted of two parts. In the first part, five compounds were listed and the participant was asked to write down the corresponding formulas. In the second part, five formulas were listed and the participant was asked to write down the corresponding compound. Three examples were provided for each type of question.

Procedure

All participants were run in a computer lab consisting of 24 computers. Upon entering the lab, participants were instructed to take a seat at any computer. Each computer screen displayed the following statement: Welcome! Please wait for further instructions.

As the participants sat down, they were instructed to complete a demographic data sheet requesting their (a) age, (b) gender, (c) year in college, (d) major, (e) cumulative GPA, (f) years of high school chemistry, (g) the letter grades earned in each class, (h) advanced placement or honors, (i)

Fluorine

- F
- Non-Metal, Gas
- Atomic Number = 09
- 7 Valence Electrons
- Oxidation State - -7

FIGURE 3. Verbal description for fluorine.

semesters of chemistry in college and the grades received, and (j) the course title and number. After participants completed the demographic data sheet, they were instructed to press the space bar and read a set of experimental instructions on the screen.

The instructions informed the participants that they would be viewing 15 chemical elements and that a testing session would commence immediately after observing the elements. Participants were informed they would have 23 min to view the elements and they could move back and forth between elements at their own pace. Depending on the condition, the instructions informed participants exactly how each element would be presented. The instructions were delivered via a Microsoft PowerPoint presentation with each line appearing in a timed sequence.

In the metaphorical graphics condition, the instructions informed participants that each slide contained a metaphorical graphic of a chemical element personified with human characteristics. Thus, each element was personified to show characteristics of the element's chemical properties in terms of gender, personality, attire, and demeanor. The participants were informed that the characteristics were derived from pop culture and standard textbooks of chemistry.

Participants in the orbital diagram condition were informed that they would be viewing slides that contained orbital diagrams of chemical elements. The instructions explained further that the diagrams were derived from standard textbooks of chemistry. Finally, participants receiving the verbal descriptions condition were simply informed that they would be viewing descriptions of chemical elements.

After participants were informed as to the presentation of the elements, they were directed to locate the interpretive key under the keyboard of the computer at which they were seated. Participants were allotted enough time to become familiar with the key before exposure began, and were permitted to use the key during exposure to the experimental materials. Questions were answered and the experimenter repeated the instructions verbally. Participants were then informed to begin by striking the space bar that prompted the appearance of the first chemical element.

After 23 min elapsed, participants were instructed to turn off their computer screen. The interpretive key was then collected. This marked the end of their exposure to the experimental materials. The experimenter then handed out the first dependent measure: the free-recall question. Participants were allotted 10 min to complete the section. Then, the experimenter collected this section and handed out the second section. Participants were given 7 min to complete the 13 scenario cued-recall questions. When 7 min passed, the experimenter collected the test and handed out the third section. Participants were allotted 6 min to complete the element cued-recall section. After 6 min had elapsed, the experimenter collected the third section and handed out the fourth section. Participants were given 10 min to complete the five comprehension questions. After 10 min passed,

the final section was collected. This marked the end of the testing session.

Results

Protocols were scored for participants' responses on the four measures of retention—specifically, free-recall, scenario cued-recall, element cued-recall, and comprehension tests. Each measure was entered separately into the basic design, consisting of two factors: previous high school chemistry instruction and presentation type. All tests were accepted as statistically significant if the alpha level exceeded .05.

Free-Recall Measure

In the first analysis, free recall protocols were scored for the number of the element characteristics participants recalled. Specifically, the (a) element names, (b) symbols, (c) atomic number, (d) oxidation state, (e) electrons in the outer shell, (f) physical appearance, and (g) atomic weights were tabulated. A bivariate correlation matrix of these characteristics revealed that participants' retention of all seven was significantly correlated (see Table 2). Thus, the seven retention characteristics were entered as correlated measures into a multivariate analysis of variance of the basic design.

The multivariate analysis revealed a main effect of: (a) presentation type, Roy's Largest Root (RLR) $F(7, 115) = 4.62, p = .00$; (b) previous high school instruction, $RLR F(7, 115) = 2.83, p = .009$; and (c) the presentation type by high school chemistry instruction interaction, $RLR F(7, 116) = 1.24, p = .05$. The univariate tests revealed that participants' memory of atomic weight and atomic number failed to be affected by any of the 3 presentation types, $F(2, 121) = 1.78, MSerr = 35.28, p = .173$; $F(2, 121) = .912, MSerr = 16.94, p = .40$, respectively; previous high school instruction, $F(1, 121) = 3.15, MSerr = 62.37, p = .80$; $F(1, 121) = 2.02, MSerr = 37.55, p = .16$, respectively; or the interaction between the two $F(2, 121) = 2.44, MSerr = 48.28, p = .10$; $F(2, 121) = 0.78, MSerr = 14.54, p = .46$, respectively. However, memory for element names, symbols, number of electrons in the outer shell, and physical appearance varied significantly between levels of presentation type, and previous high school instruction, but not differentially between the two independent variables (see Table 3). Interestingly, although participants' memory for oxidation state failed to vary between levels of presentation type and high school chemistry, it was differentially affected by the interaction of the two variables, $F(2, 121) = 5.18, MSerr = 50.88, p = .01$.

Tukey HSD post hoc tests on the levels of presentation type accounting for statistically significant variation in the presentation type revealed that participants showed better memory for all characteristics of the elements except atomic number and atomic weight when given verbal descriptions compared to metaphorical graphics (all p values $< .05$). Although memory for symbols, the number of electrons in the

TABLE 2. Correlation Matrix for Elements' Characteristics from the Free Recall Test ($N = 132$)

Variable	1	2	3	4	5	6	7
1. Element name	—	.675	.502	.346	.341	.482	.455
2. Element symbol		—	.417	.375	.346	.464	.375
3. Atomic number			—	.514	.547	.310	.288
4. Oxidation state				—	.488	.373	.244
5. Electrons in the outer shell					—	.445	.224
6. Physical appearance						—	.277
7. Atomic weight							—

outer shell, and physical appearance were also better remembered when participants were given verbal descriptions compared to orbital diagrams ($ps < .05$), the atomic number and atomic weight failed to be differentially affected by any of the three presentation types ($ps > .05$).

As for the interaction on participants' memory for oxidation states, simple effects tests revealed that participants with 1 year of previous high school chemistry remembered significantly more than participants having no previous high school chemistry, but only when given verbal descriptions during study ($p = .00$). All other pairwise comparisons failed to reach an acceptable level of statistical significance, (all $ps > .05$). See Table 4 for the means and standard deviations for this analysis.

Scenario-Cued Measure

The scenario cued-recall measure consisted of two types of questions: inference questions and predictive questions.

Inference questions. Participants' performance on the inference questions revealed a main effect of presentation type, $F(2, 122) = 8.17$, $MS_{err} = 15.24$, $p = .000$, with participants viewing metaphorical graphics ($M = 4.33$, $SD = 1.53$) out-

performing both participants viewing orbital diagrams ($M = 3.03$, $SD = 1.25$) and verbal descriptions ($M = 3.53$, $SD = 1.28$). All pairwise post hoc comparisons were statistically significant using Tukey's HSD at a $p < .05$. Both the effect prior chemistry instruction, $F(1, 122) = 0.091$, $MS_{err} = 0.17$, $p = .764$, and the interaction, $F(2, 122) = 0.02$, $MS_{err} = 0.00$, $p = .98$, failed to reach an acceptable level of statistical significance. See Table 5 for the means and standard deviations for this analysis.

Predictive questions. In the next analysis, participants' performance on the predictive questions was entered into the design. The resulting analysis revealed both an effect of previous high school chemistry instruction, $F(1, 122) = 5.07$, $MS_{err} = 14.06$, $p = .03$, and the presentation type by chemistry instruction interaction, $F(2, 122) = 3.05$, $MS_{err} = 8.47$, $p = .05$ (see Figure 4). The main effect due to presentation type failed to reach statistical significance, $F(2, 122) = 1.03$, $MS_{err} = 2.86$, $p = .36$. A simple effects test on the interaction demonstrated that participants with one year of previous chemistry instruction significantly outperformed participants with no previous chemistry instruction for both the metaphorical graphic and the verbal description groups when compared to the participants studying orbital

TABLE 3. Multivariate Tests for the Free Recall Test

Effect	Value	F	Hypothesis df	Error df	p	Partial η^2
Intercept RLR	.946	289.453	7	115	.000	.946
Presentation type RLR	.279	4.615	7	116	.000	.218
Previous chemistry instruction RLR	.172	2.826	7	115	.009	.147
Presentation Type \times Chemistry Instruction RLR	.126	2.083	7	116	.051	.112

Note. RLR = Roy's Largest Root.

TABLE 4. Means and Standard Deviations for the Characteristics of the Free Recall Test

Presentation type	Previous chemistry instruction					
	1 year			None		
	M	SD	n	M	SD	n
	Element name					
Metaphor	10.885	2.805	26	9.462	3.406	13
Orbital	11.958	2.820	24	11.313	3.135	16
Verbal	12.676	1.857	37	10.731	3.066	12
	Element symbol					
Metaphor	8.346	4.307	26	6.385	3.501	13
Orbital	9.542	4.283	24	8.438	4.308	16
Verbal	11.973	2.363	37	8.667	4.075	12
	Atomic number					
Metaphor	5.077	3.979	26	4.692	4.191	13
Orbital	6.250	4.286	24	5.750	5.000	16
Verbal	7.351	4.386	37	4.833	3.927	12
	Oxidation state					
Metaphor	2.731	2.779	26	3.000	2.915	13
Orbital	3.708	4.268	24	2.688	2.182	16
Verbal	5.568	3.253	37	1.250	1.485	12
	Electrons in the outer shell					
Metaphor	3.346	3.273	26	2.231	2.386	13
Orbital	2.417	3.501	24	0.938	1.436	16
Verbal	5.487	4.147	37	3.250	3.545	12
	Physical appearance					
Metaphor	4.308	3.159	26	3.077	3.402	13
Orbital	3.500	3.065	24	1.813	2.588	16
Verbal	7.595	3.539	37	3.917	3.801	12
	Atomic weight					
Metaphor	6.231	4.598	26	4.308	4.250	13
Orbital	6.750	4.989	24	7.688	4.963	16
Verbal	8.306	3.756	37	4.750	4.434	12

diagrams ($p < .05$). Conditions of presentation type failed to exert an effect on predictive questions when participants had no chemistry instruction, ($p > .05$). See Table 6 for the means and standard deviations for this analysis.

Element cued-recall measure. In order to determine whether participants were able to accurately relate relevant personality characteristics to the graphic renditions

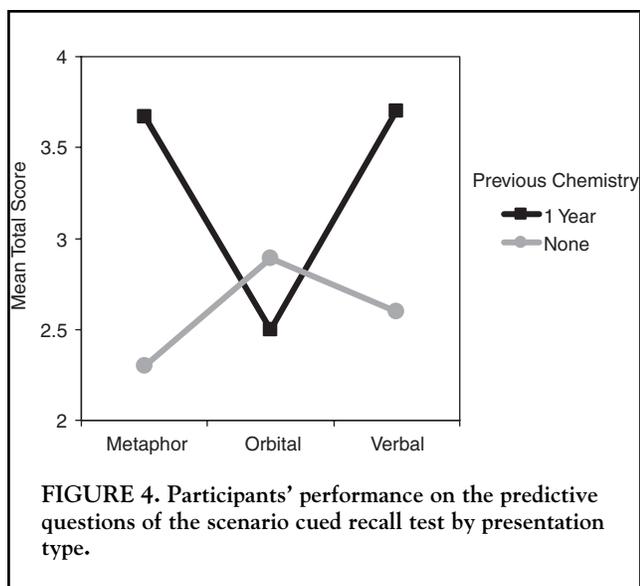
of the chemical elements for the element cued-recall questions, four independent evaluators trained by a professor of chemistry rated the descriptions of the characteristics participants wrote. Ratings were derived by having each evaluator designate whether participants' written descriptions were or were not an accurate reflection of each element's

TABLE 5. Means and Standard Deviations for the Inference Questions from the Scenario Cued-Recall Test

Presentation type	M	SD	n
Metaphor	4.333	1.528	39
Orbital	3.025	1.250	40
Verbal	3.531	1.276	49

TABLE 6. Means and Standard Deviations for the Predictive Questions from the Scenario Cued-Recall Test

Presentation type	Previous chemistry instruction					
	1 year			None		
	M	SD	n	M	SD	n
Metaphor	3.692	1.914	26	2.308	0.947	13
Orbital	2.500	1.474	24	2.875	1.544	16
Verbal	3.812	1.777	37	2.667	1.826	12



personality. The scores obtained ranged from 0 to 5 because there were five randomly selected elements to describe. In order for a description to be designated as an accurate personality descriptor, consensus had to be reached between all four evaluators. A rating was not assigned until all four raters conferred on the same value by way of discussion. The ratings were entered into the basic design described previously.

The results yielded a main effect of presentation type, $F(2, 122) = 23.39$, $MS_{err} = 30.79$, $p = .00$, with the post hoc Tukey HSD revealing that participants in the metaphorical graphic group made significantly ($p = .00$) more accurate descriptions of personality ($M = 2.50$, $SD = 1.45$) than both the orbital diagram ($M = 0.98$, $SD = 0.97$) and the verbal description groups ($M = 0.89$, $SD = 0.98$). Previous chemistry instruction, $F(1, 122) = 0.82$, $MS_{err} = 1.09$, $p = .37$, and the first-order interaction, $F(2, 122) = 0.57$, $MS_{err} = 0.71$, $p = .59$, failed to reach an acceptable level of statistical significance. See Table 7 for the means and standard deviations for this analysis.

TABLE 7. Means and Standard Deviations for the Personality Ratings from the Element Cued-Recall Test

Presentation type	M	SD	n
Metaphor	2.487	1.449	39
Orbital	0.975	0.974	40
Verbal	0.898	0.984	49

TABLE 8. Correlation Matrix for the Assignment of Element's Properties from the Comprehension Questions Test ($N = 132$)

Subscale	1	2	3	4	5
1. Gases	—	.176	.171	.356	.294
2. Inner-transition metals		—	.271	.426	.447
3. Nonmetals			—	.312	.325
4. Regular metals				—	.610
5. Transition metals					—

Comprehension Measure

The comprehension questions were scored for the degree to which participants were able to correctly place elements into groups of similar properties. Specifically, the properties were (a) gases, (b) inner-transition metals, (c) nonmetals, (d) regular metals, and (e) transition metals. A bivariate correlation matrix of the number of correct placements revealed that all participants' assignments of elements into groups were significantly correlated (see Table 8). Thus, the five placement categories were entered as correlated measures into a multivariate analysis of variance of the basic design.

The multivariate analysis revealed only a main effect of presentation type, $RLR F(5, 119) = 5.76$, $p = .00$. Both the effect due to previous high school chemistry instruction $RLR F(5, 118) = 0.51$, $p = .77$, and the presentation type by high school chemistry instruction interaction, $RLR F(5, 119) = 1.19$, $p = .32$, failed to yield an acceptable level of statistical significance. The univariate tests for the presentation type main effect revealed that participants in the verbal descriptions group made significantly more accurate assignments of elements to their respective categories for all five types of property groupings (see Table 9). Post-hoc Tukey HSD tests further revealed that participants given verbal descriptions made significantly more accurate assignments for all property groups than participants in any other presentation type, with the exception of the property of gases. In this area of assignment, verbal descriptions yielded significantly more accurate assignments than the metaphorical graphic group only. See Table 10 for the means and standard deviations for this analysis.

Discussion

This investigation attempted to combine the learning benefits of both metaphors and graphics to improve learners' understanding of the behavior, reactivity, and properties of chemical elements. This was accomplished by constructing appropriate metaphorical graphics depicting chemical elements in the form of human figures. Katz (1996) contended that students who have a deeper understanding of the behavior, reactivity, and properties of chemical elements would

TABLE 9. Multivariate Tests for the Assignment of Elements into Groups of Similar Properties

Effect	Value	F	Hypothesis <i>df</i>	Error <i>df</i>	<i>p</i>	Partial η^2
Intercept RLR	5.725	135.122	5	118	.000	.851
Presentation type RLR	0.242	5.760	5	118	.000	.195
Previous chemistry instruction RLR	0.022	0.511	5	118	.767	.021
Presentation Type \times Chemistry Instruction RLR	0.050	1.191	5	119	.318	.048

Note. RLR = Roy's Largest Root.

have an easier time learning more advanced, higher order concepts in chemistry. An understanding of higher order concepts requires that learners comprehend (a) which elements bond with one another to form compounds, (b) what kinds of bonds are formed, (c) how strong the bonds are, (d) what kinds of chemical reactions can be expected between elements, and (e) the way chemical elements are balanced in formulaic equations. In short, a conceptual understanding of chemical elements functions as a cognitive prerequisite for the comprehension of other fundamental concepts inherent in the domain of chemistry.

As described previously, students have difficulty relating to or visualizing abstract and microscopic properties ger-

mane to chemistry. It has been argued that students also typically fail to effectively learn chemistry due to the ineffective ways that concepts of chemistry are taught (Katz, 1996). Metaphorical graphics were designed to aid in this problem by depicting chemical elements in a way that allows learners to summon prior knowledge about the behavior and stereotypical features of humans that could be used to interpret information about the behavior, reactivity, and physical properties of chemical elements.

Overall, the results revealed that metaphorical graphics helped learners to develop a deeper understanding of the behavior and reactivity, but not the physical properties, of the 15 selected chemical elements. A more detailed discussion of the results is presented in the following sections and organized in light of the four measures utilized in this study.

TABLE 10. Means and Standard Deviations for the Assignment of Elements into Groups of Similar Properties

Presentation type	M	SD	<i>n</i>
Gases			
Metaphor	2.846	1.226	39
Orbital	3.025	1.368	40
Verbal	3.551	1.335	49
Inner-transition metals			
Metaphor	0.282	0.456	39
Orbital	0.275	0.452	40
Verbal	0.551	0.503	49
Nonmetals			
Metaphor	0.923	1.010	39
Orbital	1.050	1.300	40
Verbal	2.245	1.910	49
Regular metals			
Metaphor	0.718	0.826	39
Orbital	0.675	0.944	40
Verbal	1.245	1.110	49
Transition metals			
Metaphor	0.462	0.756	39
Orbital	0.675	1.185	40
Verbal	1.551	1.473	49

Recall of Basic Characteristics and Properties

It was hypothesized that participants' recall of basic isolated facts about the chemical elements would not differ due to presentation type. This was tested through the free recall measure where participants were asked to recall each element's chemical name, chemical symbol, atomic number, number of electrons in the outer shell, oxidation state, physical appearance, and atomic weight. As expected, the results revealed that neither the orbital diagrams nor the metaphorical graphics differentially increased recall of these facts. However, participants receiving the verbal descriptions recalled significantly more of the characteristics of the elements, except for atomic number and atomic weight compared to participants viewing either the metaphorical graphics or the orbital diagrams. The comprehension measure involved five questions requiring participants to apply their knowledge of each element in typical problems involved in chemistry.

Only one question produced statistically significant results. This question required participants not only to determine the physical property of each element but also to place the elements into groups of similar physical properties. As

with the free recall measure, participants in the verbal descriptions group significantly outperformed participants in the metaphorical graphics group and the orbital diagrams group thus partially confirming the hypothesis.

It is believed that the better recall of these characteristics and properties in both the free recall measure and in the comprehension measure occurred due to the way this information was presented to the learner. That is, participants viewing either the metaphorical graphics or orbital diagrams were required to discern the characteristics of the elements from an interpretive key as opposed to viewing a simple bulleted statement of each characteristic. Working memory may have become overloaded with information as a result of the cognitive resources necessary to determine these characteristics. This overload may have resulted in a deficit in learning and thus participants would show less recall of the required characteristics and properties when viewing metaphorical graphics or orbital diagrams. In this case, the bulleted format present in the verbal descriptions provided a useful instructional aid that enhanced participants' ability to memorize basic aspects of the chemical elements by means of highlighting such characteristics, and thus not overloading working memory. If the key was committed to memory and provided less of a demand on working memory, then perhaps the two graphical presentation formats would foster greater retention.

Although verbal descriptions seem to have enhanced the learners' encoding and further retrieval of some of the basic features of chemical elements, the present study was designed to further examine instructional adjuncts that facilitate the learners' understanding of higher order concepts in chemistry. It was believed that metaphorical graphics would constitute a potentially fruitful adjunct because they convey information regarding the behavior and reactivity of each element beyond the basic characteristics and properties of chemical elements. In other words, the metaphorical graphics were designed with the goal of allowing learners to use the semantic relationships within the graphic and the similarities between the topic and the vehicle to increase comprehension of chemistry-related information necessary to make inferences and predictions of the behavior and reactivity of the chemical elements.

Element and Scenario Cued-Recall Measure

In order to determine the effectiveness of the metaphorical graphics to convey the correct behavior and reactivity of the chemical elements, a measure was designed to require participants to describe each element as if it were a person. Participants were required to make descriptions about five elements' respective personalities as if the participants were to interact with those chemical elements in a social setting.

The results indicated that participants viewing metaphorical graphics made significantly better descriptions of attributes of personality consistent with the behavior and reactivity of each chemical element than participants

receiving orbital diagrams or verbal descriptions. These participant-generated descriptions support the notion that the metaphorical graphics served to convey accurate personifications of the behavior and reactivity of the chemical elements. Alternatively, the results showed that elements presented as either orbital diagrams or verbal descriptions could not convey these personifications.

Scenario Cued-Recall Measure

Inference questions. It was hypothesized that participants receiving metaphorical graphics would make significantly better metaphorical inferences about the chemical elements compared to participants receiving orbital diagrams or verbal descriptions. That is, it was expected that metaphorical graphics would be able to assist in the depth of comprehension required for generating these inferences, because these graphics would be able to link pre-existing knowledge about stereotypical human behavior with the behavior of chemical elements.

This hypothesis was tested with the inference questions of the scenario cued-recall test requiring participants to make metaphorical inferences about the elements. The results confirmed the hypothesis. Participants receiving metaphorical graphics made significantly better inferences than participants receiving orbital diagrams or verbal descriptions. That is, the metaphorical graphics served to enable learners to summon the appropriate prior knowledge conveyed by the graphic to make inferences consistent with the behavior and reactivity of the elements. In contrast, both the orbital diagrams and the verbal descriptions were unsuccessful in enabling learners to activate these element-relevant characterizations. This finding is supported by the results of the element cued-recall measure indicating that metaphorical graphics can convey personality features and thus summons prior knowledge of these features.

These results can be attributed to the fact that the inferences required the learners to reason from factual knowledge about human behavior in order to derive logical conclusions about the behavior and reactivity of the chemical elements. Further, it is believed that this factual knowledge of the elements is conveyed through the semantic relationships present within the metaphorical graphics. In contrast, this type of information could not be obtained by viewing the other two methods of presenting the elements.

Predictive questions. Similarly, for predictive questions, the learners were required to predict future states of the elements' behavior and reactivity. It was assumed that predictions would not require the learners to use the skills of reasoning necessary for generating inferences. Instead, predictions would simply require learners to retrieve either prior knowledge of the chemical elements behavior or prior knowledge of human behavior relative to the elements. It was thus expected that prior knowledge would mediate the

learning of the chemical elements relative to making predictions about the elements.

It was hypothesized that participants with prior instruction in chemistry would perform better on predictive questions of chemical elements behavior when compared to participants without previous instruction in chemistry. This was tested with the seven questions of the inference test requiring participants to make predictions about behavior and reactivity of the elements given a statement.

The results partially confirmed the hypothesis. Participants reporting 1 year of previous chemistry instruction who received metaphorical graphics significantly outperformed participants who received orbital diagrams with or without instruction. The metaphorical graphics apparently served as retrieval devices for the chemistry-related prior knowledge by way of the personifications necessary for making the predictions, whereas the orbital diagrams, graphics providing no access to personifying variables, could not.

However, participants receiving verbal descriptions significantly outperformed those receiving orbital diagrams as well and failed to differ significantly from participants receiving metaphorical graphics. The verbal descriptions, without the benefit of personifying information, probably required learners to use whatever networks of knowledge they had available in memory to make the predictions. In other words, the verbal descriptions most likely triggered learners' previous verbally based chemistry knowledge, which in turn enhanced their ability to make predictions. When taken together, these results suggest that the chemistry knowledge necessary to make the predictions is most stored as verbal propositions rather than nonverbal codes.

Theoretical Implications

Schnotz (2002) explained that when learners view information in the form of a graphic, prior knowledge of graphic-relevant information is summoned from long-term memory and attached to the graphic to yield a stronger dual code. He also contended that graphics are processed in both the verbal and the nonverbal systems (Schnotz, 1993). Thus, when combined with the propositions and images from both the internal and external information sources, rich dual codes are formed which lead to the best conditions for learning.

The finding with respect to the predictive questions suggests that with prior instruction both the metaphorical graphics and the orbital diagrams probably functioned in the fashion described by Schnotz (1993). However, the two spatial referents probably summoned very different information from prior knowledge. That is, although the orbital diagrams encoded information both nonverbally and verbally, the information was restricted to what was most salient in the diagram; in the case of the present study, information regarding the number of electrons present. Learners viewing the diagrams were apparently not able to access the prior knowledge necessary to make the predictions because the diagrams restricted the learners' focus on the number of

electrons present in the element as well as the number of electrons in the outer shell.

Kulhavy et al. (1985), through their conjoint retention hypothesis, further explained that graphics serve to organize and restrict verbal codes to the locational features, and the spatial configuration of those features, during processing. Thus, the orbital diagram apparently confined learners' attention to specific information (i.e., the number of electrons present in each element) about the chemical elements that was not relevant for making the inferences and predictions about the behavior and reactivity of the elements.

The confining effects of the orbital diagrams, on the other hand, did not restrict verbal descriptions. In other words, learners' attention was not restricted to a dominant salient feature, but rather to all of the relevant features of the chemical element. In sum, learners viewing verbal descriptions who had prior chemistry instruction may have searched their prior knowledge more liberally for verbal codes that would allow them to encode the chemical element information relevant to predicting future states of the elements.

The results of the inference questions of the scenario cued-recall measure also suggest that the metaphor component of the metaphorical graphics acted in similar way that metaphors did as described by Glucksberg et al. (1997). Specifically, the metaphorical graphics served as effective metaphors for elements of chemistry in terms of human characteristics, with the graphic acting as the vehicle for the topic of chemistry. Although the topic—chemistry—and the vehicle—human behavior—were entirely unrelated concepts, learners were apparently able to determine similarities between the two in order to gain a richer understanding of the topic. This, in turn, allowed learners to make accurate inferences and predictions of the behavior and reactivity of the chemical elements. Of particular note, the benefits of metaphorical graphics were not as robust when it came to memorizing basic characteristics of chemical elements in this investigation such as the physical property of the element.

With regard to the recall of basic characteristics, the findings suggest that certain information about chemical elements is best recalled when organized in a linear fashion as indicated by the participants' better performance in the verbal descriptions condition. Further, when an appropriate graphic is used to convey information beyond basic facts, the graphic should not attempt to include information about the basic facts as well. In summary, the findings suggest that the strongest effect would be found with the metaphorical graphics accompanied by short verbal descriptions conveying information not found in the graphic. This coincides strongly with the results reported by Mayer and Johnson (2008), but extend it a step further. Metaphorical graphics enable learners to access to the information in a manner that cannot be conveyed through simply text alone. The results of the present study attempt to add to the cognitive theory of multimedia learning, by combining both words and pictures in the absence of text, and thus lessening the attentional strain during encoding while including more information

from prior knowledge. We believe that information presented in this fashion would produce the strongest dual code without exhausting necessary cognitive resources.

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