Chapter 5
How Effective Is the Use of Analogies in Science Textbooks?

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Introduction

Both scientists and science educators use analogies, in either written or oral form, to convey information to others: to their colleagues, to the media, to their friends, and to their students. Simply put, an analogy is a comparison between two domains of knowledge – one familiar and one less familiar. In the literature, the familiar domain is referred to as the "vehicle," "base," "source," or "analog" domain, and the less familiar domain, or the domain to be learned, is referred to as the "target" domain. For the purposes of this chapter, I will refer to the two domains as the "analog" and "target" domains, respectively.

To say that an analogy is a comparison may be an oversimplification. An analogy is not just a comparison between different domains: it is a special kind of comparison that is defined by its purpose and by the type of information it relates. "An analogy," according to Gentner (1989), "is a mapping of knowledge from one domain (the base) into another (the target), which conveys that a system of relations that holds among the base objects also holds among the target objects" (p. 201). The purpose of an analogy is the transfer of relational structure from a known, or familiar, domain to a less known domain (Mason & Sorzio, 1996). Thus, the strength of an analogy lies less in the number of features the analog and target domains have in common than in the relational structure overlap between the two domains and the system of connected information that it conveys (Gentner, 1983).

Analogies are often used in educational settings to help students develop an understanding about topics that are unfamiliar or abstract by comparing them to information that is already familiar to the students (Beall, 1999). They can be particularly

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helpful in science education, where many concepts are not only new and, thus, unfamiliar but also abstract. However, the potential of analogies to help students develop understandings of scientific concepts is not always achieved. Both research and experience indicate that not all analogies are good analogies and that an analogy that is useful for one person may not be useful for another person.

Although the ultimate focus of this chapter will be on the effectiveness of analogy use in scientific textbooks, it will be useful to first briefly review some of the roles that analogies can play in promoting meaningful learning, some of the challenges and difficulties associated with using analogies in educational settings, and what research says about effective classroom analogy use.

Potential Roles of Analogies in Promoting Meaningful Learning

There are three main roles that analogies can play in promoting meaningful learning (Venville & Treagust, 1997): they can help students develop an *understanding* of new information, they can help students *visualize* new or abstract information, and they can *motivate* students to learn meaningfully.

First, analogies may help learners develop an *understanding* of new information, particularly when students lack sufficient background in a content area (Thiele & Treagust, 1992). Analogies can help students connect new information to already understood, already developed concepts (Thiele & Treagust, 1995), a process that is essential for meaningful learning (Glynn & Duit, 1995), by arranging existing memory to prepare it for new information. They can also give structure to information being learned by drawing attention to significant features of the target domain (Simons, 1984) or to particular differences between the analog and target domains (Gentner & Markman, 1997). In some cases, analogies can be used to support the development of conceptual models (Iding, 1997) or even serve as initial mental models (Glynn & Takahashi, 1998).

Second, analogies may help students *visualize* abstract concepts or phenomena that cannot be observed or experienced directly (Curtis & Reigeluth, 1984; Dagher, 1995a; Harrison & Treagust, 1993; Iding, 1997; Simons, 1984; Thiele & Treagust, 1994a; Venville & Treagust, 1997). Analogies may also provide a concrete reference that students can use when thinking about challenging, abstract information (Brown, 1993; Simons, 1984).

Finally, analogies can play a *motivational* role in meaningful learning (Bean, Searles, & Cowen, 1990; Dagher, 1995a; Glynn & Takahashi, 1998; Thiele & Treagust, 1994a). Analogies' connection of unfamiliar, abstract information to students' real-world experiences and analogies' familiar language can motivate students to learn new information meaningfully (Thiele & Treagust, 1994a). Lemke (1990) asserts that students are three to four times more likely to pay attention to an analogy than to a "scientific" explanation of a concept, perhaps because the language of an analogy is more familiar and accessible than scientific language. In fact, Dagher (1995a) says that the language of analogies can demystify scientific language and reports that the use of narrative analogies tends to result in higher student motivation and engagement.

Challenges and Difficulties Associated with Using Analogies in a Classroom Setting

While analogies can help students understand new information, visualize abstract concepts, or be motivated to learn, the effects of analogy use are not always positive. In the best-case scenario, students can ignore or not use the analogies provided to them by their teachers. In other cases, students may resort to mechanical use of an analogy, with no thought of the target concept which the analogy was meant to convey. In the worst-case scenario, an analogy can promote the formation of misconceptions about a topic. Some of these negative effects can be avoided if teachers follow certain guidelines in their teaching with analogies practices (see the following section), but at least some of these negative effects are possible even when teachers follow those guidelines.

There are multiple situations in which students might ignore or not use an analogy. When students do not understand what analogies are or how analogies can be used as instructional tools, students may not use analogies or may transfer only the surface features of the analog concept to the target concept instead of focusing on the transfer of a system of relationships from the analog concept to the target concept (Raviolo & Garritz, 2009; Thiele & Treagust, 1992; Venville & Treagust, 1997). Additionally, although, in theory, analogies are meant to convey new information about a target concept by relating it to a familiar analog concept, it may be that an analog concept that is familiar to an instructor is not familiar to the students. When the analog concept is not familiar to students, the analogy is not understandable and may be ignored (Venville & Treagust, 1997).

Even if students understand the analogies presented by their instructors, they may not use them – or may not use them as their instructors intend. For example, although both teacher and student may consider a particular analogy useful for learning new information, the analogy might be superfluous information if the student already has an understanding of the target concept being taught (Thiele & Treagust, 1992; Venville & Treagust, 1997). Additionally, if there is an algorithm that students can use to solve a problem, the students will most likely not pay attention to an analogy that has been presented with the goal of helping the student solve the problem (Friedel, Gabel, & Samuel, 1990).

Alternatively, a student could resort to using the analogy mechanically, without considering the meaning the analogy was meant to convey about the target concept (Arber, 1964; Gentner & Gentner, 1983; Venville & Treagust, 1997). Part of the mechanical use of analogy may be due to the students' not being willing to invest time to learn a concept if they can simply remember a familiar analogy for that concept.

The mechanical use of an analogy may also be due to a student's inability to differentiate the analogy from reality (Thiele & Treagust, 1995). No analogy is perfect because an analog concept, though *similar* to a target concept, is not the *same* as the target concept. In other words, each analogy has limitations. Unfortunately, students often do not know enough about the target concept to understand or identify the limitations of a given analogy (where an analogy "breaks down") – particularly when those limitations are not explicitly identified by their instructor.

When students inappropriately apply irrelevant concepts from the analog domain to the target domain, they can develop misconceptions about the target domain (Brown & Clement, 1989; Clement, 1993; Duit, 1991; Glynn, 1995; Kaufman, Patel, & Magder, 1996; Thagard, 1992; Venville & Treagust, 1997; Zook, 1991; Zook & DiVesta, 1991; Zook & Maier, 1994). For example, an analogy that is often used in biology courses compares a cell to a factory and the different organelles to parts of the factory. Students who know a lot about factories but little about the cell might mistakenly assume that the cell, like the factory, has a limited number of entrances. The misconceptions that are developed as the result of an analogy can be difficult to remedy.

Finally, and ironically, although one of the purposes of an analogy is to help students learn a concept meaningfully by relating that concept to the students' prior knowledge, the use of a single analogy may limit a student's ability to develop a deep understanding of that concept (Brown, 1989; Dagher, 1995b; Spiro, Feltovich, Coulson, & Anderson, 1989). When only one analogy is used to convey information about a particular topic, students may accept their teacher's analogical explanation as the only possible or necessary explanation for a given topic.

For example, Spiro et al. (1989) found that medical students were kept from a full understanding of concepts associated with myocardial failure because of analogies they had learned. They noted:

> […], although simple analogies rarely if ever form the basis for a full understanding of a newly encountered concept, there is nevertheless a powerful tendency for learners to continue to limit their understanding to just those aspects of the new concept covered by its mapping from the old one. Analogies seduce learners into reducing complex concepts to a simpler and more familiar analogical core. (Spiro et al., 1989, p. 498)

It may simply be more convenient for students to think of a concept as being explained by one familiar analogy than to invest the time to learn a new explanation for or develop a complete understanding of that concept. Spiro et al. (1989) do indicate, however, that the tendency for a single analogy to limit students' ability to develop deep understandings of concepts can be overcome through the use of multiple analogies because of the different perspectives that these analogies can provide about a given topic.

What Does Research Tell Us About How Analogies Should Be Used?

While some research indicates the positive effects of analogy use (Beveridge & Parkins, 1987; Brown & Clement, 1989; Cardinale, 1993; Clement, 1993; Donnelly & McDaniel, 1993; Fast, 1999; Glynn & Takahashi, 1998; Harrison & Treagust, 1993; Hayes & Tierney, 1982; Holyoak & Koh, 1987; Simons, 1984; Solomon, 1994; Treagust, Harrison, & Venville, 1996), other studies indicate that the use of analogies results in either mixed, neutral, or negative results (Bean, Searles, & Cowen, 1990; Friedel et al., 1990; Gilbert, 1989). Fortunately, there are several strategies that can be used to increase the probability of an analogy's having a positive effect on students' learning (to promote "analogical transfer").

Training in Analogy Use. The first strategy that can be used to help students learn from analogies is to teach students how to use analogies and to help them recognize the role that analogies can play in learning (Goswami, 1993; Harrison & Treagust, 2000; Iding, 1997; Klauer, 1989; Venville, Bryer, & Treagust, 1994; Venville & Treagust, 1997). The lack of such instruction in textbooks or in classrooms implies that textbook authors and teachers believe that their students are capable of both recognizing and applying analogies in order to learn. However, this assumption may not be warranted. The lack of spontaneous transfer of analogies demonstrated in the literature indicates that students are not familiar with the use of analogies as a learning tool.

Venville et al. (1994) assert that students must be familiar with the process of analogical thinking in order for their learning with analogies to be effective. They divided a class of 9th grade students at a Catholic secondary school into two groups. One group of students was trained in analogy use; the other group was not. An analogy (how a bookcase is like the shells of an atom) was presented to the whole class, and students were interviewed a day later. Immediately following the interviews, all students in the class completed an exam. The students in the analogy group had a better understanding of the word "analogy" and of the educational purpose of an analogy than their peers. There was little difference between the two groups in their ability to map out the similarities between the bookcase and the atom. The trained students, however, were more aware of and able to point out the limitations of the analogy than the other group. The ability of the trained students to recognize the limitations of the analogy may keep those students from developing analogy-based misconceptions.

Analog Explanation. Even when students understand what an analogy is and how to use it to learn, they may struggle with applying the analogy when they do not understand the analog concept. For this reason, several researchers suggest that instructors provide at least a brief explanation of the analog concept when using an analogy (Curtis & Reigeluth, 1984; Hayes & Tierney, 1982; Iding, 1997; Venville & Treagust, 1997). Such an explanation can be brief and should necessarily highlight transferable features and relationships in the analog concept but would ensure that all students in the class start with the same understanding of the analog concept.

The explanation of an analog concept could also be given in the form of a figure. Thiele and Treagust (1992) indicate that the use of a picture decreases the likelihood that a student is unfamiliar with an analog concept; other studies show increased understanding and retention of target concepts when analogies are accompanied by pictorial representations. Bean, Searles, Singer, and Cowen (1990) presented the analogy of a cell with a factory to high school students. Some of the students were presented with pictorial representations of the analogy. Others were not.

The students that received the pictorial instruction did significantly better than their peers on a comprehension/retention test. A study by Beveridge and Parkins (1987) suggests that visual representations of analogies are particularly useful in promoting meaningful learning when those representations highlight features or relationships in the analog concept that are to be transferred to the target concept.

Providing Hints. Another strategy that can promote analogical transfer is providing a hint to students that the analog and the target share similarities or that features of the analog can be used to solve a target problem (Anolli, Antonietti, Crisafulli, & Cantoia, 2001; Gick & Holyoak, 1980; Goswami, 1993; Spencer & Weisberg, 1986). In essence, "providing a hint" is equivalent to notifying the student that there is a connection between the analog and target concepts and implying that the student should look for that connection. Providing a hint is especially important in promoting analogical transfer when analog and target concepts are presented at different times or in different contexts (Spencer & Weisberg, 1986).

Explicit Mapping of Shared Attributes and Identification of Analogy Limitations. Beyond providing a hint, a teacher should promote analogical transfer by explicitly stating the similarities between the analog and target concepts and by stating the limitations of the analogy (Harrison & Treagust, 1996). Analogies are often used to make new information intelligible by drawing comparisons between it and knowledge the students already have. Students do not know which aspects of the analog apply to the new information and which do not. If teachers explicitly identify these similarities and limitations, students will be less likely to incorrectly apply the attributes of the analog to the target and more likely to apply the appropriate attributes.

Textbook Analogies

Analogies are often included in textbooks because some students require alternative presentations of different concepts in order to learn them meaningfully (Thiele, Venville, & Treagust, 1995) or because they make the text more "friendly" to students (Bean, Searles, & Cowen, 1990). In science textbooks, analogies may also serve the purpose of introducing students to the scientific style of writing. Unsworth (2001) found that in science textbooks, many events are "nominalized." In other words, events and generalizations are grammaticalized as "things." An example is using the words "his departure" (a noun) instead of "he departed" (an event). Analogies can be bridges between "regular" or "common" and "nominalized" text/grammar. In fact, analogies are often preparatory for the introduction of nominalized language in educational scientific texts.

Even though there are potential advantages of using analogies in textbooks, as implied by the fact that most textbooks, and particularly physical science textbooks, contain analogies (Duit, 1991), there are also potential problems associated with the use of analogies in textbooks. Textual analogies are very different from oral analogies because they offer no mechanism for immediate feedback or modification for individual students or for the correction of misconceptions that students might develop from the printed analogies. For these reasons, text analogies must be presented in such a way that their explanations are very clear in order to be effective (Curtis & Reigeluth, 1984).

Analogies, however, are not often presented as effectively as they could be in science textbooks. In the next two sections, I will focus on the somewhat limited literature base about the use of analogies in science textbooks. The focus will be twofold: (1) research about the effects of textual analogies about science concepts on student learning and (2) research about how – and how effectively – analogies are used and presented in science textbooks, when compared with the strategies that are known to promote analogical transfer.

Research About the Effects of Textual Analogies on Learning

The studies that have been done on the usefulness of textual analogies in science have been inconsistent; sometimes the analogies have aided learning; other times, they have not. For example, Bean, Searles, and Cowen (1990) gave high school students text passages about enzyme catalysis. Half of the students' passages contained a simple, unexplained analogy; the other half did not. After they read the prose, the students were asked to summarize and explain concepts about enzyme catalysis. The quality of the summaries and explanations given by the students who read the text containing the analogy was roughly equivalent to the quality of the summaries and explanations written by the students whose text did not include an analogy. The use of a written analogy did not improve learning under these conditions, perhaps, the authors state, because students do not take advantage of analogies unless they are specifically told to do so.

Gilbert (1989) followed a procedure similar to that of Bean, Searles, and Cowen (1990). He gave 9th and 10th grade Indiana high school students texts on either embryo and seed development or Mendelian genetics. Half of the readings were analogy enriched. The other half were literal. When students were tested for recall, retention, and attitude toward learning, no significant differences were found between the two groups. Gilbert concluded that there is no evidence that analogies should be used in text to promote either achievement or positive attitudes. The analogies used in this study, like those used in the Bean, Searles, and Cowen study, were fairly "simple," meaning that the presentation of the analogy did not include any explicit statements about the correlations (shared attributes) between the analog and target concepts or any explicit statements about the limitations (unshared attributes) of the analogy.

There have also been studies in which the use of textual analogies has produced mixed or positive results. The purpose of Simons's (1984) study was to examine the effects of written analogies on secondary students' understanding of scientific concepts. Two groups of students participated: an experimental/analogy group and a control group. Both groups were given readings about electricity. After they studied the material, the students were given comprehension and recall tests. Simons concluded that the students who scored high on operational learning and students who were visualizers (as opposed to verbalizers) performed better when they used texts that contained analogies.

Even though the analogy group outperformed the control group on both comprehension and recall tests in Simons's study, the analogy group took much more time to read and study the information than did the control group. When the reading and study time were controlled, the differences between the students disappeared. Simons interpreted this evidence to mean that analogies are effective reading aids only when there is sufficient time for students to compare analogies with target concepts.

In another experiment, Simons (1984) examined the kind of information that was transferred when students studied with analogy. In this experiment, it is important to know that the students in the control group were instructed in analogy use and asked questions throughout the text that should have helped them integrate the analogy and target concepts. The factual knowledge of the two groups was the same, but the experimental group had a better understanding of relations between concepts in the target domain. Simons's experiments indicate that textual analogies are beneficial under conditions of sufficient study time and that while analogies are particularly useful in conveying relational information to students, they may not convey any more factual information than more traditional means of instruction. Similar results were seen in studies by Hurt (1985, 1987) and Donnelly and McDaniel (1993), in which students who were provided with analogy-enriched text outperformed their peers on questions that required them to make inferences about a target concept while performing similarly to their peers on factual recall questions. Each of these studies suggests that the real educational power of a textual analogy is not in its ability to help students learn and recall factual information but in its ability to help students understand relationships within and make inferences about target concepts.

In another study, Cardinale (1993) explored the effects of textually embedded etymologies, causal relations, and analogies on the learning of information about the human heart. Her participants, undergraduate students in science education courses without much biology background, received either a control text or a text that contained an embedded explication of some kind. Two days after reading the text, students received a cued-recall test, an identification test, a definition test, and a comprehension test. Students who received either the analogy or causal relation texts scored significantly higher than the other groups of students on cued-recall and definition tests. Cardinale interprets the results to mean that both encoding and retrieval processes were enhanced by the analogy and causal relation explications and states her belief that textual analogies will particularly enhance learning in situations where vocabulary is unfamiliar or concepts are complex and abstract.

Glynn (1991) and Glynn and Takahashi (1998) assert that the inconsistency of the learning effects of textual analogies is the result of the inconsistency of the presentation of those analogies. In his 1991 study, Glynn examined 43 elementary, high school, and college science textbooks, looking for analogies in which there were explicit statements highlighting the relevant features of the analog concept, mapping concepts from the analog to the target concepts, and identifying the limitations of the analogies; but the presence of these "elaborate" analogies was rare. He proposed that students were more likely to learn from elaborate analogies than from simple analogies.

In 1998, Glynn and Takahashi (1998) examined the effects of an "elaborate" textual analogy on learning. In this study, 8th grade students read either an elaborate analogy-enhanced text or a "regular" text about the cell. They were asked to study the reading because they would be asked questions about the functions of the cell parts later. Students who studied with the analogies had higher recall scores that were maintained (factual retention) for at least 2 weeks. When younger students (6th grade) were examined under the same conditions, both the recall and retention advantages were maintained with the analogy group. The students were also asked to rate the concept they were studying in terms of importance, interest, and understandability. There was no significant difference in the importance ranking of the concept between the two groups. However, students in the analogy group ranked the concept of more interest and higher understandability than the control group.

Paris and Glynn (2004) used similar methods to examine undergraduate preservice elementary school teachers' learning about scientific concepts from elaborate analogy-enriched text. For each of three science topics – animal cells, the human eye, and electrical circuits – three text versions were prepared: one containing no analogies, one containing a simple analogy, and one containing an elaborate analogy. Each preservice teacher received a set of three texts to read – one text about each science concept, with the analogy conditions randomly assigned among the participant group. After they completed the readings, the preservice teachers were asked to respond to a questionnaire about their interest in, understanding of, and ability to explain (to a 5th grade student) each of the science concepts. The preservice teachers also completed a knowledge measures survey that included questions meant to examine the teachers' retention of knowledge about the target concepts, their ability to make inferences about the target concepts, and their metacognitive awareness (how well they believed they understood the concept or how correctly they felt they answered the question).

The preservice teachers ranked topics for which they had received the elaborate analogy-enriched text higher in interest, understandability, and explicability than topics for which they had received either the text with a simple analogy or the text with no analogies, regardless of the topic. All knowledge measures – retention, inference, and metacognitive awareness – were also higher for the science topic for which the teachers received elaborate analogy-enriched text. The preservice teachers indicated in subsequent interviews that they felt more confident explaining a science concept after learning it from an elaborate analogy-enriched text because the elaborate analogy explicitly compared the science concept with another concept with which they were already familiar. Paris and Glynn conclude that:

> The findings of the present study suggest that an elaborate analogy can help learners to make correct inferences by making the similarities between the analog and the target concept verbally and visually explicit. In addition, an elaborate analogy can remind learners that analogies are not perfect and provide examples of where the analogy breaks down, thereby reducing the likelihood that misconceptions will be formed. (Paris & Glynn, 2004, p. 242)

It is apparent from the literature that textual analogies may play a role in making scientific text more accessible to students and that they can be effective and useful learning tools if they are clearly thought out and effectively presented, if students have sufficient time to compare the analog concepts to the target concepts, and if the students know how to use textual analogies as learning tools. In fact, if used well, textual analogies can play an important role in the meaningful learning of scientific concepts. The question, then, is how effectively are analogies currently being used and presented in science textbooks?

How Effective Is Analogy Use in Science Textbooks?

There have been a limited number of published analyses of analogy use in science textbooks, and the majority of these are based on an analysis framework presented in a seminal work by Curtis and Reigeluth (1984), who examined analogy use in 26 elementary, secondary, and postsecondary science textbooks. Since the development of the initial analogy classification scheme by Curtis and Reigeluth, five additional studies have reported analyses of textbook analogies in science textbooks at various grade levels using this scheme or a modification of the scheme. Curtis (1988) used the original classification scheme to compare the use of analogies in science textbooks to that in social science textbooks. Thiele and Treagust (1992, 1994b, 1995) modified the scheme slightly to examine analogy use in high school chemistry textbooks, while Thiele et al. (1995) compared analogy use in high school chemistry textbooks with analogy use high school biology textbooks. Newton (2003) analyzed the use of analogies in 80 elementary science textbooks, and Orgill and Bodner (2006) used a slight modification of Thiele and Treagust's classification scheme to describe analogy use in college-level biochemistry textbooks.

Because each of the aforementioned analyses was done with Curtis and Reigeluth's classification scheme or with frameworks that contained slight modifications to that original scheme, I will first present the modified version of the analogy classification scheme used by Thiele and Treagust (1994b), Orgill (2003), and Orgill and Bodner (2006) before describing the results of the published analyses of analogy use in science textbooks.

Analogy Classification Framework. Curtis and Reigeluth's (1984) original analogy classification scheme was used to systematically analyze analogies according to features that are known to promote meaningful learning of scientific concepts. The slightly modified "Analogy Classification Framework" (Orgill, 2003; Orgill & Bodner, 2006; Thiele & Treagust, 1994b) categorizes analogies in the following areas:

1. *The content of the target concept* – Are there specific concepts that tend to be taught with analogies? Are there specific concepts that are not taught with analogies?
2. *The location of the analogy in the textbook* – Is the analogy found at the beginning of the textbook, in the middle of the textbook, or at the end of the textbook?

In both the Thiele and Treagust (1994b) and Orgill and Bodner (2006) studies, analogy location was determined by dividing the textbook into ten equal parts by page numbers and assigning an analogy to a particular tenth of the textbook.

3. *The analogical relationship between analog and target* – Do the analog and target concepts share similar "structure"? Similar "function"? Similar "structure-function"? Analogies in which the analog and target concepts share only similarities in external features or object attributes – and not in relational structures – are said to have similar "structure." Analogies for which the analog and target concepts share similar relational structures – in which the function or behavior of the analog and target concepts are the same – are said to have similar "function." Analogies for which the analog and target concepts share both similar relational structure and similarities in external features are said to have similar "structure-function."
4. *The presentation format* – Is the analogy presented verbally (in words) or is the analogy presented verbally and pictorially? Here the focus is not on a pictorial representation of the target concept, but on a pictorial representation of either the analog concept or of the analogy – a picture that compares the analog concept to the target concept.
5. *The level of abstraction of the analog and target concepts* – For a given analogy, is the analog concept abstract or concrete? Is the target concept abstract or concrete? In the study completed by Orgill and Bodner (2006), a concept was considered concrete if it was something that a student might see, hear, or touch with his eyes, ears, or fingers in the course of his daily activities. All other concepts were considered to be abstract.
6. *The position of the analog relative to the target* – Is the analog presented before the target concept as an "advanced organizer," with the target as an "embedded activator," or after the target, as a "post-synthesizer"? Orgill and Bodner (2006) considered an analogy to be an "embedded activator" if the analogy was presented in the main text of the chapter in which the primary discussion of the target concept was found. They considered the analogy to be an "advanced organizer" if was presented either in a chapter that preceded the primary discussion of the target concept or if it was presented in a chapter preface where the preface was separated from the main text of the chapter. They considered the analogy to be a "post-synthesizer" if it was presented after the main chapter discussing the target concept.
7. *The level of enrichment* – How much mapping is explicit? Is the analogy "simple," "enriched," or "extended"? While there is some disagreement in the literature about the features of an "extended" analogy, the difference between a "simple" analogy and an "enriched" analogy is clear. A simple analogy is a statement that an analog is similar to a target concept (i.e., "a cell is like a factory"). In an enriched analogy, the analogy statement is accompanied by explicit statements mapping the system of relations in the analog concept to the target concept. "Extended" analogies are either those for which there are multiple explicit mappings (Thiele & Treagust, 1994b) or those which are used multiple times in the same textbook (Orgill & Bodner, 2006).

8. *Analog explanation* – Is the analog concept explained in any detail – either verbally or pictorially?
9. *Indication of cognitive strategy* – Do the textbook authors indicate that they are using an analogy to explain a concept with the word "analogy"?
10. *The limitations of the analogy* – Do the authors state any limitations of the analogy?

Analysis of the Use of Analogies in Science Textbooks. Although the specific number of analogies varies from textbook to textbook, published analyses indicate that the use and presentation of analogies in science textbooks is fairly consistent and not as effective as it could or should be, regardless of the grade level or content focus of the book.

Number of Analogies in Science Textbooks. The number of analogies found in these textbooks was relatively small, seemed to increase with the grade level of the book, and may be correlated with the content focus of the book. In their original study, which included elementary, secondary, and postsecondary science textbooks, Curtis and Reigeluth (1984) found an average of 8.3 analogies per text, which is substantially higher than the number of analogies (2.7/book) found in social science texts (Curtis, 1988). However, studies with more narrow grade foci show an interesting trend. Newton (2003) examined 80 elementary science textbooks. Of these, 45 contained no analogies. In the remaining 35 books, there was an average of 2.6 analogies per book. In their analysis of high school chemistry books, Thiele and Treagust (1994b, 1995) found an average of eight to nine analogies per book. Orgill and Bodner (2006) analyzed college-level biochemistry textbooks, which had an average of approximately 20 analogies per book. It would appear, then, that, in general, more analogies are used in textbooks prepared for students at more advanced grade levels than in textbooks prepared for students at lower grade levels – with the number of analogies increasing, perhaps, with the number of abstract concepts presented in the text. However, this trend may only be true for books in a given content area. While Thiele and Treagust (1994b, 1995) found 8—9 analogies per high school chemistry book, Thiele et al. (1995) found an average of 43.5 analogies per high school biology book. It appears, then, that the number of analogies per science textbook may be a function of both the grade level of the book and the content focus of the book, although this assumption needs to be verified through future research. The number of analogies found in each textbook may also be a function of the individual preferences of the authors (Curtis & Reigeluth, 1984; Thiele & Treagust, 1992) or a function of the manner in which a subject has traditionally been taught.

The published data about the most common location of analogies in science textbooks is very limited. In both secondary chemistry and college-level biochemistry textbooks, more analogies were found toward the beginning of the text than toward the end (Orgill, 2003; Orgill & Bodner, 2006; Thiele & Treagust, 1994b). Common sense suggests that students may need analogies to familiar concepts to help them initially become acquainted with the new topics and words presented in the beginning of a science textbook. However, as students become familiar with the language and concepts of the discipline at the end of a semester or the end of a textbook, they may not require as many analogies to everyday objects and experiences help them understand new science concepts. Instead, they can reference new information to information they have learned previously in the course or in the textbook. Research about biochemistry analogies, however, indicates that the location of analogies in science textbooks may be related to the positioning of particular topics in the textbook (Orgill, 2003; Orgill & Bodner, 2006). For example, all biochemistry textbooks have analogies about enzyme/substrate complementarity, so the sections of the textbook that include the topic of enzymes contain analogies. On the other hand, there is not a single analogy about carbohydrates or lipids in any of the biochemistry textbooks examined by Orgill and Bodner (2006); accordingly, the sections of the book that cover these topics do not contain as many analogies, no matter where the chapter is placed in the textbook. Even so, the chapter layouts of biochemistry textbooks are very similar. Each textbook covers the main topics in roughly the same order, and the topics for which there tend to be analogies tend to be found closer to the beginning of the textbooks than to the end. Whether the placement of more analogies at the beginning of chemistry and biochemistry textbooks is a function of the topics typically covered at the beginning of these textbooks or a pedagogical choice on the part of the textbook authors is unclear. Indeed, it remains to be seen if analogies are more commonly located in the beginning than the end of all types of science textbooks.

Content Foci of Analogies in Science Textbooks. Based on their original, systematic analysis of analogies in science textbooks, Curtis and Reigeluth (1984) suggest that analogies are most effective for concepts that cannot be directly experienced. Duit (1991) noted that in physical science textbooks – which usually have the highest number of well-explained analogies – analogies are used to explain abstract or challenging information (Duit, 1991). This is consistent with the results of Thiele and Treagust (1994b), who found that analogies in chemistry textbooks were associated with concepts that are thought to be difficult or abstract for students, such as atomic structure, bonding, and energy – concepts that are also difficult for students to visualize. Analogies in biochemistry textbooks also tend to focus on abstract or hard to visualize topics, such as reaction energetics, the storage and transfer of genetic information, complementarity of enzymes and their substrates, the functions and behaviors of proteins, cell membrane structure, membrane transport, and the regulation of metabolism (Orgill, 2003; Orgill & Bodner, 2006).

Level of Abstraction of Analog and Target Concepts. The notion that analogies usually cover target material that is difficult or abstract is also supported by the relative levels of abstraction of the analog and target concepts. Overall, the majority of target concepts in science textbooks are abstract in nature, while the majority of analog concepts are concrete in nature (Curtis, 1988; Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b; Thiele et al., 1995). Generally, concrete concepts are thought to be easier for students to understand than abstract concepts. Therefore, a concrete analog should be used, and generally is used, to help students understand abstract target concepts (Curtis & Reigeluth, 1984). There is, however, another interesting exception in science textbooks written for elementary school students. In those books, concrete analog concepts are often used to explain concrete target concepts – particularly for biological concepts. This may be related to the type of content elementary students are expected to master (i.e., elementary school students might be expected to master science content that is more concrete than what a college student might be expected to master) or of the content focus (i.e., biological concepts may be more concrete overall than physical science concepts); however, this is another matter that will need to be confirmed through future research.

Analogical Relationship Between Analog and Target. Analogies are generally used to make the relational structure of the features of abstract target concepts more clear to students than they would have been after a direct explanation of the target concepts. This finding is demonstrated by the fact that, overall, the majority of science textbook analog/target pairs share similar "function" (Curtis, 1988; Curtis & Reigeluth, 1984; Thiele & Treagust, 1994b, 1995; Thiele et al., 1995). Again, however, the proportion of analog/target pairs sharing similar "function" (as opposed to similar "structure") increases with the grade level of the book (Curtis & Reigeluth, 1984; Newton, 2003; Orgill & Bodner, 2006). For example, the majority of analogies in elementary science textbooks could be considered "structural" analogies, focusing mainly on surface features of the analog and target concepts (Newton, 2003), while approximately 80 % of the analogies in college-level biochemistry textbooks could be considered "functional" because the analog and target concepts share similar functions or behaviors, but not similar surface features (Orgill, 2003; Orgill & Bodner, 2006). This trend may indicate that the expectation for students to learn more abstract or relational features about a target concept increases with grade level.

Level of Enrichment of Analogies in Science Textbooks. Although most analogies in textbooks for elementary schools students are "simple" (Newton, 2003), the majority of analogies in science textbooks for secondary or postsecondary students are explained ("enriched") to some extent (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b, 1995; Thiele et al., 1995). These analogies are not, however, completely explained. The fact that they are "enriched" to some extent only indicates that they contain at least one explicit mapping between features in the analog and target domains or one explicit indication of why the analog and target domains are being compared. Still, many textbook analogies could be considered "simple" or unexplained. This is particularly true in biology textbooks, which include many simple, unexplained analogies, such as "DNA is the powerhouse of the cell" or "ATP is cellular currency" (Thiele et al., 1995). Unexplained, simple analogies like these can result in misconceptions about scientific concepts (Orgill, 2003; Orgill & Bodner, 2006).

Ideally, analogies should be completely explained or enriched if they are to be understood (Curtis & Reigeluth, 1984; Glynn & Takahashi, 1998), but this is not the case for any of the analogies reported in the published analyses of science textbooks.

Presentation of Analogies in Science Textbooks. The last general set of findings about analogies in science textbooks concerns the manner in which the analogies are presented in the text: whether they are presented verbally or pictorially; whether analog concepts are presented alongside, before, or after target concepts; whether analog concepts are explained; whether analogies are identified as "analogies"; and whether the limitations of analogies are explicitly mentioned. Overall, the presentation of analogies in science textbooks is fairly consistent, regardless of the grade level or content focus of the book, and is not as effective as it could be.

Verbal or Pictorial Presentation? Most analogies in science textbooks are presented in writing or "verbally," to use the phrase from the Curtis and Reigeluth analogy classification scheme (Curtis & Reigeluth, 1984; Newton, 2003; Orgill & Bodner, 2006; Thiele & Treagust, 1994b, 1995; Thiele et al., 1995). Although biology textbooks contain more pictorial representations of analogies than chemistry textbooks (Thiele et al., 1995), none of the textbooks in the published analyses contains many pictorially represented analogies. Curtis and Reigeluth (1984) took the relative absence of pictorial representations of analogies to mean that a verbal presentation of an analogy may be sufficient to promote the educational purpose of the analogy, but those sentiments are not consistent with other published studies, which suggest that the presence of an pictorial representation of an analog concept can promote analogical transfer (Beveridge & Parkins, 1987; Bean, Searles, Singer, & Cowen, 1990). Given the potential importance of pictorial representations of analog concepts for promoting analogical transfer, it is unfortunate that many of the existing pictorial representations of analog concepts in science textbooks are printed in the text margins instead of being aligned with the main text (Thiele & Treagust, 1992, 1994b). Interviews with textbook authors suggest that this marginalization of pictorial representations of analogies is the result of pressure from textbook publishers to minimize the length of science textbooks (Thiele & Treagust, 1992, 1994b).

Relative Position of Analogies and the Main Presentation of Target Concepts. Analogies in science textbooks are typically presented along with (in the same chapter as) the target concept to which they are being compared as "embedded activators" of the target concept (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b). At times, analogies are presented as "advanced organizers" before the target concept is presented, but they are very rarely presented as "post-synthesizers" after the target concept has been presented. Curtis and Reigeluth (1984) suggest that this placement of analogies as either "advanced organizers" or "embedded activators" relative to target concepts indicates that the most effective position of analogies is either with or before the target concept; however, no published studies have examined the effects of analogy position (before, with, or after the target concept) on student learning.

Analogy Explanation. Finally, despite existing knowledge about factors that promote analogical transfer, analog concepts are rarely explained in science textbooks (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006), analogies are explicitly identified as "analogies" only ~15 % of the time (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1992, 1994b, 1995), and the limitations of analogies are infrequently mentioned (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele

& Treagust, 1995). Additionally, none of the science textbooks examined in the published analyses includes a general statement about analogy use or about how students should use analogies to learn (Curtis & Reigeluth, 1984; Orgill & Bodner, 2006; Thiele & Treagust, 1994b, 1995). By leaving out any explicit statements that indicate the presence of an analogy or explain how analogies are used to learn concepts, textbook authors have implicitly stated their beliefs that students should know how to identify and use analogies on their own. Such spontaneous recognition and use of analogies is not often reported in the literature (Anolli et al., 2001; Holyoak & Thagard, 1989).

Implications for the Future Use of Analogies in Science Textbooks

Science textbooks are important resources for both students and teachers (Newton, 2003), particularly when they are unfamiliar with a given topic. Textual analogies can play an important role in helping both students and teachers develop understandings of these unfamiliar topics, but current research shows that analogies are not used as effectively as they should be in science textbooks. None of the analogies in these books are completely explained, very few are identified as "analogies," and the limitations of the analogies are rarely mentioned. Textbook authors may assume that classroom instructors will explain the analogies that are present in their textbooks, but this is not the case (Orgill, 2003; Orgill & Bodner, 2006). Therefore, textbook authors must provide explanations of their analogies and their limitations if they want students (and teachers) to effectively use these analogies to learn science concepts.

As mentioned previously, the literature about the use of analogies in science textbooks is somewhat limited. The literature about specific pedagogical strategies for effectively presenting analogies in science textbooks is even more limited. However, several researchers have suggested models by which science analogies can be taught and presented effectively. Although the models have not been rigorously tested, they are consistent with the factors that promote analogical transfer. Some of these models were developed exclusively for use by classroom teachers, but their steps, strategies, and points of reflection should also be relevant for those wishing to present textual analogies as effectively as possible.

In the next two sections, I will present two of the teaching models from the analogy literature.

Teaching-With-Analogies Model

The teaching model cited most frequently in the literature is the Teaching-With-Analogies (TWA) model (Glynn, 1991, 1995, 1996). Glynn developed his guidelines for teaching with analogies by examining what he considered to be exceptional analogies from science textbooks. The Teaching-With-Analogies model outlines six steps that teachers and textbook authors should follow when using analogies as teaching tools. Each step is consistent with the factors that have been reported as having positive effects on correct analogical transfer:

1. Introduce the target concept.
2. Cue retrieval of the analog concept.
3. Identify the relevant features of the target and analog concepts.
4. Explicitly map the similarities between the target and analog concepts.
5. Indicate where the analogy breaks down.
6. Draw conclusions about the target concept based on the analog concept.

While these steps do not need to be followed in any certain order, teachers and textbook authors should include the features of each of the six steps outlined above in any discussions that include analogies. According to Glynn (1991), analogy-generated misconceptions can be avoided if teachers and textbook authors explain their analogies clearly by following the TWA model.

Although the TWA model is mentioned extensively in the analogy literature and is consistent with the pedagogical strategies known to promote analogical transfer, there are not many published studies that examine its effectiveness. Additionally, I am not aware of any situation in which a textbook author has used this model to present the analogies in a science textbook.

FAR (Focus, Action, Reflection) Model

Treagust and his colleagues (Treagust, 1993; Treagust, Harrison, & Venville, 1998) developed their FAR (Focus, Action, Reflection) model after observing five experienced teachers who used the TWA model with their favorite analogies. They found that although these experienced teachers did use each of the steps of the TWA model of teaching with analogies when they taught, they did not use the steps in any consistent order. Instead, they modified the order of the steps to meet the needs of their students and of the lesson they were teaching. Though not consistently, these experienced teachers also spent some time preparing their analogies before instruction and reflecting on the effects of using the analogy after instruction – actions that Treagust, Harrison, and Venville felt were necessary for the teachers' efficient use of analogies. Accordingly, the FAR guide integrates preparation and reflection stages into the actual instruction stage of using analogies.

The FAR guide is simpler than the TWA model and is so by design. The developers of the FAR guide felt that there were too many steps to remember in the TWA model, so they developed a guide for teaching with analogies that any teacher could remember easily (Treagust, 1993; Treagust et al., 1998). The steps of their FAR guide are found below (Treagust, 1993, p. 299). Although the FAR model for teaching with analogies was developed for use by classroom teachers, its focus and the questions it poses are relevant for anyone who wants to use textual analogies effectively.

F: FOCUS on the concept being taught and the analog to be used. Is it difficult, unfamiliar, or abstract? What do students know about the concept? Are students familiar with the analog?

A: ACTION. Explicitly connect the similarities between the analog and target concepts and discuss the limitations of the analogy.

R: REFLECTION. Evaluate how the analogy came across to the students and make improvements as needed.

Conclusions

There are a limited number of studies about the effects of textual analogies in science and about how analogies are currently being used in science textbooks. Clearly, more research needs to be done to determine how analogies can be used most effectively in science textbooks and how both students and teachers use analogies from science textbooks to learn. Once that research base has been established, the challenge will be to share this information with textbook authors and to help them find efficient, practical ways to invite investigation into scientific concepts through the effective use of analogies.

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