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ARTICLES:

More than Meets the Eye
The Role of Visuals in Science Textbooks

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1. Introduction

In this article we will examine the role, or functions, of visuals in introductory science texts. These functions are surprisingly varied and numerous; as many as ten or fifteen, depending on what you might consider primary or secondary functions. But more of this in a moment. My point is that there are more major functions than meet the eye, far more than the traditional role we attribute to visuals--that of creating or heightening the reader's interest.

Our study begins with a section on The Significance of Visuals, including a few words on scientists' use of visuals, a topic that has received a great deal of attention by scholars and scientists alike; it also treats the reader's use of visuals. The next section addresses the problem of Understanding Visuals, including the degrees of reality, or *similitude*, of various visuals; and with various genre-specific problems. The third section will explore the many functions of visuals, that appear in our corpus and other genres of scientific writing.

Part Four will analyze the corpus, which is drawn from two university-level texts: *Biology: Life on Earth* (Audesirk & Audesirk, 1993) and *General Chemistry* (Ebbing, 1990). This section will examine such verbal-visual relationships as: captions and figure references, complementarity and redundancy, linearity and branching, and the interaction between graphics.

It will also discuss the reciprocity between genres and functions. I would like to begin with a few remarks on the iconic nature of written language.

2. The iconic nature of written language

> The evolution of language started with pictures, progressed to pictographs... to phonetic units, and then to the alphabet
>
> The symbol systems we call language are inventions and refinements of what was once the object perceptions in picture-strip mentality
>
> Donis Dondis

The use of visuals in human communication has been with us since the start of recorded time. Twenty thousand years ago, before alphabets and written language, there were cave paintings with iconic meanings behind them, that reported the world as people understood it at the time (Dondis, 1973: 2. Chauvet, 1996).

As philologist I. J. Gelb emphasizes, all writing is basically pictorial, representational, in origin (Gelb, 1980: 1). "Thinking in concepts," suggests Koestler, "emerged from thinking in images through the slow development of the powers abstraction and symbolization, just as phonetic script emerged by similar process out of pictorial symbols and hieroglyphics" (1964: 322). Egyptian hieroglyphics, for example, blended iconic and phonetic signs into what C.E. Hodge calls a superb semiotic system (Meltzer, 1980: 64).

Indeed, graphic devices, as Macdonald-Ross reminds us, have been invented "to help *represent*, *explain*, and *control* the world in which we live" (Macdonald-Ross, 1977: 48). We find a clay map from Mesopotamia, for example, dated as early as 2500 B.C.

The **iconic** nature of written language comes down to us today, in Chinese and Arabic. We find iconic elements as well, in languages that use the Roman alphabet; for instance, in certain typographic marks: the ampersand (&), and percent sign (%); parentheses, or the exclamation point for emphasis (!), plus various prosodic markers like the interrogative (?) and others that indicate different degrees of pause. Typographic marks, in short, are nonalphabetic and thus represent an additional semiotic system that is integrated with what we think of as writing.

Other elements of typography provide emphasizers, signaling the important of certain information--items like boldface, italics and underlining, as well as different type size in quotes and headings.

We find further remnants of the iconic in our use of Arabic numbers, in which one mark may signify a series of letters that spell out the word (7 and seven, for example), or two marks representing a single word (19 and nineteen). In fact, the entire symbol system of mathematics has a strong iconic bias.

3. Significance of visuals

> It is impossible to think, analyze, or create without mental imagery
>
> Aristotle, DeAnima

> Visualization is the way we think. Before words, there were images.
> Visualization is not just an idea; it is one half of consciousness.
>
> Don Gerard, in Samuels, 1975, xi.

Our first learning comes through tactile awareness, quickly integrated with the sense of taste, smell, and hearing. These senses are soon overshadowed by iconic forces -- the perception of the world by visual means.

"From nearly our first experience of the world," urges Donis Dondis, "we organize our needs and pleasures, preferences, and fears, with great dependence on what we see" (Dondis, 1973: 1). Arnheim argues for the perceptual basis of thought itself, especially for such operations as *comparisons* and *problem-solving* (functions we will examine below).

He states that "Concepts are perceptual images, and ...thought operations are the handling of those images;" a strong claim modified by the caution that "images come at any level of abstraction" (Arnheim, 1969: 13, 227)

Estimates are that about 85% of all the messages we receive are visual, 10% auditory, and the rest taken in through other channels (Doblin, 1980: 89). We can divide visual messages into two classes: *orthographic* (words) and *iconographic*, including elements like pictures and diagrams.

In this paper, I will use the term visuals to refer to iconographic elements. Similarly, we may distinguish graphic from typographic; using graphic to refer to visuals.

The role and significance of visuals vary with the genres they appear in. About 30% of scientific and technical prose in general are illustrative in nature (Rubens, 1986: 80). This would include a range of types, from textbooks to research articles and technical manuals. Similarly, visuals (figures, tables, etc.) occupy one-third to one-half the space in typical research articles, as shown in an analysis of *Science* and *Nature* (Miller, 1998: 29).

Within that genre, experimental reports tend to display more graphics, theoretical analyses more equations (with their strong iconic element) (Lemke, 1998: 89).

3.1 Scientists' use of visuals

> The words or the language, as they are spoken and written, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be "voluntary" reproduced and combined.
>
> Einstein

Many scholars--historians, philosophers of science, and scientists themselves--have commented on the role of visualizing among practitioners, both for *discovering* and *explaining* their work. Einstein, for one, always claimed to think in terms of nonverbal imagery. Indeed, nuclear physicists in general rely heavily on *models*, especially those that can be drawn on paper (Giere, 1988: 137). As we will see, models--specifically three-dimensional models--represent the closest thing to "reality," even more than do photographs. Many studies have shown a strong correlation between physics and spatial visualization (For references, see Lord, 1983: 5).

One study revealed that spatial ability was very important in conceptualizing chemical reactions (Baker & Tally, 1972). And of course we have Kekulé's well-known narrative describing his discovery of the benzene ring (Shepherd, 1978) (For an excellent list of citations in different sciences, see Lord, 1983: 3ff). Indeed, an investigation of 64 eminent scientists found that all of them possessed an extremely high degree of spatial conceptualization (Roe, 1952).

What explains this strong correlation between scientific inquiry and visualization? As philosopher of science Steven Toulmin explains: "The heart of all major discoveries in the physical sciences is the discovery of *novel methods of representation* (italics mine) and so of fresh techniques by which inferences can be drawn (Toulmin, 1953: 103ff). Macdonald-Ross cites as examples of these, the use of the calculus in Newtonian dynamics and the role of chemical equations in the periodic table (Macdonald-Ross, 1977: 71).

The visual element also provides "the material form of scientific phenomena;" in other words, a form in which the object of one's inquiry may be examined and manipulated (Lynch, 1985: 43). Lemke offers a further insight: "The concepts of science," he suggests, "are not solely verbal... They are *semantic hybrids*, simultaneously... verbal, mathematical, and visual" (1998: 87).

Explanation. As Lynch and Woolgar point out, "engineering, botany, architecture, mathematics, none of these sciences can describe what they talk about with texts alone" (1990: 34). When scientists communicate in print, they combine these verbal, mathematical, and iconographic elements "and a host of specialized visual genres seen nowhere else" (Lemke, 1998: 87). Many scientists actually write their articles in order to highlight the visual. (Miller, 1998: 30. For a deeper analysis, see Miller, 1981: 383-395).

3.2 The reader's use of visuals

Scientists and nonscientists sometimes read things differently. An expert reader may actually study the visual before reading the rest of the article (Miller, 1998: 30).

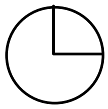
In the field of biology, Lord has described how the entire discipline has shifted from a taxonomic to a "conceptual" approach, with greater stress on lab work and a deemphasis on lecture. Likewise, a movement from rote recall to inquiry. And finally, the movement from dull two-dimensional graphs to color-filled multidimensional displays and the manipulation of models. All this has brought with it the development of iconic processes. At this point, competence in visual literacy "became an important aspect of achievement." (Lord, 1983: 16-17).

4. Understanding visuals

Before we proceed to the functions of visuals and analysis of our corpus, I would like to say a few words on the matter of understanding visuals. We will then use this information in the inquiries that follow.

4.1 Degrees of similitude

A central concept for our study is the **degree of similitude** of a visual, or graphic. In other words, how close does the graphic come to "the real thing," to the actual phenomenon? For this analysis, I would like to draw on the work of industrial designer Jay Doblin, who presents an excellent typology of messages in print media (Doblin, 1980: 89-111) Doblin divides messages into three classes, or forms, which we can call verbal (lexical), numeric, and visual. Every message, suggests Doblin, has an independent form and content; citing, as example, the phrase: "It is three o'clock," which can also be represented as

3:00 or  .

He then offers three subsets under the category of visuals. Let us call them **ideographic, diagrammatic,** and isogrammatic, or **realistic**. Ideographs include such things as Chinese characters, road signs, and flags. He also uses the term **marks** for geometricized symbols with ascribed arbitrary meanings; in other words, letters. Diagrammatic visuals include charts and graphs "used for visualizing processes that are otherwise difficult to comprehend." Realistic techniques are visual representations of reality, and include items such as drawing, photographs, and models. Maps would be somewhere between the last two categories since their contours have similitude but their contents may not. Degrees of similitude could thus be arranged on the following scale:

abstract ———————————————————— **realistic**

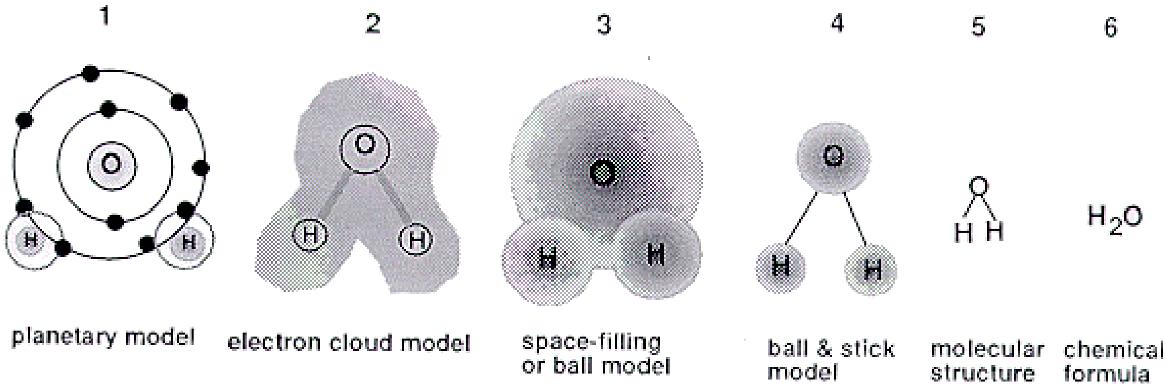
marks tables charts & graphs diagrams maps drawings photographs models

The segment including charts, graphs, and diagrams forms a bridge between the abstract (words) and the most realistic representations. This makes them better suited to describe processes than would pictures. Winn cites as an example, a simplified diagram of the digestive system, which he suggests, illustrates more effectively how it works than a realistic picture of organs and tissues (Winn, 1987: 153).

Doblin notes that "the most realistic form of drawing, illustration, is nearly as realistic as color photographs, but not nearly as realistic as prototype models." He goes on to say that an object can be represented in any of the forms listed above, a claim open to some dispute (Lemke, 1998: 110. Gombrich, 1972: 87).

4.2 Representations and reality

Our biology text itself discusses some of the problems in representing simple molecules (B33). The authors describe *six different ways* of visualizing a water molecule (H2O), each with its own benefits and drawbacks. The most familiar (1) is the planetary model, depicted as a miniature solar system, with the electrons revolving around the nucleus. Despite the fact that planetary models are inaccurate, it best illustrates how atoms bond together to make a molecule. The (2) electron cloud model (in which the three atoms form a triangle, with the entire surrounding area shaded in) is the most accurate representation since it captures the idea of electrons roaming over a relatively large area. But it is hard to draw.



This roaming nature of electrons is best captured by a (3) space-filling, or ball model, which shows two small balls marked **H** (hydrogen) in front of a large ball marked O (oxygen). This contrasts with (4) the ball-and-stick model, which shows three small balls connected by sticks (single, double, or triple sticks, depending on the number of bonds). Ball-and-stick models are easier to draw and best represent the bonding feature of molecules. The simplest and easiest geometric representation (5) shows the three atoms in triangular relationship, with simple lines connecting the two hydrogen atoms to the one oxygen atom. Finally, if the structure doesn't need to be shown at all, one can use (6) the simple chemical formula.

Thus we have trade-offs: *different criteria* as a basis for the various forms of representation. These criteria include: accuracy #1: methods of bonding; accuracy #2: number of bonds; ease of drawing; to which we may add the saving of space (with the chemical formula).

4.2 Genre-Specific Problems

Individual graphics have their own problems: in design, function, and comprehension. Design considerations fall outside of our inquiry. The relation of graphic to function will be discussed in Part Four. Here, I would like to examine some of the comprehension problems posed by several visuals. But first, I would have a word about definitions. There is some confusion about the words *chart* and *graph*. The two words are often used indiscriminately, even by experts. Graphs are sometimes considered a type of chart. In this paper, I will use the term **graphs** for those items that have trend lines--lines that indicate changes. The term **chart** will be used for graphics that enclose volumes of space (bars, circles, etc.) (For a slightly different view, see Winn, 1987: 153).

a) Photographs

Kolers suggests that few photographs are a truly accurate reflection of reality. And that one must learn to read picture just as much as any other form of symbols (Kolers, 1980: 257. Gombrich, 1972: 89). The greater the realism in a photograph, the more information. But realism does not necessarily correlate with learning. As Perkins points out, the important factor is whether or not that realism adds information that the viewer needs (Perkins, 1980: 269).

We may even find “too great a degree of realism.” In its effort at achieving the highest fidelity, a photograph or realistic drawing may include *too much* irrelevant information, that detracts from the function of the visual.

Another consideration is the problem of multiple photographs. As soon as the reader is confronted with a series of pictures, she must decide on the relationship between them. In our corpus, these relationships are one of:

(1) comparison, (2) sequence, or (3) details (e.g., a large picture and several small inserts).

b) Tables

A problem with tables is the difficulty of deciding what is important since all items receive equal emphasis. They do not specify relationships and so are easy to misinterpret. A significant trend is much harder to identify in a table than in a chart or a graph. There are many people who cannot interpret the simplest table. This may be due in part to its unfamiliar perspective: the need to process information vertically and horizontally at the same time--which of course is so different from the way we read. Another weakness, as Macdonald-Ross suggests (1977: 63), is its abstract nature, composed as it is solely of words and numbers. In this way, it is one of the least iconic of all graphical forms.

c) Graphs

After tables, graphs seem to pose the greatest problem to understanding. One reason is that they are hard to interpolate because of their continuous nature. In order to get even an approximate value, one has to interpolate, or mentally connect the point on the graph line to its corresponding points of the vertical and horizontal axes. In addition, some graphs contain more than one trend line, which adds the function of comparison to the other correlations. In short, graphs are good for presenting data but not especially good for teaching. As Winn says: “Their function is mainly descriptive and not really instructional (Winn, 1987: 192). We find an acknowledgment of this complexity in our biology text (B366), where the text goes into considerable detail explicating the graph in general and the four individual trend lines in particular.

In a study of seventh graders, Roller found that graphs actually increased the difficulty of reading despite adequate literacy and math skills of the students. Vernon (1951) came to a similar conclusion in her study with an older population. Roller suggests that “text and graph information are not commonly merged in the mind of the reader” (1980: 307).

5. Functions of visuals

Thought needs shape

Rudolph Arnheim

Visuals serve far more functions than meet the eye. Our corpus reveals at least a dozen. We can examine them along several dimensions. One is to think in terms of primary and secondary functions of visuals. Primary visuals are those that are an end in themselves, such as understanding or remembering. Secondary functions are those that ultimately serve a primary function. One such is summarizing, which can serve the primary functions of understanding, remembering, and so forth. Secondary functions are no less important than primary ones.

I would like to begin this section by noting the various functions of visuals and offering a few comments on each:

5.1 Interest-Motivation

A chief function of visuals in most genres of science writing, apart from research articles, is that of interesting or motivating the reader. From the creator’s point of view, it may also be seen as an instance of artistic expression. One study by Mayer found that 85% of the illustrations in sixth grade science textbooks were “decorational”, which the author defines as having no useful information; or “representational,” such as an unlabeled photo of a rocket ship in test flight (Mayer et al, 1995: 31). We find comparable graphics in our corpus--usually photographs. I would suggest, however, that such visuals serve a very important function; namely, that of interest.

As for artistic expression, Gelb points out that historically, there was no sharp division between artistic and communicative graphics. “The aims of communication and expression are so closely intertwined in all forms of human behavior that normally it is impossible to discuss one without being forced to consider the other” (Gelb, 1980: 8. Gombrich, 1972: 94).

5.2 Understanding

Another main function of visuals in our corpus is that of understanding. There are many items that are hard to grasp through words alone: various concepts and physical relationships, processes and temporal occurrences. Some simultaneous events are hard to understand through the linear constraints of text. In Arnheim’s words: “Intellectual thinking dismantles the **simultaneity** of spatial structure” (1969: 246). Even sequentiality--especially if complex--may also be hard to follow in words. Visuals such as diagrams are particularly well-suited to express temporal events, both simultaneous and sequential. Similarly, a long stretch of text may be quite inadequate for describing the parts--say, of an organ or bodily system, and the relative position of those parts. Visuals serve the following major subfunctions in our corpus. Understanding of (1) abstract processes (B338), (2) parts and spatial relationships (B33, 196, 247, 248. C202), and (3) movement and sequence (B244, B404. C192).

In general, according to Lemke, “our visual discrimination is far better than our linguistic system at dealing with... continuous variations in space, line, shape, and color” (Miller, 1998: 31. Quoting Lemke, 1995).

Visuals also eliminate the lexical and grammatical complexity often found in text. They have no *ifs, althoughs, howevers,* or *instead ofs* that can make the verbal message extremely confusing. There is one less symbol system the reader must decode. This, of course, depends on the visual’s degree of similitude. Graphs, as we have seen, require a great deal of interpretation, especially for the uninitiated, while photos require far less.

Dondis goes as far as to suggest that people actually *prefer* visual representations to written explanations, noting: “In the modern media...the visual dominates; the verbal augments. Print media is not dead yet, nor will it ever be, but, nevertheless, our language-dominated culture has moved perceptibly toward the iconic” (Dondis, 1973: 7). This is apparent in the ever-increasing influence of television and computers. As we have seen, it is also reflected in the changed approach in the teaching of biology, that emphasizes visual, object-oriented, hands-on phenomena.

For Quick Understanding. Speed of processing is an additional factor in our discussion of understanding. Certain visuals in our corpus allow the reader to grasp information much faster than does printed text. This realization is the basis for those semiotic system in which rapid understanding and reaction is crucial; systems such as road signs and warnings (on labels and otherwise). We respond to these stimuli quickly once the are learned. As a result, “they diminish the amount of decoding time needed” (Goodman 1997: 42).” Sight,” in the words of one scholar, “is swift, comprehensive, simultaneously analytic and synthetic” (Gattegno, 1969).

5.3 Remembering

> Sight...requires so little energy to function--as it does--at the speed of light, that it permits our minds to receive and hold an infinite number of items of information in a fraction of a second.
>
> Caleb Gattegno

Psychologists have conducted a great many experiments on the relationship between visuality and memory. The general consensus is that information entered visually is more easily remembered than information taken in verbally (Shepherd, 1966; Tuersky, 1969; Paivio, 1986; Lord, 1983). Fleming emphasizes that “objects and pictures are remembered better than their names, and concrete words... better than abstract words” (Macdonald-Ross, 1977: 56. Citing Fleming, 1970). And Pressley, in a study with eight-year-olds, found that having the children form a picture in their heads after reading each paragraph of a story--improved their recall of the information, compared to a control group that did not form images (Pressley, 1976).

Gombrich speaks of the **mnemonic** power of the image (1972: 91), as does Levie (1987: 16). And Yates, in his classic study, describes how Roman orators would remember their topics by placing them in imaginary rooms in an imaginary house, and stroll from one room to another, retrieving them.

Shepherd and Chipman (1970) describe the relationship of the mental image to the real event or object--as a second order isomorphism. In other words, people tend to have a one-to-one relationship between the mental representation and the thing itself. As for the range of graphics found in our corpus, most do <u>not</u> have a high degree of similitude. Only photographs, 3-dimensional models, and some drawings “pretend” to an approximation of reality. We will examine the idea of degrees of realism later in the article.

Samuels suggests what we might call a certain "haptic" or "synesthetic" function of visuals--I'm not sure there is a word for it--when he says: "Visualization enables a person to incorporate into his body or being in a concrete way that which must otherwise be an abstract idea" (Samuels, 1975: 28). We might think of this as a process of reification: making real--in this case, with a visual--a concept that does not have a natural physical form. We can infer that the more tangible a concept or phenomenon, the easier it is to understand and remember it.

5.4 Elaboration

As we will see in Part Four, a major function of visuals in our corpus is elaborating on statements in the text. Graphics can show physical relationships, size, shapes, etc., without having to describe them in detail. They can provide additional information, sometimes in the form of details, sometimes in the form of **examples**. Examples thus become a secondary function of visuals.

5.5 Economy

> One of the factors which makes graphic organization so powerful is that it can draw simultaneously on a number of different codes and so achieve great economy of expression.
>
> Macdonald-Ross

Conversely, visuals provide a source of economy; specifically, lexical economy. A visual requires fewer words to be processed than does text. As Lord points out, this saves space in a textbook (Lord. 1983: 94; Miller, 1998:30). In this context, let us examine one or two graphics from our corpus and see how they would be rewritten as text.

The first is a photograph from our chemistry book, in which the text states: "Figure 11.38 shows a demonstration of the electrical conductivity of graphite" (C440). The photo then shows an 8-volt battery, a meter, and a graphite pencil, all connected to each other by alligator clips. The visual-to-verbal rewrite might look something like this: "The conductivity of graphite can be easily demonstrated by an 8-volt battery, connected to a meter and a pencil by wire. The 6-volt reading on the meter indicates that the graphite pencil conducts electricity."

That was a short one; what Edward Tufte calls a visual with low *information density*. However, visuals often contain a lot more information, that would require a lot more words to compensate for them. Take another example; in this case, a drawing of the regions of the brain, including the functions of the various regions (B799). The lead-in from the textbook reads: “The functions of the cerebral cortex are localized in discrete regions.” My rewrite:

> The human cerebral cortex is divided into four regions: the frontal, parietal, occipital, and temporal lobes. The frontal lobe deals with the higher intellectual functions such as speech. It is also the premotor and primary motor area, governing the movement of legs, trunk, arms, torso, hands, face, and tongue. The parietal lobe is the primary sensory area and governs sensory associations. The occipital lobe is the area of visual association while the temporal lobe governs language formation and comprehension.

The drawing present the information in a much more holistic way.

5.6 Summarizing

A major function of visuals, in our corpus and universally, is their ability to summarize--to pull together in one focused space--a considerable amount of previously given information. At the same time, we must consider summarizing as a secondary function. What are the reasons for summarizing? They include: remembering, understanding, and quick reference.

When placed at the beginning of a section, such visuals can serve as advance organizers, providing an organizational framework for the material (Winn, 1987: 159; Levin et al, 1987: 56).

5.7 Reasoning/Analysis/Exploration/Discovery

> We envision information in order to reason about, communicate, document, and preserve... knowledge.
>
> Edward Tufte

The chief function of statistical graphics, according to Tufte, is helping people reason about quantitative information (1983: 91). One way of accomplishing this is enabling people to perceive new relationships. This visual can do by providing comparisons and bringing out cause-and-effect relationships. “Such displays,” urges Tufte, “are often used to reach conclusions and make decisions” (1997: 10).

Making Comparisons. Several writers on the subject stress the importance of graphics for making comparisons. Otto Neurath, father of the isotype chart, states that comparison is the major function of visuals (in Macdonald-

Ross, 1977: 55). Likewise, Howard Paine, art director of *National Geographic*, mentions comparison as an important function of visuals (Paine, 1980: 143). Similarly, Tufte (1983: 13) notes that graphics “encourage the eye to compare different pieces of data.” Macdonald-Ross (1977: 403) notes that “many of the formats (such as bar charts and isotypes) are naturally adapted for visual comparison, and would hardly be chosen if rote recall of exact numbers was the intention”. In research articles, according to Miller (1998: 37), the most important use of visuals is highlighting relationships of comparison, in order to imply cause-and-effect relationships. In our corpus, comparison is presented chiefly by tables, drawings and multiple photos.

5.8 Problem-Solving

Studies of cognition suggest that humans have two types of cognitive processes: a linguistic-analytical type and a holistic-image-based model (Loftus & Bell, 1975). French (1965) found that most cognitive tasks can be solved by using one or a combination of both strategies.

As we have seen, visuals can represent a simplified or codified form of information, that is more easily analyzed and manipulated than text, thus making them suitable for solving problems (Szlichcinski, 1979: 254). Herbert Simon suggests that one of the key steps in solving a problem is to represent it “so as to make the solution transparent” (Simon, 1969). For certain types of problems, graphics provide an ideal format. Some of the more useful graphic formats for solving problems include: tables, algorithms, and diagrams. “Even diagrams in anatomy texts,” suggests Macdonald-Ross, “could be considered as problem-solving tools for dissection and surgery” (1977: 60).

It is instructive to recall certain idioms in the English language that reveal the visual nature of analysis, understanding, and problem-solving. These include words and phrases like: *insight* and *imagination*. Or the terms *visionary* and *far sighted*, meaning someone who is able to “see” beyond the ordinary and thus achieve a creative solution to a problem. Similarly, the words *seer* and *enlightening*; or the word *illumination*, meaning a sudden understanding. Likewise, the act of *reflecting*, a synonym for thinking itself. We have in addition, words like *viewpoint* and *perspective*, meaning a different way of examing a problem, which, as we have seen, is often key to solving it. Even words like *uncover* and *research* have a visual substratum. And the phrase “I see what you mean” has come to have the connotation “I understand.” Arnheim goes as far as to suggest that “words that do not now refer to direct perceptual experience did so originally” (1969: 232).

Design scholar Donis Dondis describes the process from the visual thinker’s point-of-view: “In some mysterious way, we form the sight of something we never saw before. Vision, previsualization, is intricately linked to the creative leap... as *a primary means of problem-solving* (underlining mine). And it is this very process of moving around in mental images in the mind that frequently takes us to the point of breakthrough and solution" (Dondis, 1973: 8).

Significant treatments of the topic include Borow and Colins (1975), Kleinmutz (1966), Newell and Simon (1975), and McKim (1980)

5.9 Argument-Persuasion

> There is no such thing as 'facts displayed' pure and simple. All facts presented in papers and textbooks are selected from a huge pool of possibilities.
>
> Macdonald-Ross

The persuasive function of graphics is far more prominent in research articles than in textbooks. And logically so. The main purpose of textbooks is to instruct. The chief function of research articles is to prove a point--to persuade the reader of one's argument. In doing this, the author tries to make the facts "speak for themselves" (Miller, 1998: 30. Also Bazerman, 1988. Myers, 1990). Those facts, in the forms of graphs, photos, and tables, "give the illusion of direct access to the data" (Miller, 1998, 30). Thus, while persuasion is a major function of visuals in research articles, it does not play a prominent part in our corpus.

6. Analysis of the corpus

In our analysis of the corpus, material from the chemistry text will be indicated with a **C**, material from the biology text with a **B. B12**, for example, refers to material on page 12 of the biology text. I would like to approach the corpus from two points of view. The first examines the reciprocity between major elements; specifically: (a) book text, (b) visual, and (c) caption text. We will explore such questions as: How do the three elements interact? To what extent are they complementary or redundant? How do different kinds of visuals interact with each other? We will also look at the use of figure references in the text, plus the issues of complementarity and redundancy, linearity and branching.

The second section will examine the relationship between functions and genres: What are the main functions of different genres (of tables, for example)? And conversely: Which genres are used for different functions (Which genres are most used for comparisons, for instance)?

6.1 Verbal-Visual Relationships

> The concepts of science... are semiotic hybrids, simultaneously verbal, mathematical, visual.
>
> Jay Lemke

This being the case, it is natural to find these modalities used in science textbooks. In our corpus, this includes *prose (text), visuals*, and *caption text*, and, of course, formulas and equations. Captions are less common than one might think, at least in the biology text, which uses them only for tables and occasionally for graphs; reflecting, perhaps, the realization that these two genres need support for interpretation. Other visuals in the biology text have no captions. In contrast, the chemistry volume uses captions for all visuals except cartoons and beginning-of-chapter photos, which are repeated on the following page, in reduced form and with captions. The chemistry volume makes additional use of formulas and equations.

6.2 Interaction of different modalities

Our corpus shows great variation in the relationship between text, visual, and caption text. At one extreme, we find a case in which the text contains no verbal reference to the photo (a cesium clock) (C14); only a figure reference. At the other extreme, we find two pages of text describing the first appearance of land plants and animals. The accompanying artist's rendering of a Carboniferous swamp forest adds no new information whatsoever, but does provide a visual *summary* of the information (B412).

6.3 Where the information lies

In different instances, the bulk of the information may be found in one modality or another. In our case of the cesium clock, above (C14), the bulk of information is found in the caption text, which contains information on the visual, and which also adds information to the general discussion. Here are some ways that text, visual, and caption text relate to each other:

1. A short statement in the text, plus information in the visual (B243, B402, B403)
2. A short statement in the text, plus information in the caption text (C14)
3. A short statement in the text, plus information in visual and caption text (B340, B341, B346)
4. Main discussion in the text, plus information in the visual. That information often takes the form of example, comparison,

summary, or illustrating a process or sequence (function: understanding)

5. Text gives detailed extended description of the visual (C144)

6.4 Caption text

Caption text is an unacknowledged part of the package. It serves a variety of functions, some of them crucial. These functions include:

1. explaining the visual (B347)
2. adding information to the general discussion (B346)
3. a combination of both functions, as in the cesium clock example (C14).

In one interesting case, the text sentence is a general statement ("To maintain homeostasis and to grow, organisms need materials and energy") (B5). The visual is a photograph of a cape buffalo grazing in the tall grass. Nothing in the text relates it explicitly to the visual. This is done in the caption text, without which there would be no connection between text and visual.

The "success" of a visual depends greatly on its relationship to text, caption, and caption text. The more iconic visuals (photos, models, realistic drawings) may be described in the text by a particular sentence. But there are a hundred other statements one could also make about the visual (Gombrich, 1972: 82). The viewer of a visual requires verbal guidance unless the purpose of that visual is strictly one of interest.

6.5 Complementarity and redundancy

The relation of the modalities may be one of **complementarity** (adding new information) or **redundancy** (restating old information). The choice of one or the other seems to depend on the complexity or importance of the concept. The greatest number of iterations--eight--occurs in the chemistry text, in the discussion of Boyle's Law (C146). This includes two separate discussions in the text, an equation, three graphics (table, graph, and drawing), and two captions texts. Though not strictly redundant--the second text discussion, table, and graph contain *elaboration* of details--this provides a canonical form of the interaction between the various modalities.

While information in some of our cases may be redundant, functions are not. For example, a passage from the biology text (B242) describes the steps in the life cycle of a certain bacterium. The accompanying drawing gives a visual depiction of the sequence, its function being *understanding* (understanding a sequence of events).

Complementarity in a visual often takes the form of details, examples, or comparisons. In a sample from our corpus (B347), on homologous (comparable) structures in animals, we find all three. The text states: “Despite the enormous diversity of functions, the internal anatomy of all bird and mammal forelimbs is remarkably similar.” The visual (a drawing) then includes examples of various animals--nine in all--highlighting the homologous structures (in wings and feet).

6.6 Interaction between Graphics

In addition to the modalities discussed above, visuals also interact with each other. These interactions usually take the form of: (1) comparison (B795, B1015), (2) examples (B416), or (3) details (B778, C34-35). For instance, we find several instances of photographs as “main topic,” with three of four small insets providing details. (B945, 953, 1023, 1026, 1031, 1033, 1035). A typical display is a large photo of a tropical rain forest, with four insets of plants and animals that live in it. An explanation of their ecology appears in the caption text.

We also find reciprocities between different types of visuals. The biology text contains several cases of a graph paired with a photo (B1018-1019, B948). One (B952) shows the effects of introducing an animal population (reindeer, in this case) into an area that has no predators. The statement in the text is brief and general (“Other dramatic cases of overgrazing have occurred when herbivores such as reindeer have been introduced onto islands without large predators”). The photo shows a herd of reindeer; while the graph plots the introduction, the sharp rise, and dramatic decline of the population. Interpretation is left to the caption text, which describes the event in words. This grouping reveals an added function of caption text: keeping text in the main body of the book from becoming “clogged;” that is, from becoming too detailed, which runs the risk of drowning the reader in a sea of information.

6.7 Figure References

Figure references--references in the text, to an accompanying visual--fall into two classes: (1) as part of a sentence, and (2) subordinated in parentheses. We may refer to them as the strong form and weak form:

As Part of the Sentence (Strong form):

1. “The interrelationship of experiment and explanation is displayed in Figure 1.5” (C7).
2. “In Figure 1.6, a steel rod has been placed next to a ruler.” (C8)

3. Full sentence in parentheses: ("Figure 1.11 and 1.12 dramatically show the relative densities of substances") (C17)
4. "Table 2-1 lists the most common elements in the universe, the Earth, and the human body" (B24)
5. "Figure 17-3a illustrates two important points about genetic drift: (1)..." (B366)

Subordinated in Parentheses (Weak form):

1. "Balances measure mass...the quantity of matter in a material (Figure 1.2)" (C4).
2. "The flash from a (flash)bulb accompanies a chemical reaction triggered by the heat of an electrical current (See Figure 1.3)" (C5).
3. "Most laboratory glassware (Figure 1.10) is calibrated in liters or milliliters." (C17)
4. "A crystal of table salt (Fig. 1-1a), for example, consists of just two elements..." (B1). *Note*: The sentence mentions the function of the visual.
5. "The phylum name means 'spiny skin,' which is *especially obvious* in sea urchins (Fig. E1-13)" (B11)
6. "Because the water molecules at the surface of a pond cohere to one another, the surface film acts almost as a solid--supporting relatively dense objects such as fallen leaves (and) *water striders* (Fig. 2-13a)" (B38).

A Comparison. In the strong form, the actual reference may appear in initial, medial, or final position. In the weak form, it appears only in medial or final. Sentences in the strong form normally explain what the visual contains or does; that is, they often state or infer the function of the visual. In this way, the strong form provides greater cohesion between text and visual. The strong form is also closer to natural language.

Sentences with the weak form do not refer to the visual, except obliquely, as we can observe in the sea urchin example above (#5), where the phrase "especially obvious" points the reader toward the photo located directly below it. Similarly, in sentence #6. Here the sentence *does* mention to topic of the visual (an insect called the water strider) Thus, we can discern even in the weak form, different *degrees of reference*, with sentence #6 exhibiting a high degree of reference (Also B23, B65, B66, B67, 368), sentences #5 and 4 a medium degree, and examples #1-3 a low degree of reference. Weak forms are far more frequent in our corpus.

6.8 Linearity and Branching

Lemke notes that “scientific text is not primarily linear” (Lemke, 1998: 96) and is not meant to be read sequentially. In this light, it is interesting to observe the placement and operation of figure references; and also of chapter references--those little notations that say: “See Chapter 12.” Or “We will discuss the matter in Chapter 27.”

Figure references point in various directions. They may refer to a figure on the same page or an adjoining one. They may also refer to a graphic that appeared several pages earlier; in some cases, as many as five (B6, B25, B32, B53, B57; and B37, which appears five pages earlier). We also find examples of double branching, in which the text points in two directions; in one case, to the same page and also to a later chapter (B5). As for chapter references, they are overwhelmingly forward branching (For examples backward branching, B69, and B361).

Several questions come to mind: How does the reader respond to the author’s suggestion? And how does the author *want* her to respond? If the reader indeed follows the author’s invitation and skips to the visual, what effect does it have on her comprehension? For verifiable answers, these question are best answered by empirical studies. We may, however, offer a few comments on the matter.

Presumably, chapter references in the form of “See Chapter 24,” if the reader is currently on Chapter 7, serve as a type of forecasting statement, or advance organizer. However, the actual referent usually appears so much later in the book that this function probably has little effect. More likely, the purpose of the reference is the equivalent of saying: “This is a preliminary discussion. We will discuss it in more detail in Chapter 24” (B4, B5, B6). It is not even likely that the author wants the reader to interrupt what she is reading and turn to the distant chapter. My guess is that--almost invariably--the reader rejects the invitation. What about figure references? Here the situation is less certain. Most figure references direct the reader to nearby graphics; in which case, it is more likely she will accept the invitation. There’s even a good chance she will encounter the visual before actually reading the text. Either way, we are forced back to the question of reciprocity.

Visuals and Branching. A visual may relate to the end of a topic (say, an item mentioned at the end of a paragraph); in which case, it does not interrupt the passage, but provides instead a transition from the end of one topic to the beginning of the next. This is much less disruptive, and may even have a beneficial effect for the reader, somewhat akin to white space or a paragraph ending. (e.g., B23)

It is also much easier to skip from text to photo and back to text than from text to a graphic that needs considerable analysis, and back to text again, which is often the case with nonpictorial graphics. In this way, photos are less disruptive than most other visuals, and are thus a more preferable way--for the reader--of receiving details and examples (B51, B367). For visuals that require a great deal of interpretation, the figure reference, if followed, can make comprehension more difficult.

7. Genres and functions

Several problems arise in our effort to understand the relationship between genres and functions. These include, among other things, issues of interest, multiple functions, and demonstrability.

Interest: While the function of interest may be seen to hide behind most visuals, some seem more challenging and repelling than inviting. Some seem to say: “Figure me out if you can.” This, as we have seen from our earlier analysis, includes graphs and tables. It also includes certain types of drawings.

With drawing, we can distinguish between drawings of the familiar and those of the unfamiliar. Drawings of the familiar are more pictorial, depicting things that we have seen and that we know. Drawing of the unfamiliar--of the microscopic or submicroscopic, or internal bodily systems--have a less pictorial “feel” to them and thus are closer to the abstract.

Demonstrability. It is easier to determine when a visual increases interest, adds detail, provides an example, or summarizes. Apart from empirical studies, it is harder to decide how much it increases understanding, persuades the reader, or aids in remembering. For this reason, I have omitted the function of remembering, analysis, and persuasion from the tabulation. Earlier on, we reviewed several laboratory studies that did evaluate some of these functions. And that is as far as we can go in terms of efficacy. However, our study focuses more on function than on efficacy.

This said, let us look at the various functions and visuals and see which--in our corpus--is used to express the other. I would like to present the information in the form of a table; after which, I will offer a few comments.

A capital **M** in the cell means that it is a major function of the visual; a function that has appeared a dozen or more times in the corpus. A small **m** indicates a minor function; one that appears a half dozen times or less:

	Photo	Table	Drawing	Diagram	Chart	Graph	Map
Interest	M						
Under- standing	M		M	m			m
Elaboration by details	M	M	M			m	m
Comparison	M	M	M			m	
Example	M		M				
Summary		M					
Handy reference							

Interaction of Genres and Functions

The Pictorial. The more pictorial a graphic, the greater the **interest** it arouses. Similarly, it is things pictorial that create emotions; the farther from the pictorial, the less emotional. In this way, the more pictorial graphics tend to be more **persuasive**, since ultimately we are persuaded more by emotions than by numbers and logic. Pictorial genres give us tangible objects; things closer to the real world as we know it. For this reason, the best **examples** are also things closest to real world phenomena, in contrast to numbers, which are one step further removed from reality.

Photographs. As we can see from the matrix, the major functions of photos are interest, understanding, adding details, comparison, and examples. In short, even photos--the most pictorial of graphics-- serve other vital functions apart from simply heightening interest. Indeed, several studies showed that subjects who viewed a picture after reading a passage improved their understanding of the material (Bradford, 1983: 264). With the prominence of computer graphics, the line between drawings and photographs grows thinner, as does the difference between artifice and reality.

Maps. Maps have their own uniqueness. They are not pictorial in the literal sense. Still, the average adult has seen enough globes and maps of the world, to have a strong visual image of it. In that sense, maps do have a pictorial feel to them; a feeling of the known, the familiar. There are actually very few maps in our corpus: seven in the biology text and none in the chemistry. For this reason, though I have had to enter a small **m** next to their functions for understanding and details, these are their two major functions in the corpus.

Tables. Tables, as we might have guessed, serve the three major functions of summarizing, adding details, and comparing; and a minor function as a handy reference. It is important to realize that tables *are* implicit comparisons.

Drawings. Drawings, as we might expect, also serve several major functions in the corpus. However, I would stress that many drawing in the corpus are very difficulty to understand, and as such fail to accomplish the purpose they were intended for. These include especially drawings of microscopic and submicroscopic processes, things most people have no internal representation of.

Viewing the matrix from the other direction, it is also interesting to see which genres the authors rely on most, for presenting the major functions of understanding, details, comparisons, and examples. Here we find elaboration of details done chiefly by photos, tables, and drawings. Likewise, comparisons are also made chiefly by photos, tables, and drawings. Examples are expressed chiefly by photos and drawings. And understanding is achieved chiefly through photos, drawings, and diagrams. Elsewhere I have noted that visuals are often used to show the results of experiments. In some cases, the results are presented *only* in the visual and not in the text (Darian 1997: 33).

8. Conclusion

We have touched on the ontology of language and its development from iconographic to more typographic forms. We have also noted that iconic elements are still quite prevalent in modern written language--as seen in typographic and punctuation marks and in the "alphabet" of numeracy.

We have also examined, in greater detail, the relationship between visuals and reality--what I have called degrees of similitude. We have seen that, in some cases, reality (as exemplified by photographs) is not the ultimate criterion for the creation of a visual. But that it does have certain specific benefits, such as speed of processing, which is important as the reader's eye flits from text to visual and back again.

We have explored the functions of visuals, from which comes the following recommendations: When deciding to use a visual, or graphic, to illustrate a text, there are important things to be aware of, including: (1) the best form of representing the information; (2) whether the information in the graphic should be complementary or redundant; (3) the function of the visual; and (4) the reciprocity between text, visual, and caption text. There are, likewise, important considerations for the reader. These include items three and four, just mentioned, and the need, in some cases, for training and interpreting graphs and tables.

We come away with the thought that the relation between visuals and text is extremely complex, subtle, and crucial--to the communication of ideas in science and to the communication of knowledge in general.

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ABSTRACT

More than Meets the Eye
The Role of Visuals in Science Textbooks

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Visuals and visuality are an integral part of science; whether in the thinking of scientists, the portraying of their work, or in the teaching of science. This paper examines the role of visuals in university-level textbooks.

Apart from the function usually associated with visuals--that of interest--graphic devices serve a wide range of functions--as many as 10 or 15, some of which are crucial to the scientific process. These functions include such items as elaboration and economy, understanding and remembering, persuasion and analysis.

We will explore some of these functions as well as the different degrees of reality that various graphics contain. We will also analyze the critical relationship between text, visual, amd caption text; a relationship that is not fully appreciated by readers and writers alike. The paper further investigates such issues as linearity and branching in the text, plus the interaction between graphics. The final section discusses the relationship between genres (e.g., pictures and tables) and functions (e.g., remembering and problem-solving).

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