1985

The use of metaphor in scientific writing

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by

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A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF ARTS

Major: English

Iowa State University
Ames, Iowa

1985

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INTRODUCTION

For centuries both philosophers of science and scientists have challenged the use of metaphor in scientific discourse (Hoffman, 1980a,b), but a close look at this discourse reveals metaphor as a vital and necessary tool in developing scientific terminologies and hypotheses.

I will begin my examination of metaphor in scientific discourse, with definitions: Simply put, metaphor is an implicit analogy of two unlike things. I.A. Richards (1936) refers to these two unlike parts of the metaphor as the "tenor," the primary subject, or the thing being described, and the "vehicle," which is the secondary subject or what the primary subject is being compared with. For example, in the metaphor "the moon is a pumpkin," moon is the tenor (primary subject), and pumpkin is the vehicle (secondary subject).

Then, "what is scientific discourse?" James Kinneavy provides a definition in terms of discourse based on its referential "aim" (1971) in the study of scientific principles. In discussing referential discourse, Kinneavy identifies three types: informational, exploratory, and scientific.

Informational discourse presents a comprehensive discussion of a subject. Exploratory discourse explores a problem and tentative solutions or an issue and possible beliefs entailed in a subject. Scientific discourse posits and supports, either inductively or deductively, a hypothesis about a subject. My focus is on scientific writing, although what I consider can be applied to informative and exploratory discourse as well.

Each type of referential discourse has its own style, but the stylistic features of scientific, informative, and exploratory discourse have strong similarities. According to Kinneavy, "'Objectivity' is the great virtue of scientific style." Most of the semantic and grammatical properties of this style, in fact, stem from the "objectivity of science, the attempt to reproduce reality as accurately as possible." Referential discourse as a whole is "reality-dominated," and features a "plain" style.

Metaphor, however, has traditionally been associated with what Kinneavy terms the "literary aim" in which language calls attention to itself, an aim in apparent opposition to that of referential discourse. Because the goal of the scientific researcher is to approach truth by developing accurate hypotheses and verifiable results in terms of objective reality, the language used in science must be clear and easy to interpret. Therefore figurative language, including metaphor, has been eschewed in theory by many philosophers of science, even though in practice scientists themselves often use metaphor in their writing. As noted by Richard Honeck and Robert Hoffman (1980), Aristotle deplored figurative language as unnecessary and in opposition to objectivity. And Hobbes, Locke, Hume, and Bentham all subscribed to Bacon's assessment of metaphor as one of the "fantasies of the marketplace." In a scathing condemnation of figurative language, John Locke (1706) asserted

> if we would speak of things as they are, we must allow that . . . all the artificial and figurative application of words eloquence hath invented, are for nothing else but to insinuate wrong ideas, move the passions, and thereby mislead the judgment; and so indeed are perfect cheats: and therefore, however laudable or allowable oratory may render them in harangues and popular addresses, they are certainly, in all discourses that pretend to inform or instruct, wholly to be avoided; and where truth and knowledge are concerned, cannot but be though a great fault, either of the language or person that makes use of them (III.x.34).

And C. C. Anderson (1964, cited in Hoffman, 1980a) writes that in the modern age, as scientific and technical advances were made, metaphor was "classified as an embellishment designed to dupe the unwary."

This paper challenges the long-standing philosophical objections to using figurative language in referential discourse. Specifically, it posits theoretical justifications for using metaphor in scientific writing, addresses lingering concerns regarding the use of metaphor, and then examines a select body of scientific writing to evidence and characterize the place of metaphor in such discourse.

THE FUNCTIONS OF METAPHOR IN SCIENTIFIC DISCOURSE

Despite the allegations against figurative language, metaphor is helpful, at times essential, in performing three functions: establishing terminologies, expressing abstract concepts, and developing hypotheses.

Metaphor in Scientific Terminology

Metaphor's role in scientific terminology has been a particular concern of philosopher Richard Boyd. According to Boyd, metaphor can perform the vital catachretic function of developing terminology where none before existed (Boyd, 1979).

In many cases, when fulfilling a catachretic function, metaphor may be considered from the traditional substitutional rather than interactive view. The substitution view, handed down from Aristotle, is that metaphor is no more than a comparison of two things, presenting a concept which could also be stated in literal terms. It states that A is B, or, for example, "my brother is a rock."

A subdivision of the substitution view is the "comparison" view that metaphor is nothing more than an elliptic simile (Johnson, 1980). It states that A is like B in X respect, or, for example, "my brother is like a rock in that both are firm and stable."

Boyd (1979) presents two examples of metaphor used in this way to develop scientific terminology:

1) there are "wormholes" in general relativity, and

2) bound electrons appear in "electron clouds."

Of course, these statements could be made in literal terms. For example, we could say that there are undefined elements in the theory of general relativity. This shows why the substitution view of metaphor may be at least partly responsible for the belief that it is merely ornamental and is primarily appropriate to poetry, where it fulfills an emotionally pleasing or descriptive role.

But in some cases of catachresis, metaphor must be considered from the interactive perspective. The interactive view, established by Max Black and based on ideas from Richards, presents the idea that when the tenor and vehicle are compared, an "interaction" between the two takes place within the minds of the speaker and hearer. The speaker and hearer select and emphasize certain characteristics of both subjects, creating a new view of one or both of them. Metaphor then expresses something which may not be as aptly expressed in literal terms, and in fact may be not at all expressable in any other terms. In this instance one topic is seen through the "filter" of another: A is seen through the filter of B. Viewing my brother through the "rock filter" I pick out the characteristics a rock has that my brother also has, and because there may be no exact literal words to explain those characteristics, I may rely on metaphor to express them.

In such instances, metaphor may be necessary to the creation of terminology and be what Boyd (1979) calls "theory constitutive"; that is, metaphor not only defines the theory it represents, but also is not alternately expressable in literal terms. Such metaphors may hold their constitutive status for only a short time, until replacement by other "literal" language, or may maintain their status indefinitely; but, either way, they hold a vitally important function in scientific research. Two of Boyd's examples of theory constitutive metaphor are drawn from cognitive psychology, computer science and information theory:

1) thought is a kind of **information processing,** and the brain is a sort of **computer**, and
2) certain motoric or cognitive processes are **preprogrammed.**

According to Boyd, computer metaphors seem to be especially useful to cognitive psychologists in presenting their theories, and, for the moment at least, are the most concrete way of expressing them. For these writers of scientific discourse, then, metaphor is certainly more than mere ornament.

Whether replaceable by literal language or theory constitutive, metaphor is has been established as a way of developing scientific terminology.

Metaphor in Abstract Expression

As well as helping to establish terminologies, metaphor facilitates abstract expression. The role of metaphor in abstract expression is best articulated by George Lakoff and Mark Johnson (1981), a linguist and a psychologist, respectively, who maintain that metaphor is fundamental to the human conceptual system, which they break into nonmetaphorical and metaphorical categories. Nonmetaphorical concepts involve 1) spatial orientations (e.g., UP-DOWN, IN-OUT, NEAR-FAR), 2) ontological concepts which come from physical experience (e.g., SUBSTANCE, CONTAINER, PERSON), and 3) structured experiences and activities e.g., EATING, MOVING). Lakoff and Johnson postulate that we use these nonmetaphorical concepts in a metaphorical manner to understand and communicate abstract notions.

For example, one metaphorical notion which incorporates a nonmetaphorical concept is "more is up."

When we make a statement such as "you made a high number of mistakes," or "my income rose last year," we are using our nonmetaphorical, spatial orientation to say something about mistakes or income. It is as if we were able to stack the mistakes or the dollars from the ground up, so that more would make a higher stack and fewer would make a lower stack. It is equally common to say "the number of your errors is quite low," or "my income fell last year."

Ontological metaphors, which give entity status to something which does not inherently have such status, also incorporate nonmetaphorical concepts. We might say "it's difficult to put my ideas into words," or "try to pack more thought into fewer words," indicating that we consider ideas as things or entities, and words as the containers for them. Another "container" for ideas is the mind. Consider such familiar sentences as "I can't get the tune out of my mind," "his brain is packed with interesting ideas," and "I need to clear my head."

Another form of metaphor involves applying nonmetaphorical concepts of physical experience to nonphysical experience. We then apply these experiences to nonphysical experiences. When we say "I see what you mean" or "It looks different from my point of view," we are not referring to a literal view, an actual physical experience, but we are expressing the similarity between our physical vision (seeing) and our mental vision (understanding).

If we accept, as Lakoff and Johnson posit, that metaphor is essential for abstract expression, we must conclude that metaphor has an important place in scientific discourse, where abstract expression becomes essential to the communication of scientific concepts and principles.

Metaphor in Hypothesis-building

Metaphor is also essential to scientists for expanding their understanding of the universe, or of those things which they cannot, perhaps never will be able to, experience with their five senses, such as particle physics, or the cognitive characteristics of the human brain. It is as important for hypothesis-building as it is for abstract expression. In fact, we can draw a direct correlation between hypothesis-building and the processes by which psychologists say we expand our knowledge.

Cognitive psychologists see metaphor and related devices as possible catalysts for assimilation and accommodation in the learning process. According to developmental psychologist Claude Piaget, assimilation is the way in which environmental perceptions are incorporated into stable conceptual schemata. Accommodation is the change of the schemata themselves in response to perceptions and experiences. If metaphor is a catalyst for general knowledge acquisition, it is likely also a catalyst for the expansion of scientific knowledge where the processes of assimilation and accommodation undoubtedly also come into play.

Boyd's atom-as-solar-system example (1979) illustrates the role of metaphor in assimilation and accommodation and in the development of a hypothsis. When physicist Niehls Bohr wanted to present his hypothesis of the appearance of an atom, he used a metaphor comparing the atom with the solar system. Bohr's perceptions of the atom were assimilated into his understanding of accepted natural principles, specifically of the solar system, resulting in a change in the stable conceptual schemata, or accepted theories, to accommodate the perception.

The atom-as-solar-system theory is clearly metaphorical; it is based upon the comparison of two things in which the reader can immediately infer similarity--that is, between the tenor (the atom) and the vehicle (the solar system). Using metaphor, Bohr could present his theory in a manner which, though it could have been alternately expressed in "literal" terms, was not only clear, but also succinct. In addition, the metaphoric association with an already established and accepted natural theory helped to support and develop the new theory. The lack of previous information on the makeup of atoms required that Bohr present his theory in terms of natural principles his colleagues had already conceptualized, and the atom/solar system analogy worked well for this purpose. Thus the atom/solar system analogy established by metaphor provided a basis for continued research, a useful concept for further communication, and a linguistic expression which not only succinctly and effectively identified the atom's nature but also influenced how we conceive of the atom to this day.

Boyd (1979) posits that metaphor is "especially well suited to the introduction of terms referring to kinds whose real essences consist of complex relational properties, rather than features of internal constitution." The atom/solar system metaphor describes such complex relational properties, and provides a classic illustration of metaphor playing an important role in the development and presentation of a scientific hypothesis.

CONCERNS ABOUT METAPHOR IN SCIENCE

Having discussed metaphor in scientific terminology, abstract expression, and hypothesis-building, I will address two lingering concerns about using metaphor in science: 1) that it is difficult to understand, and 2) that it lacks "truthfulness" (Hoffman, 1980b).

The Cognitive Qualities of Metaphor

Compared with literal language, metaphor is often thought more vague or ambiguous and difficult to understand (Harris, Lahey, and Marsalek, 1980). Now individuals in the new discipline of cognitive science (which combines linguistics, philosophy, computer science, and psychology to study artificial and natural cognition) are studying metaphor to assess its cognitive qualities--how quickly, easily and accurately it is understood, how well it is remembered, and how much information it can carry.

Psychologists believe that to comprehend metaphor readers must go through a two-step process, 1) deciding whether the passage is metaphorical, and 2) determining the meaning of the metaphor. First they must determine whether a passage is literal or metaphorical. After reading a passage literally and failing to make sense of it, they reread it looking for a metaphorical interpretation. For example, because "a heated debate" is a semantic anomaly and a literal reading clashes with their knowledge of what is physically possible, they will interpret it as saying something non-literal about the debate. Some metaphors, of course, can be read literally, as in "the battle lines are drawn." Still, readers choose a metaphorical reading of the phrase when a literal one strikes them as irrelevant to the context.

Second, they must ascertain the meaning of the metaphor. Plautus' metaphor "man is a wolf" is not taken to mean that man is literally a wolf, but is in some respect like a wolf--he is ruthless, or savage, or bent upon his individual survival over any other's. To determine the shared similarity between topic and vehicle as perceived by the writer, readers consider the context. For example, if I say "my brother is a rock," I could mean, among other things, either that he is firm and stable or that he is intellectually dense. The readers of the metaphor would have to interpret my intention based upon the context in which the statement is uttered.

Even though metaphor is often considered more difficult to understand and less effective for referential discourse than literal language, Richard Harris, Mary Anne Lahey, and Faith Marsalek (1980) have found no basis for these beliefs. These researchers used sets of three sentences: the first with an unusual metaphor, the second with a dead metaphor, and the third with a nonmetaphorical phrase. For example, a set might include "the ivy cuddled up to the window, the ivy crept up to the window, the ivy grew up to the window." Undergraduate psychology students at Kansas State University were asked to listen to a tape recording of these language sets, then respond to questions provided by the examiner. The researchers broke the results into three categories: 1) recognition memory, 2) imageability ratings, and 3) informativeness ratings.

In the first category, recognition memory, the researchers found no significant difference in recall between the metaphorical and the nonmetaphorical sentences, thus indicating that metaphorical language is not inherently more difficult to understand and remember than literal language.

For the second category, imageability ratings, the results showed no obvious correlation between metaphor and imagery; in other words, despite the fact that we generally consider metaphors as image-producers and imagemaking an important mnemonic technique, imageability is not a good predictor of memorability. We may conclude, therefore, that the memorability of metaphor comes from something other than its power as an image-producer.

In the third category, informativeness ratings, no significant difference was found between metaphorical and nonmetaphorical sentences in the amount of information they are able to convey.

Evaluating the results from the above experiment and several others like it, Harris et al. conclude that metaphors are as easy as, if not more easy than, nonmetaphor to understand and remember, and they can carry as much information. The studies of Harris are supported by others, who also find no significant differences between literal and nonliteral material in either reading time, verification time, or correct recognition a short time after reading.

Some metaphors are more easily understood and more effective than others, however. Just as some literal language is considered poor and some good, there are poor and good metaphors. Some studies have been conducted in an effort to determine what differentiates the two.

In one such study, conducted by Michael Johnson and Robert G. Malgady (1980, see also Malgady and Johnson, 1980), 28 metaphors and similies were taken from a breadth of literary sources and presented to college undergraduates to evaluate as "good" or "bad" based upon the student's own nonexpert criteria. The conclusion was that metaphors with a greater apparent similarity between topic and vehicle, e.g., "The snow this morning was like white confetti picked up by the wind," were considered easier to understand and more satisfying than those with a more opaque similarity, e.g., "Your smile was a warm wind." Perceived goodness was translated, then, into shared properties or features between tenor and vehicle. It is here that Roger Tourangeau (1982) also sees the separation between good metaphors and bad ones. He states,

> Among a host of other factors, agreement between the metaphor's picture and our own and incongruence between domains seems to contribute to our liking for a metaphor. Disagreement produces one sort of novelty--new beliefs--and incongruence another sort--a new structure for our beliefs"(1982).

However, the shared similarities between tenor and vehicle must fall into a middle ground between "literalness" and "nonsense" to be understandable and satisfying to the reader, according to a study done by Malgady (1975, cited in Malgady and Johnson, 1980). In other words, when comparing three levels of phrasing, "Robes are justice" (figurative), "Robes are garments" (literal), and "Robes are trucks" (nonsense), figurative judgements decrease as similarity increases or decreases away from the middle range. Phrases which are transparent or trite or far from the realm of possibility are less successful than those which make sense and provide a new insight. Johnson and Malgady (1980) summed up the link between recent studies by saying:

> A metaphor will be comprehensible (easy to interpret) to the extent that a relationship can be easily perceived between the topic and vehicle terms in the metaphor.

Johnson and Malgady found that another characteristic of a satisfying metaphor is "richness," or the possibility of more than one interpretive possibility (1980). They point out that the quality of richness is consistent with the interactive view of metaphor, where new meanings, not just substitutions, are possibile.

As a caution we should note that because serious scientific study of metaphor and its role in the cognitive process has only just begun, little can be conclusively stated. Malgady and Johnson (1980) emphasize that theoretical asssumptions about metaphor are still sketchy, and argue that more discussion is needed to clear up three areas: 1) the lack of agreement on what comes under the domain of metaphor (there is little agreement in the academic community as to representative examples of metaphor), 2) lack of agreement on approaches to the study of metaphor, and 3) the failure of experimental psychology to develop some hard facts on the subject, a matter which they say may be in the nature of the subject involved. Even with this in mind, however, results of the hypothesis testing which has been done supports the cognitive significance of metaphor. In fact, Johnson and Malgady (1980) state that, if anything, study has shown metaphor to have a central, rather than peripheral, role in the comprehension process.

Just as scientists must carefully choose literal language to convey the intended meaning, so metaphor must be carefully fashioned to be effective. In light of these studies, there is no basis for the theoretical exclusion of metaphor from scientific discourse on the ground that it is difficult to understand.

The Truthfulness of Metaphor

A final common objection to metaphor in science is that it does not provide the precision, objectivity and truthfulness required of scientific writing. To this one could ask two questions: 1) Is there is such a thing as linguistic precision and any way to avoid referential ambiguity? and 2) Do scientific theories represent the truth?

In regard to the first question, Boyd (1979) suggests that if metaphor seems to be too imprecise for theory construction, we have a faulty view of the precision by which scientific referencing takes place. There are two major hypotheses on the manner in which reference is fixed in scientific and everyday discourse. Empirical theory states that most general terms are true by stipulation; the meanings are fixed in advance of their use. According to the opposing ostensive view, reference comes about by interaction between the users of the terms and the instances to which they belong. In empiricism, terms must be clearly and explicitly defined before use to avoid vagueness and imprecision--changes in theories almost always come from alterations in the subject matter or from the conceptual framework rather than from new discoveries. The ostensive account, on the other hand, is that terms are fixed nondefinitially with accommodation taking place as more is discovered. Both approaches to referencing leave room for ambiguities. In empiricism, the terms are clearly defined but are of undetermined accuracy, and there is no accommodation for new discoveries. In ostension, the terms are nondefinitional, therefore ambiguous, but there is accommodation for new discoveries.

Regarding the question of whether metaphor represents the truth, Hoffman (1980b) notes that scientists themselves will admit that theories are not really the TRUTH. Not that they are wrong, really, or they could be replaced by a more acceptable theory, but they are not entirely true, either. For example, the definition of a "quark" in physics as a "particle" is itself metaphorical because a quark has no spacial extension. When physicists speak of the constituents of a quark, they describe them as "pointlike (structureless)." And the movement attributed to quarks is again expressed metaphorically; quarks are said to "spin," even though the movement referred to is not a rotational one, but an "angular" momentum.

It has been said that metaphor "masks" the truth. According to Hoffman (1980b), if metaphor masks the truth it is because of "flabby theorizing" on the part of the researcher. If a researcher takes the metaphor too literally, it can hide the truth. For example, if the statement that elementary particles "feel" a force is taken to mean that they feel in ways similar to a human being, that is the fault of the researcher, who should use the metaphor heuristically rather than definitionally. If used properly, metaphor can be helpful in pointing the way to possible characteristics of the subject under study.

METAPHOR IN SCIENTIFIC RESEARCH: A CASE STUDY

The first part of this study has established metaphor as theoretically important to the development of scientific terminology, to the expression of abstract concepts, and to the processes of accommodation and assimilation in research. The second part will test these functions through a case study designed to discover how metaphor is used in a select area of scientific writing.

Procedures: For the purposes of this study, "scientific terminology" refers to terms which have a meaning specific to science. "Abstract expression" refers to the articulation of scientific concepts or ideas. And "hypothesis" is a testable assumption. This case study itself is based on the August 15, 1985, issue of *The Journal of Biological Chemistry*, the publication of The American Society of Biological Chemists, Inc. Out of 68 scientific articles in this issue, I selected every tenth article, for a total of six articles. I then scanned each article for use of metaphor, noting the metaphors upon first encounter, then analyzing them according to the three functions established above.

Results: In the six articles, I identified these 22 metaphors:

The first article, "The Kinetic Equation for the Chloride Transport Cycle of Band 3," by Joseph J. Falke, Katherine J. Kanes, and Sunney I. Chan yielded

1) A **ping-pong** model of the chloride transport cycle,
2) leaky (red cell) **ghosts**,
3) **pulses** (of rotation in a Waring blender),
4) lower **sensitivity** of bacteria, and
5) **lifetime** of chloride.

The second article, "Turnover and Short-term Regulation of Fatty Acid Binding Protein in Liver," by Nathan M. Bass, Joan A. Manning, and Robert K. Ockner, yielded

6) an abundant **expression** of this protein.

The third article, "Inosine Analogs," by Stephen W. LaFon, Donald J. Nelson, Randolph L. Berens, and J. Joseph Marr, yielded no unrecorded metaphors.

The fourth article, "Dependence of Maltose Transport and Chemotaxis on the Amount of Maltose-binding Protein," by Michael D. Manson, Winfried Boos, Philip J. Bassford, Jr. and Beth A. Rasmussen, yielded

7) **encoded** by genes,
8) the malT gene, **mapping** at 74 min,
9) the cell **envelope**,
10) membrane **partners**,
11) cells were **harvested**,
12) a toluene-based **cocktail**, and
13) **swarming behavior** (of mutant bacteria).

The fifth article, "Regulation of Epidermal Growth

Factor Receptor by Estrogen," by Venkat R. Mukku and George M. Stancel, yielded

14) **clockwise** rotation of flagella, and
15) protein may **behave** differently.

And the sixth article, "Androgen Regulation of MAK mRNAs in Mouse Kidney," by Lauren D. Snider, Donna Kind, and Jerry B. Lingrel, yielded

16) polypeptide **chain,**
17) **triggering** the uterine growth,
18) a stable cell **population,**
19) a cDNA **library,**
20) **wells** of microtiter dishes,
21) **colonies** of bacteria, and
22) library **screening** (of cDNA).

Of these metaphors, some functioned in two or three capacities; for example, the term "ping-pong" transport cycle operates not only as a scientific term, but also as an abstract expression, and it aids in presenting and explaining a hypothesis as well. In sum, 15 of the metaphors functioned as scientific terminology, 16 functioned as abstract expressions, and 4 in the presentation of hypotheses. Three acted in all three capacities, eight functioned in two capacities, and eleven served in only one.

<u>Discussion:</u> Metaphor was indeed found helpful in all three capacities posited in the opening part of this study. The scientific terms based on metaphor were useful to researchers in the data, even though in many

cases the metaphorical wording could have been replaced by literal terms. For example, in Falke's article about how chloride moves in and out of cells (Falke et al, 1985), a **ghost** was the metaphorical expression for an emptied cell, which has a filmy look. Similarly, in Manson's article about the uptake of maltose (a sugar) in bacteria (Manson et al., 1985), a **cell envelope** was the term for the outer membrane of the cell, and a toluene-based cocktail for a solution containing toluene mixed with other chemicals. In Snider's article about how a male hormone regulates DNA transcription (Snider et al., 1985), **wells** of microtiter dishes are simply holes dug in the agar contained in a petrie dish. In each of these cases, the metaphor could have been replaced by literal language, but the metaphors shortened description necessary to the understanding of the scientist's meaning by fulfilling a catachretic role, providing a term where none before existed. However, in Manson's article, one term did prove to be theory constitutive. That term, **encoding**, as in **encoding by genes**, is, in fact, cited earlier in this study as an example of theory constitutive metaphor.

Metaphor was also found in abstract expression in the data. For example, a **cDNA library** is a collection of synthetically manufactured, or "copied," genetic materials. There are thousands of kinds of DNA genes in an animal, governing all characteristics, from basic body form to eye color, and a genetic laboratory utilizing modern molecular biology techniques will likely have a rather complete set of cDNA stored indefinitely in the chromosomes of growing bacteria, so that each kind of cDNA can be "checked out" when needed for experimentation, just as a well stocked book library will have a good number of books which can be checked out when desired. In another instance, **expression of protein** (Bass et al., 1985) draws an analogy with human speech. In a process termed "expression," some of the total genetic information in the nucleus of a cell directs the synthesis of protein molecules in the cell cytoplasm. Not all of the genetic material held in the nucleus is used to direct the synthesis of protein in the cytoplasm, just as not all thoughts in our mind are expressed through spoken words. Using the term **lifetime of chloride** (Bass et al., 1985), Bass refers to the length of time chloride is present at a particular site in the membrane of a cell. a corrolation with the length of time human beings are present on earth.

The value of metaphor in the presentation of a hypothesis was especially apparent in the data in the term **ping-pong** transport cycle (Falke et al., 1985), used to describe an as yet unproven hypothesis of the pattern by which chloride passes in and out of a cell. In this instance the popular game of ping-pong provides a term for a biochemical process. According to the hypothesis, a protein within the cell wall metaphorically paddles the chloride back and forth across the membrane net. The ping-pong metaphor is useful for describing the process, and it may also help further the hypothesis, for it may point the way to analagous principles operating in purportedly analagous situations. In another two cases, metaphor may at one time have been helpful in presenting a hypothesis which the current articles assumed to have been established: 1) bacteria grow in groups, or **colonies** (Snider et al., 1985) and 2) polypeptide takes the linear form of a **chain** (Mukku and Stancel, 1985). Before anything was known about bacteria and polypeptide, these associations with known entities could have been helpful for visualizing and presenting a hypothesis which subsequently gained acceptance.

While only the ping-pong metaphor was theory constitutive in the absolute sense, all the metaphors certainly were more than mere ornament in that they provided for at least one, sometimes two or all three of the functions--terminology, abstract expression, and hypothesis-formation and presentation.

This case study supports the theory that metaphor provides a way to express an idea which cannot be otherwise expressed. It provides for terms and abstract expressions, and it helps visualize, present, perhaps even form, hypotheses.

Finally, my analysis of the data also indicated that the metaphors themselves often lose some of their power of analogy and take on a literal meaning through extended use. For example, when the term **polypeptide chain** (Mukku and Stancel, 1985) was first used fifty years ago, it probably helped scientists envision the shape of a polypeptide, something they could not see. Today, knowledgeable scientists no longer focus on the physical similarities between a neckchain and a polypeptide chain; the term has become less a description than a name. Thus, **polypeptide chain** has evolved from a figurative to a literal meaning.

Furthermore, the study highlighted the degree of borrowing extant between scientific and nontechnical language. **Ping-pong transport cycle** (Falke et al., 1985), **cell ghosts** (Falke et al., 1985), **toluene-based cocktail** (Manson et al., 1985), **popypeptide chain**

(Mukku and Stancel, 1985), **triggering of uterine growth** (Mukku and Stancel, 1985), and **cell population** (Snider et al., 1985) are all scientific terms rooted in non-technical language. Possibly, heavily-used scientific terms which originated in nontechnical language will again migrate back into nontechnical usage, albeit with changes in meaning in accordance with changes in audience and aim of discourse.

Thus, in addition to affirming the theoretical functions of metaphor presented earlier in the paper, the study suggests changes in it meanings at two levels. One change is between literal and figurative. Another is between nontechnical and scientific language.

SUGGESTIONS FOR FURTHER STUDY

A thorough study should be done of metaphor in a cross-section of disciplines. By studying in depth and comparing metaphor in the physical, biological, and social sciences we can determine if a given discipline lends itself more frequently to metaphor and in what situations. Such a study would provide a basis for a much-needed taxonomy of scientific metaphor. For a model of such a taxonomy we might look to the work of Roland Bartel.

In Metaphors and Symbols (1983), Bartel discusses the many kinds of metaphor there are in literature. This study provides a suggestion of the variety of metaphor which might be found in science writing. Popular metaphor, he says, includes riddles (e.g., the moon is a pumpkin in a meadow), folk expressions and proverbs (e.g., bring home the bacon), cliches (e.g., jump the gun), literal words (what we consider dictionary meanings often originated through metaphorical reference, e.g., a door is an entrance to a room; it is also an opportunity, for education or a career), and slang (e.g., cat's pajamas). Literal comparisons, such as "the explosion produced a crater seven football fields long and three football fields deep," are metaphors. He distinguishes four kinds of metaphor in poetry: 1) causal metaphor, such as cliches and synesthetic metaphors (metaphors which mix sensory perceptions, such as "silent form," or "scarlet pain"), 2) sensuous metaphors which create a strong image, such as "a spider rappelling from the ceiling," 3) resonant metaphors, which add implication to sensuousness, such as "undernourished children whose skins peeped through by bones," and 4) complex and subtle metaphors, which reflect multiple meanings, expressing depths of emotion, such as "the stunted, unlucky heir of twisted bones, reciting a father's gnarled disease" (from Spender's "An Elementary Classroom in the Slum").

In the sciences we often find exegetical or pedagogical metaphors which aid in the teaching or explication of theories, as, for example, such terminologies as "wormholes in general relativity," "electron cloud," and atoms as "miniature solar systems."

An analysis of scientific metaphor would require an intensive and specialized, but potentially highly productive, study. It should show us how often, what kinds, and in what ways metaphor is used.

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ACKNOWLEDGEMENTS

I thank Dr. Helen Rothschild Ewald for her knowledge, guidance, and patience in helping me prepare this thesis. I also thank Dr. Neil Nakadate and Dr. La Rue Pollard for their expert comments on several drafts of it.

Thanks are also in order to my family, especially my beautiful, intelligent mother, Noreen Orngard, who has supported me unfailingly throughout my life and education.

And special thanks go to my husband and best friend, Rich, who has believed in me even in the most difficult times.