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High School Biology Students' Participation in a Year-Long Sequence of Analogical Activities: The Relationship of Development of Analogical Thought to Student Learning and Classroom Interactions.

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HIGH SCHOOL BIOLOGY STUDENTS’ PARTICIPATION IN A YEAR-LONG SEQUENCE OF ANALOGICAL ACTIVITIES: THE RELATIONSHIP OF DEVELOPMENT OF ANALOGICAL THOUGHT TO STUDENT LEARNING AND CLASSROOM INTERACTIONS

VOLUME I

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

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B.S., University of New Orleans, 1969
M.N.S., Louisiana State University, 1984
May, 1999
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ABSTRACT

This research explored development of analogical thought through high school biology students' participation in a year-long sequence of analogical activities. Analogizing involves: selecting a familiar analog; mapping similarities and differences between the analog and less familiar target; making inferences from the analogy; evaluating validity of the inferences; and ultimately, understanding the biological target (Holyoak & Thagard, 1995). This investigation considered: student development of independence in learning through analogical thought, student learning of biology, the relationship between development of students' analogical thinking and students' learning of biology, and the quality of student interactions in the classroom.

This researcher, as teacher participant, used three approaches for teaching by analogy: traditional didactic, teacher-guided, and analogy-generated-by-the-student (Zeitoun, 1983). Within cooperative groups, students in one honors biology class actively engaged in research-based analogical activities that targeted specific biological topics. Two honors biology classes participated in similar, but nonanalogical activities that targeted the same biological topics. This two-class comparison group permitted analytical separation of effects of the analogical emphasis from the effects of biology content and activity-based learning.

Data collected included: fieldnotes of researcher observations, student responses to guidesheets, tapes of group interactions, student products, student perceptions survey evaluations, ratings of students' expressed analogical development, pre- and posttest scores on a biology achievement test, essay responses, and selected student interviews. These data formed the basis for researcher qualitative analysis, augmented by quantitative techniques.

Through participation in the sequence of analogical activities, students developed their abilities to engage in the processes of analogical thinking, but attained different levels of independence. Students expressed ownership of the biological knowledge they...
constructed through higher level analogical thought. Their biological learning showed integration of knowledge that was broader and deeper than the comparison group. Their learning of biology content on the knowledge level was as good as that of students who engaged in traditional nonanalogical learning activities when probed with conventional assessments. In addition, students gained a metacognitive tool that taps into imagination. Biology classroom interactions were enriched in respect to student motivation, enjoyment, group dynamics, and meaning making.
INTRODUCTION

Value of Analogical Thought

Metaphor is pervasive in everyday life, not just in language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature. (Lakoff & Johnson, 1980, p. 3)

Learning language is a child's biggest cognitive accomplishment (Novak & Gowin, 1984), so it is important for educators to recognize the metaphorical basis of language comprehension. Linguistics expert Lakoff and philosopher Johnson (1980) argue that figurative language (analogies, similes, and metaphors) is not a colorful extra, but is essential to our everyday language and thought. Muscari (1988) agrees that “the awareness that the world is not very much apart from the symbol system we use has continually made the literal much less unambiguous and the metaphorical much more suggestive” (p. 423). Cognitive scientist Hofstadter (1995) concurs:

Analogy-making lies at the heart of pattern perception and extrapolation. . . . And when this banality is put together with my earlier claim that pattern finding is the core of intelligence, the implication is clear: analogy-making lies at the heart of intelligence. (p. 63)

Metaphorical and analogical thought are natural tools for learning.

The goal of this research was to study how high school biology students developed analogical thought as they participated in a year-long sequence of activities based on analogies, metaphors, and similes. With guidance from the teacher, students used these activities as catalysts for further development of analogical thought, improvement in biological learning, and enhancement of classroom interactions.

Research Questions and Overview of Research Study

Research Questions

The primary research question that guided this study was: How do high school biology students develop analogical thought as they proceed through a year-long sequence of research-based analogical activities?
The subquestions were:

1. How does students' dependency on the teacher change as they participate in the sequence of analogical activities?

2. How does students' biology learning change as they participate in the sequence of analogical activities?

3. Are there any parallels between the students' development of analogical thought and their learning of biology content?

4. How does the quality of biology classroom interactions of these students compare to equivalent biology classes?

A Gowin's Vee Diagram of Research

A Gowin's Vee Diagram (see Appendix A) provides a detailed plot of this research study. The center of the Vee states the research questions; the far left side of the Vee diagram indicates the foundational knowledge (consisting of world views, theories, principles, and concepts) that together provide a solid basis for this research; the objects and events that are the focus of this study are located at the point of the Vee; the right side of the Vee indicates the object and event records and transformations of these records; and above these are knowledge and value claims supported by the results of this study.

Flow Chart Diagram of Research

A flow chart diagram of this research (see Appendix B) provides a time line overview. It divides the research into phases which included: the literature search (1991-1996); development of research-based analogical activities that target biology (summer and fall 1995); pilot studies of six specific analogical activities with high school biology students (spring 1996); preparation and presentation of prospectus proposal (summer 1996 to spring 1997); research study of 1996-97: establishment of baseline (weeks 1-6 of 1996-97 school term), student participation in analogical activities or nonanalogical activities that target biology (weeks 7-36 of 1996-97...
school term), final data collection (weeks 34-36 of 1996-97 school term); analysis and evaluation of the research study (ongoing throughout the 1996-97 school term); and final analysis and evaluation of 1996-97 research study expressed in a written dissertation (summer 1997 to spring 1999).

The Analogical Voices of Scientists—Past and Present

Voices of Scientists—Past

Scientists' Historical Use of Analogy

Do historical examples of scientists' practices point to the relevance of this research for biology education? Cognitive psychologist Holyoak and philosopher Thagard (1995) note that while everyone uses analogy as a "mental tool" (p. x); scientists, in particular, have depended on analogy for assistance in "discovery, development, evaluation, and exposition" (p. 189). Sutton (1993) agrees that scientists have relied on figurative language to help them "think, see, talk and act in new ways" (p. 1219). Numerous historical examples support these claims.

Fourth Century B.C. Greek Philosophers

The Greek philosophers of the fourth century B.C. favored metaphorical language as a method of explanation. Plato called knowledge "the food of the soul" (Protagoras, p. 52, trans. Jowett, 1948) to emphasize that knowledge is necessary for growth of the spirit. In Plato's Apology of Socrates (40d, trans. West & West, 1984), Socrates uses a metaphor to explain why he accepts rather than fears death: he compares death to "a sleep in which the sleeper has no dream at all." Aristotle uses analogies to carry the meaning of the concept of an active creative male who animates or gives life to the inert embryo of a passive female. The offspring of the male and female "comes from them only in the sense in which a bed comes into being from the carpenter and the wood, or in which a ball comes into being from the wax and the form" (On the Generation of Animals, 729b, trans. A. Platt, 1941).
**Medieval Alchemists**

Gentner and Jeziorcki (1990) find that the rules for acceptance of an analogy have changed for scientific thinkers throughout history. Medieval alchemists often formed analogies based on surface features rather than deeper relations. For example, alchemists linked the moon to the metal silver because of the silvery white color and the yellow sun was matched to gold. The chief god of their Roman antecedents was Jupiter, and the color blue signified royalty, so naturally blue was paired with the planet Jupiter; but the metal tin was paired with Jupiter also on the basis of color because its silvery color resembled the planet’s color in the sky. These hodge-podge pairings, in the intellectual context of medieval science, made sense.

But, medieval analogies seem strange to us because sound analogies today require consistent one-to-one pairings. For example, a procaryote cell—a primitive cell with a cell membrane, cytoplasmic contents, but no nucleus—may be compared to a plain M & M. The shell of the candy corresponds to the cell membrane and the chocolate center to the cytoplasmic contents of the cell. A peanut M & M would not work well because the procaryote cell has no nucleus, and thus nothing to correspond to the peanut. On the other hand, a peanut M & M would be a good analog for a eucaryote cell which has a cell membrane, cytoplasmic contents, and a nucleus. The candy shell could pair with the cell membrane, the chocolate with the cytoplasmic contents, and the peanut with the nucleus. Medieval scientists did not see a need for such consistent one-to-one mappings in their analogies.

**Francis Bacon—a Seventeenth-Century Scientist**

The sixteenth and seventeenth centuries saw a change from the heterogeneous analogies of the Middle Ages to a more systematic approach. For example, the seventeenth-century scientist Francis Bacon (1620/1960) in *The New Organon* is very explicit about his points of comparison and one-to-one mappings:
The men of experiment are like the ant, they only collect and use; the reasoners resemble spiders, who make cobwebs out of their own substance. But the bee takes the middle course: it gathers its material from the flowers of the garden and of the field, but transforms and digests it by the power of its own. (p. 93)

Clearly Bacon is comparing the experimentalists to ants, the rationalists to spiders, and the "modern scientist," who combines both approaches, to the bee. He is saying that knowledge cannot be based simply on the senses, nor simply arrived at through reason, but that knowledge in fact depends on both observational data and critical thought.

**Analogies and Scientific Theories**

Analogies have played a role in the development of many significant scientific theories. Holyoak and Thagard (1995) identify some analogies used in the past which have led to important scientific advances. For example, they cite two analogies that helped Charles Darwin in the discovery, development, and explanation of natural selection as the driving mechanism for evolution. Darwin saw a similarity between artificial selection, which results in new varieties of plants or new breeds of animals, and nature's selection process, which leads to new species. Darwin also used an analogy to explain the idea of survival of the fittest: he drew a parallel between the conflict for the necessities of life that must result from unlimited human population growth, and the constant competition by organisms for vital resources that results in nature’s selection of the fittest to survive. Pioneer geneticist Thomas Hunt Morgan relied on an analogy of beads on a string to assist him in understanding the phenomenon of genes crossing over on chromosomes. And Kekule, the discoverer of the structure of benzene, came up with the idea for benzene's ring structure after dreaming of a snake biting its tail.

**Voices of Scientists—Present**

Analogical thought continues to play an important role in scientific thought. Science historian and paleontologist Gould (1980) declares, "If genius has any common
denominator, I would propose breadth of interest and the ability to construct fruitful analogies between fields" (p. 66). Who would not be struck by Gould's own delightful explanation of neoteny, the retention of juvenile features into adulthood, through his analogy to the progressive juvenilization of Mickey Mouse's cartoon depiction over time? Biologist Dawkins (1986) explains that "The human mind is an inveterate analogizer. We are compulsively drawn to see meaning in slight similarities between very different processes" (p. 195). Dawkins exemplifies his own words when he explains genes and their function through an extended computer metaphor (pp. 43-74; 111-137); and also when he throws light on DNA's function through a cake baking analogy (pp. 294-298).

Implications of the Voices of Scientists—Past and Present

So many scientists throughout history have tapped the power of analogy, it is clearly part and parcel of scientific thinking. Important advances in scientific thought have often arisen not from the discovery of new information, but from creative organization of existing knowledge (as in the examples from Darwin). This conceptual parallelism is a type of analogical thought. So when two existing phenomena are compared and that comparison leads to a new theory, analogical thinking has itself advanced scientific knowledge. And there are examples (Morgan and Kekule) in which an analogy with a commonplace thing (Morgan's beads on a string) or even a fanciful image (Kekule's dreams of a snake biting its tail) has been the *sine qua non* of an important scientific advance. Finally, scientific progress depends not only on experimentation and conceptual advances, but also on the clear description and explanation necessary for other scientists to understand, reproduce, and build upon existing theories. Analogies are vital in this regard because they provide a means to relate new concepts to familiar ones, establish a foundation of similarity, and call attention to important points of departure.
When all these points are taken together, it becomes clear that analogical thinking is not merely a useful addition to scientific thinking, it is an inseparable component of it. From Aristotle's analogy of the carpenter and the wood to Dawkins' culinary metaphor for DNA, science has relied on analogies, and analogies have shaped science. Therefore, it is critical that students of the sciences be intentionally and methodically encouraged to develop their abilities to think analogically, if they are to understand the foundations of science and have the potential to advance its frontiers. These analogical skills can help our young people become active participants in and thoughtful evaluators of the scientific discourse that is woven within our cultural fabric.

**Today's Calls for Research into Learning Through Analogy**

**Sparceness of Research of Practical Educational Applications of Analogical Thought**

Many researchers recognize that the ability to analogize is important for learning; yet, they find that research into the practical educational applications of analogical reasoning for science is woefully sparse (Good, 1993; Holyoak & Thagard, 1995; Lawson, 1993; Lawson & Lawson, 1993; Vosniadou & Ortony, 1989; Wong, 1993). Such work has begun in the area of physics education (D. E. Brown, 1992; D. E. Brown & Clement, 1989; Clement, 1993; Harrison & Treagust, 1993), but such work has barely started in the area of biology education (Spiro, Feltovich, Coulson, & Anderson, 1989).

**Calls for Research of Practical Educational Applications of Analogy**

This problem has not been ignored by those interested in science education research. Good (1993), a former editor of the *Journal of Research in Science Teaching*, thinks that analogy is so important for science education that he chose to focus a special issue of *JRST* on analogy. In that issue, zoologist Lawson (1993) declares a vital need “to invent and evaluate the effectiveness of various science lessons in which students use analogical reasoning to generate alternative explanations and logical reasoning to test
them" (p. 1214). Research is needed to determine the most effective analogies for teaching particular scientific concepts (Lawson & Lawson, 1993). Wong (1993) points in a different direction when he urges teachers to allow their students to generate their own analogies for scientific concepts. This constructivist approach requires creative students who are actively involved in their learning and able to improve their understanding by modification of their own analogies over time.

**Goal—Development of Students' Analogical Thought**

The analogical activities used in this study were designed to move students from depending on the teacher for an analogy and its explanation to increasingly independent use of analogy, simile, and metaphor to understand science. At each stage in their use of analogies, "selection, mapping, evaluation, and learning" (Holyoak & Thagard, 1995, p. 137), students can become more actively involved. Students may select a familiar analog to explain an unfamiliar concept, rather than relying on the teacher to supply one. Pupils can participate in mapping by identifying similarities and differences between the analog and target. They may evaluate for themselves whether a particular analogy works by judging if valid inferences can be made from the analogy. Finally, the students can be active learners who integrate the patterns they have learned into their overall knowledge framework.

**Does a Word by Any Other Name Mean the Same Thing?**

**Experts Build Theory Base and a Confusion of Terms**

This study drew upon the expertise of many who have contributed to research into thought, similarity, analogy, and metaphor. These experts include linguists, philosophers, science education researchers, historians, psychologists, anthropologists, zoologists, artificial intelligence investigators, and cognitive scientists. Their combined research provides a rich theoretical basis for practical applications of analogical thinking in the classroom.
Yet the interdisciplinary nature of this research adds confusion to the discussion. Researchers assign different meanings to the same terms or use different terms for similar concepts. Dictionary definitions provide only a start in clarification of terms. This section explores some important terms: analogy, analog, target, shared and unshared characteristics, metaphor, simile, within-domain, between-domain, and similarity.

**Analogy, Simile, and Metaphor**

**Analogy**

*Webster’s Ninth New Collegiate Dictionary* (1988) defines “analogy” as “2. a: resemblance in some particulars between things otherwise unlike: SIMILARITY b: comparison based on such resemblance” (p. 82). Clearly, similarity and comparison are important aspects of analogies. The word “analogy” comes from “analogous,” a word with Greek roots that means “proportionate” (p. 82). To delve deeper, *logos* refers to “reason” and the prefix *ana* can mean “up, back, again” (p. 81). This yields the intriguing notion of analogy as reasoning up, back, or again. In some sense, each of these prefix meanings seems applicable. In analogical reasoning, one reasons back and forth, again and again, between the familiar and the less familiar until one comes up with a new vision or understanding. Educational psychologists Vosniadou and Ortony (1989) explain that reasoning by analogies “involves the transfer of relational information from a domain that already exists in memory . . . to the domain to be explained” (p. 6), in other words from the known to the unknown.

**Analog / Target**

Researchers vary in their choice of words for the known and the unknown. In the 1990’s, the most commonly used terms are *analog* to refer to the familiar representation and *target* to refer to the less familiar representation (Dagher, Thiele, Treagust & Duit, 1993). Other terms for the analog and target include respectively: *analog* and *topic* (Zeitoun, 1983), *vehicle* and *topic* (Ortony, 1983, in particular
reference to metaphor), base and target (Gentner, 1986), source analog and target analog (Thagard, 1992), anchor and target (D. E. Brown & Clement, 1989; Clement, 1993). In keeping with Wandersee's (1985) advice to avoid excessive terminology in science education, student participants in this research will be introduced to only one set of these terms—analogy and target.

**Shared Characteristics / Unshared Characteristics**

For an analogy to exist, there must be both shared attributes and unshared attributes. For example, in the eye as a camera analogy, a shared characteristic would be that light enters both the eye and the camera; an unshared characteristic would be that the eye is part of a living organism but a camera is part of the nonliving world.

Variation in terminology is evident in Zeitoun's (1983) use of the terms *shared attributes* and *irrelevant attributes.* "Irrelevant attributes" refers to attributes that are different or that fail to correspond at all. Irrelevant is not a good term because it is important to know how the analog and the target differ as well as how they are similar. Holyoak and Thagard (1995) speak in terms of similarities and differences. These differences are "the places where the analogy breaks down" (p. 208).

Reading researchers use another set of terms when discussing metaphor: vehicle, topic, ground, and tension. "The commonality shared by the topic and the vehicle is called the ground. Any conceptual incompatibility between the topic and the vehicle is called the tension" (Rudden, 1995, p. 348). For the sake of simplicity and clarity, this project will avoid this literary terminology, using instead "like" and "unlike," "shared" and "unshared characteristics," or "similarities" and "differences."

**Metaphor and Simile**

Webster's dictionary (1988) defines "metaphor" as "1. a figure of speech in which a word or phrase literally denoting one kind of object or idea is used in place of another to suggest a likeness or analogy between them" (p. 746). Its derivation is from the Greek "metapherein, to transfer" (p. 746). Somehow meaning is
transferred from the analog domain to the target domain. Metapherein derives from "pherein to bear" (p. 746) and "meta. . . [to] change" (p. 745) which suggests the transformative power of the metaphor. "Simile" comes from the Latin word simillis meaning comparison—"a figure of speech comparing two unlike things that is often introduced by "like" or "as" (p. 1098). Similes constitute a subset of metaphors, that is metaphors that use "like" or "as"; and all similes and metaphors are by definition analogies. These definitions support the idea that figurative language of analogy, metaphor, and simile all involve analogical thinking; therefore, classroom research into analogical thinking should encompass all these figures of speech.

**Types of Analogies**

**Between-Domain / Within-Domain**

Another terminology dilemma involves the issue of the domains to which the analog and the target belong. Domain refers to some broad area of knowledge (e.g., business). An analogy is a "between-domain" kind if the domains are remote from one another, or "within-domain" if the domains involved are the same or very similar (Vosniadou, 1989, pp. 414-415). A comparison of the structure of the atom of physics to the solar system of astronomy is an example of a between-domain (interdomain) analogy, wherein the nucleus is matched with the sun, and the electrons moving around the nucleus are matched to the planets that revolve around the sun. An example of a within-domain (intradomain) analogy would be seeking a solution by comparing some math problem to another similar math problem. Both between- and within-domain types require analogical reasoning as they involve carrying over a structural explanation from the familiar analog to the unfamiliar target.

**Metaphorical / Literal**

Vosniadou and Ortony (1989) have also used the terms "metaphorical" and "literal" to describe analogies (p. 7). The within-domain analogy (e.g., two similar math problems) would be viewed as more literal, and the between-domain analogy (e.g.,
atom to solar system) would be identified as more metaphorical. Yet these researchers avoid a strict dichotomous view by suggesting a continuum from the most literal to the most metaphorical analogy. An example of a more metaphorical analogy would be Thomas's (1974) declaration that "My cells are no longer the pure line entities I was raised with: they are ecosystems more complex than Jamaica Bay" (p. 4). This is quite a unique and metaphorical way to refer to the theory of endosymbiosis—a theory of the origin of eukaryotic organelles.

**Experts Debate Value of Different Types of Analogies**

While all analogies, regardless of type, require analogical reasoning, there may be some differences in the thinking required for different types. For example, accessing a remote domain involves different challenges than using a past solution to help solve a similar problem within the same domain. Just consider the different complexity involved in understanding the math problem analogy, the atom-solar system analogy, and the cell-ecosystem metaphor. This issue of complexity has led to some contentious debates among the experts as to the relative importance of within-domain and between-domain analogies.

Some researchers have simply chosen to deny that the term analogy should apply to the within-domain types because they are too literally similar (e.g., a comparison of an eye to the model of an eye, or comparison of the eyes of a goat and a rabbit) (Zeitoun, 1983). Gentner (1988) targets only the between-domain analogies that share relationships at the deep structural level.

In direct contrast, Hofstadter and the Fluid Analogies Research Group (1995) have centered their artificial intelligence (AI) research on within-domain analogies called "intradomain analogies" (p. 165). This group studies various microdomains such as letter sequences, number patterns, analogy puzzles, and simple pictures of objects organized on top of a table. Focusing on single microdomains permits the researchers to include both breadth and depth in their models of mental processing.
Two other cognitive scientists, Holyoak and Thagard (1995) have worked to develop computer models of inference from analogy that concentrate on between-domain analogies or "cross-domain analogies" (p. 256). They do not discard within-domain analogies, but consider them trivial. They believe between-domain analogies are much more important to the study of thought. Johnson-Laird (1989) is also very keenly interested in the creativity involved in "the discovery of profound analogies" (p. 324) that are possible through connections made between remote domains.

**Teacher Use of Different Types of Analogies**

Cognitive scientists' approaches to analogy are determined by the requirements of their research into human thought, requirements that are very different from those of science educators. Teachers need not stress the terminology for the different kinds of analogies, nor choose sides in this debate over the relative importance of each kind. For pragmatic reasons, teachers use both within- and between-domain analogies, whichever works. For the same practical reason, teachers rely on all kinds of analogical thought including analogies, metaphors, and similes.

**Kinds of Similarity**

**Global / Dimensional**

At the core of these figurative devices is some kind of similarity between the analog and the target; but researchers' interpretations of similarity vary with the focus of their research. Child psychologist L. B. Smith (1989) maintains that the ability to handle relational similarity must take into account the child's developmental stage. Children first experience the whole object sensing "global resemblances and global magnitude" (p. 147) that lack a dimensional specificity. As the child's knowledge of relations grows, he will identify how objects are similar in particular dimensions. Thus Smith draws her distinction between global similarities and dimensional similarities, and stresses the challenge that dimensional complexity poses to a child's comprehension of similarity.
Surface / Deep Structural

Rips (1989), a behavioral scientist, agrees with L. B. Smith that similarity is a very complex concept. A person's perception of similarity depends on the person's conceptual and relational knowledge, which in turn varies with age, experience, gender, and other contextual factors. Rips claims that for most of the lay subjects involved in his experimental tests, "similarity denotes something like raw perceptual resemblance" (p. 51). For this reason, his research places more emphasis on the perceptual surface features in recognition of similarity, rather than deeper structural relational features.

While placing the greatest value on deeper structural similarities, Medin and Ortony (1989) agree with Rips that ease of access to representations of perceptual sameness may be important to later recognition of the sameness at the conceptual core. In fact, they visualize a continuum from those deep core properties that are more difficult to access, to the surface properties that stand out for easy retrieval. These central properties act in some way to constrain those perceptual similarities that will be selected as relevant to the core and lead towards the central knowledge representation. In contrast to the position of Medin and Ortony, Gentner (1989) demands a total shift in focus from the superficial attributes of objects to the deep structural relations of an analogy. She claims obvious descriptive object attributes are best ignored.

Salient

But, Vosniadou (1989) disagrees that all surface object attributes are easy to perceive and best ignored in analyzing an analogy. Some descriptive properties, such as the solidity of the moon, are not easily perceived; and some relations are easily accessible. For example, A. L. Brown (1989) has observed that even infants are very sensitive to movements and to their causes, whether a push, a pull, or self-propulsion. Vosniadou prefers the term "salient" rather than "surface" (p. 419) to indicate those
similarities that are easiest to retrieve, whether or not they are object attributes, abstractions, concepts, or relations.

Salient similarity can be of a perceptual or conceptual nature, similarity in descriptive or relational properties. What matters is only the status that these properties have with respect to people’s underlying representations (p. 420). This concept of salient similarity (Ortony, 1983; Vosniadou, 1989) was the appropriate one to guide this project. It places emphasis first on finding the most meaningful similarities for the students. These similarities may be or may ultimately lead to the most significant connections between the analog and target.

Implications of the Discussion of Terms

This long discussion of terms has important implications for educators attempting to encourage analogical thinking. First, new terminology should be kept to a minimum. Second, the teacher should consider the different demands placed on their students by within-domain and between-domain analogies. Third, research into analogical reasoning should include analogies, similes, and metaphors. Fourth, contextual factors will effect students’ analogical activities within the classroom. Finally, students will bring their own ideas of similarity to the task of analogizing. Some students may be operating from a global sense of similarity as well as a dimensional one, and some students may tend to think more literally than metaphorically. The teacher should build from the similarities that are salient for students toward the less accessible, but perhaps more significant similarities.
REVIEW OF LITERATURE

Theories of Analogy

Theory of Salience Imbalance

The theories of many researchers into analogical reasoning provided insights for this study. Ortony (1983) developed the theory of salience imbalance, which holds that a characteristic is more important, striking, or noticeable in the analog than in the target. In a literal comparison, features or attributes in one should apply equally to the other, such that there is equivalent salience. A comparison implied by a simile, analogy, or metaphor must involve inequality in the importance or salience of characteristics for two objects, relations, or systems that are placed in correspondence. This distinction may be used as the basis for judging whether a similarity is literal or metaphorical (Gentner, 1986). This distinction is not always apparent for students.

Structure Mapping Theory

Psychologist Gentner (1983, 1986) developed the structure mapping theory of analogy and metaphor. Her "central claim is that all analogies, and many metaphors, are fundamentally devices for mapping relational structures from one domain to another" (Gentner, 1986, p. 2). For Gentner, mapping involves making connections between the known and the unknown domain based on deeper relations and ignoring object attribute matches. Her theory demands "systematicity" (p. 11), one-to-one correspondence between the familiar and the unfamiliar concept made at the deepest level of relations possible. Evaluation of the effectiveness of an analogy may be based on four qualities named by Gentner:

. **clarity** - a measure of how clear it is which things map onto which other things;
. **richness** - a measure of how many things in the source are mapped to the target;
abstractness - a measure of how abstract the things mapped are. . . .

systematicity - the degree to which the things mapped belong to a coherent interconnected system.

(Mitchell & Hofstadter, 1995, p. 278)

These qualities may be used as standards for evaluation of student development of analogical reasoning.

Cognitive scientists Mitchell and Hofstadter (1995) agree with Gentner's criteria, but disagree with her difficult syntactical measure of abstractness with its emphasis on grammar and sentence structure. They prefer “conceptual depth” (p. 280) which highlights semantic meaning. Semantics “is the study of meaning as it is expressed through language” (Lemke, 1990, p. ix). The same meaning can be conveyed through different grammatical construction or different vocabulary. These factors make science talk difficult for students, but one goal for science teachers is to help students to discover the same semantic meaning in different word constructions. Meaning rather than syntax should be stressed.

Theories of Metaphor

Gentner (1988) categorizes metaphors into four types: attributional metaphors which map descriptive characteristics, relational metaphors which map structural relations, double metaphors which map both attributes and structural relations, and a category of complex metaphors that cannot be matched through one-to-one correspondences. Gentner's structure mapping theory applies only to metaphors with mappable relations.

Three common theories of metaphors are “substitution,” “comparison,” and “interactionist” (Ortony, 1983, pp. 6-7). Psychologist Ortony rejects substitution theory because it equates a literal statement with the exact meaning of a metaphor. Comparison theory highlights similarities between the analog and the target; but the
comparison view fails to account for the ultimate richness of more complex metaphors found in literature. Ortony favors the interactionist theory which is based on the idea that the analog and target of a metaphor "somehow interact to produce some new, emergent, meaning" (p. 7). He argues that metaphors are able to express that which could not be said in literal terms. "Such metaphors, when they get understood, often get understood in a personal, holistic, and unanalyzable fashion" (p. 10). Metaphors at this end of the spectrum seem similar to Gentner's complex metaphors that are not mappable nor analyzable in a scientific sense.

Science teachers must consider these complexities when working with figurative language. They must avoid the two extremes: viewing the meaning in metaphorical language as totally translatable into a literal statement or using such complex or mixed metaphors that there is no way to analyze them for scientific explanation. Muscari (1988) explains that while creative generativity is essential to metaphors, whether used in science or art, the particular points of emphasis vary as well as the concerns.

"Whereas the metaphor in art 'presents' the intuitions of embodied meaning, i.e., a world begot by personal participation, the metaphor in science tends to be more patiently pursued and seeks to 'represent' the realities of abstracted truth" (p. 424). There are certain regularities, such as systematicity and the structural consistency of one-to-one mappings, required for metaphors to work in the modern scientific sense that need not be requirements for the literary metaphor.

This nice distinction is blurred by popular biology writers who use metaphors both for explanation and poetic expression (Hackney & Wandersee, 1998). These writers often intend to reach the reader emotionally, not just intellectually. For example, Wilson (1992) describes the extinction of species on a remote ridge in the Andes of Ecuador as
"synonymous with the silent hemorrhaging of biologic diversity". . . "not open wounds for all to see and rush to stanch but unfelt internal events, leakages from vital tissue out of sight" (p. 243). Wilson's metaphor for extinctions that occur beyond human notice carries with it the emotional punch needed to encourage students to care about the ending of whole species no matter where this is happening. Science educators should tap such powerful figurative language to encourage their students' affective involvement in science learning.

Lewis Thomas (1974), in describing immune responses, states that "When we sense lipopolysaccharide, we are likely to turn on every defense at our disposal; we will bomb, defoliate, blockade, seal off, and destroy all the tissues in the area" (p. 78). This battle language is designed to capture the attention of the reader. Even this metaphorical quote by Thomas can be studied through comparison and contrast of the analog and the target. For just as a country's military may respond to signs of invasion by an enemy, a body's immune system will respond to the presence of foreign proteins as recognized by their peculiar lipopolysaccharide markers. The challenge of making correspondence mappings for such things as bombs and blockades might encourage students to pay attention to specific parts of the immune system such as macrophages, T cells, platelets, and antibodies. If all perfect one-to-one correspondence matches are not possible, this need not prohibit the use of the analogy to provide aid to students (Wandersee, 1985).

**Fluid Analogies Theory**

Hofstadter and the Fluid Analogies Research Group (1995) study mental processes through artificial intelligence research of intradomain analogies. They emphasize the role of higher level perception in conceptual development. Low level perception involves the
reception of sensory data and basic informational processing. High level perception "involves taking a more global view of this information, extracting meaning from the raw material by accessing concepts, and making sense of situations at a conceptual level" (p. 170). These researchers study what happens in the brain between the reception of stimuli by our senses, the raw interpretation of this information, and the movement toward semantic meaning making of deep perception. The multiple parallel processing that is carried on in the brain in just a few milliseconds, from low to high level processing is not available to the person for introspection, and yet it is vital to the actual "thought" that results. Science research educators should appreciate this as yet mysterious but vital perceptual processing.

**Multiconstraint Theory**

Cognitive scientists Holyoak and Thagard (1995) developed the multiconstraint theory, which identifies three pressures, "similarity, structure, and purpose" (p. 6) that interact to shape an analogy. Conceptual similarities are most important, but shared sensory properties are not ignored. Concepts may be connected based on similarities such as a shared category, a similar position in a hierarchy, a comparable relationship of parts to whole, or similar causality. It is these "semantic connections between concepts (that) provide important building blocks for seeing analogies" (p. 23).

In addition to similarity, structure constrains the process of analogizing. Concepts may be put together to produce a more complicated structure and thus more powerful thought. It is important to recognize that the analog and target may have parallels at this deeper level of construction, and therefore may have more than one level of correspondence.
At the simplest structural level, two objects may share semantic similarity in their attributes. Mapping of these similarities is called "attribute mapping" (Holyoak & Thagard, 1995, p. 26). While there are numerous such similarities that may be found between two objects, some will be trivial and others significant within a specific context. For example, a fire truck is red and an apple is red. Mapping of the property of redness from the truck to the apple may not be very useful; but mapping the roundness of a ball to the moon may be helpful to a child, because the roundness of the moon may not be so obvious to a child who has experienced the changing appearances of the moon in the night sky.

The next level involves mapping relations. For example, a relationship of smaller to larger may be mapped from the two propositions: a marble is smaller than a basketball; the moon is smaller than the sun. The marble and the moon are matched as smaller objects; the basketball and the sun are matched as larger objects. These less abstract relationships involve objects and are called first-order relations. The familiar "proportional analogies" (Holyoak & Thagard, 1995, p. 28), A is to B as C is to D, are first-order relations, as are the propositions: The dog chases the cat. The cat runs away. A higher order relation is formed by combining these propositions: The dog chasing the cat is the cause of the cat running away. This more complex proposition involves causality, and is an example of "higher order relations" (p. 28).

Beyond relational mapping is "system mapping" (Holyoak & Thagard, 1995, p. 31). This requires that the elements in two higher order relations be mapped in one-to-one correspondence. For example, the higher order proposition, a policeman chasing the burglar caused the burglar to run away, may be mapped to the prior example of a higher order proposition. The following mappings result: dog to policeman, cat to burglar, dog
chasing to policeman chasing, cat running to burglar running, and chasing is the cause of the running in both systems. While this example follows one-to-one matching, and therefore, may be called an "isomorphism" (p. 29); this structural constraint is not always met perfectly. This is okay. In fact there would be no room for inferences if all matching were perfect. The power of analogy lies in its ability to generate inferences, but inferences involve uncertainty. Students can learn to deal with this uncertainty, as they engage in mapping at all structural levels (attribute, first-order relation, higher order relation, and system).

Holyoak's and Thagard's (1995) third constraint is purpose in seeking an analogy. This constraint helps a person to focus on elements relevant to his or her goal and to discard irrelevant elements. There are numerous purposes for using analogies including: persuasion, explanation, planning, indirect communication, creative discovery, poetic expression, and problem solving. These general goals cover infinite possibilities determined by contextual factors involved.

The three constraints—similarity, structure, and purpose—work flexibly together to shape an analogy. Teachers can help students understand that similarity, structure, and purpose are important factors that may place stress in different directions, and some sort of balance between the constraints is essential.

"The difference between two types of knowledge, implicit and explicit, is between the ability to react to something and the ability to think about it" (Holyoak & Thagard, 1995, p. 21). Students need to be encouraged to make their knowledge more explicit, rather than just implicit. Strange as it seems, explicit representations are necessary to construct an analogy, but the actual process is implicit in that one can not explain step-by-step every part of the analogical thought process. Much of it is part of that high
level perception and multiple processing highlighted by Hofstadter and his Fluid

Neural Model of Analogical Thought

Lawson and Lawson (1993) attempt to explain, through mathematical neural modeling, why analogical reasoning leads to improvement in long term memory of concepts. An increase in the level of activity of the brain's neurons occurs, but, "the crucial element in transferring experiences to long-term memory is the brain's ability to find past experiences that are enough like the present ones to allow their assimilation (p. 1328). Similarities, shared characteristics of the analog and the target, allow for chunking and establishment of feedback loops that leads to increased cellular activity and faster learning.

Teaching Via Analogies

Teaching the Artistically Minded Child

While a teacher can appreciate a brain's neurological activity, he must work with the whole person. From this perspective, educators might adopt psycholinguist F. Smith's (1990) metaphor for the brain:

The brain is more like an artist than a machine. It constantly creates realities, actual and imaginary; it examines alternatives, spins stories and thrives on experience. The brain picks up huge amounts of "information" on our journey through life, but only incidentally, the way our shoes pick up mud when we walk through the woods. Knowledge is a byproduct of experience, and experience is what thinking makes possible. (p. 12)

Teachers work with "artistically minded" children who bring personal life experiences with them to a complex classroom environment. Teachers should use their students' experiences and natural pattern seeking to encourage analogical thinking. Experience provides a knowledge base upon which analogies depend, and the connections that must
be made for analogies depend upon the ability to perceive similarities in pattern (Hofstadter, 1995; F. Smith, 1990).

**Basic Strategies for Teaching with Analogies**

Zeitoun (1983), identifies three basic strategies for teaching with analogies. The most traditional approach, the "expository-teaching strategy" (p. 15) places all responsibility for presentation and analysis upon the teacher, with students as assimilators of information. The second approach, "guided teaching strategy" (p. 15), requires active student involvement in analyzing the analogy for shared and unshared attributes of the analog and target, but the teacher is very much involved in guiding the inference process. The third approach is the "student self-developed analogy strategy" (p. 15). Students develop their own analogies and share them with the class. All three strategies may be used within a class. One indication of development of analogical thought by students would be a transition from reliance on the teacher-centered strategy to greater reliance on more student-centered strategies.

**Glynn’s Teaching-With-Analogies Modified Model**

Glynn (1991) Teaching-With-Analogies model provides a structured pedagogical approach to teaching science using analogies. Science education researchers Harrison and Treagust (1993) have modified Glynn's model by simply switching step 5 and step 6. The modified model includes the following steps:

1. Introduce the target concept to be learned.
2. Cue the students' memory of the analogous situation.
3. Identify the relevant features of the analog.
4. Map the similarities between the analog and the target concepts.
5. Draw conclusions about the target concepts.
6. Identify the conclusions for which the analogy breaks down.

(p. 1293)

Such an approach provides structure for teaching science through analogies.
**Teaching Implications of Theories Related to Analogical Thought**

These theories provide many ideas useful to educators. A teacher should consider an analogy's saliency to students (Ortony, 1983; Vosniadou, 1993). For the purposes of science education, the comparison theory of metaphor (Ortony, 1983), is most useful; yet teachers should not discard the interactionist view of emergent meaning, because teachers may tap the poetical expressive power of metaphorical thought to reach others, as popular biology writers do.

Teachers should emphasize one-to-one correspondence mapping, systematicity, and identification of deep structural relations of the analog and the target (Gentner, 1983). Yet teachers should not necessarily discard the surface object attributes, because they may be salient to students and assist them in identifying structural similarities at the level of higher order relations and systems (Medin & Ortony, 1989; Vosniadou, 1989). Gentner's qualities for evaluation (clarity, richness, abstractness, and systematicity) provide useful guides for judging the success of an analogy. Teachers should realize that three interacting factors (similarity, structure, and purpose) constrain analogizing (Holyoak & Thagard, 1995). Despite this complexity, teachers may be reassured by neurological research (Lawson & Lawson, 1993) that supports analogical reasoning as a powerful way to learn.

Glynn's Teaching-with-Analogies Model as modified by Harrison and Treagust (1993) provides a practical structured approach to teaching through analogies that can be incorporated into any of the three strategies identified by Zeitoun (1983): expository-teaching strategy, guided teacher strategy, and student self-developed analogy strategy. As students develop their analogical abilities, they should be encouraged to move away from dependence on the teacher toward more independent analogical
reasoning. Teachers should remember that analogizing is a very fluid process (Hofstadter, 1995). Students must be given the opportunity, a safe place, and the freedom to explore analogies and a chance to do their own thinking.

**Potential Pitfalls of Teaching with Analogies**

**Too Little or Too Much Familiarity with the Analog**

Teaching through analogical reasoning is not a problem-free pedagogical strategy. If students are not familiar with a selected analog, then it will not be possible for them to identify correspondences between the analog and target (Zeitoun, 1983). A teacher must introduce students to an unfamiliar analog before using it to explain the target. For example, a teacher who uses the analogy of Lilliputians tying up Gulliver to explain how many weak hydrogen bonds can be strong enough together to effect the properties of water, might first explain who the Lilliputians are. Once reminded of Gulliver and his visit to the land of the little people, the analog may become salient for students. If students already have a firm understanding of a scientific concept, introduction of an analogy just adds an extra burden to the students’ learning process (Zeitoun, 1983). Analogical explanations are most helpful for students trekking through unfamiliar and complex territory.

**Difficulties with Mapping Characteristics of the Analog to the Target**

Students must identify the shared characteristics of the analog and the target, and these correspondences should be explicitly mapped (Harrison & Treagust, 1993). Teachers often assume that their students have made explicit connections, but the students may not have done so. Holyoak and Thagard (1995) warn that “without guidance from a teacher, analogy is often a trap for the unwary novice, rather than a stepping stone to expertise” (p. 204).
The analog and target do not correspond in every way. Significant differences should be noted explicitly because unrecognized differences can mislead (Harrison & Treagust, 1993). Students may transfer a characteristic of the analog to the target, that is not a correct mapping (Holyoak & Thagard, 1995). Teachers must help students to understand that “Metaphor is like a rubber band: stretch it too far and it breaks” (Sensenbaugh, 1989, p. 1).

**Misconceptions Associated with Learning by Analogy**

Misconceptions often accompany science students’ learning by analogy. Students’ prior knowledge may block their understanding of a traditional analogy used to explain a science concept. To remedy this problem, “bridging analogies” may be used in an interactive process with students. Bridging analogies are a series of analogies that ultimately connect the analog concept in a familiar domain to the new target concept in the target domain (D. E. Brown, 1992; D. E. Brown & Clement, 1989). A single analogy may be sufficient explanation for a simple concept. A series of analogies may be necessary for full explanation of a complex concept, and may help the learner to overcome any misconceptions that a single analogy has generated (Holyoak & Thagard, 1995; Spiro, Feltovich, Coulson, & Anderson, 1989). Medical students’ comprehension of muscle action has been improved through multiple analogies (Spiro et al., 1989).

Sometimes a simple analogy used to explain a very difficult concept leads to misconceptions, even if it is helpful in another way (D. E. Brown, 1992; Brown & Clement, 1989; Holyoak & Thagard, 1995; Zeitoun, 1983). Medical students often develop misconceptions about heart failure when they rely on the comparison of a failed heart to an overinflated balloon. A failed heart becomes enlarged, but the heart’s failure
is not a lessening of tension as in an overstretched balloon, but rather, malfunction of
the nervous activation system (Spiro, Feltovich, Coulson, & Anderson, 1989).

End and Danks (1982) find that prior priming to see a certain analogical relationship
can interfere with identification of a different analogical relationship for the same target.
Holyoak and Thagard (1995) warn that students often will not abandon the first simple
analogy they used to gain a rudimentary understanding of a science concept. For
example, younger students are often taught the concept of the atom as organized like a
solar system. As students mature, this solar system model needs replacement by the
electron cloud model because this model promotes understanding of chemical bonding
and eventually the principles of quantum mechanics. To help students break away from
their set thinking, a teacher may point out limitations in an older analogy.

Muscari (1988) recognizes the importance of metaphor in providing science students
with an "overall frame of reference. . . . for making sense of the world" (p. 427).
Nevertheless, he warns that students may come to think of the metaphor as actual
reality. While metaphorical imagery may be appealing and can lead to new insights,
science students must ultimately interpret the meaning more and more explicitly in
scientific terms.

Solomon (1985) warns that metaphorical terms that are part of everyday language
may be "dead" in the metaphorical sense, and are simply terms one uses. For example,
"harnessing energy" (p. 4) has long since lost its relationship to a massive horse
harnessed to pull a plow through a field. People are unaware of metaphorical roots of
most of the words they use (Lakoff & Johnson, 1980).

Sutton (1993) suggests that teachers "revive some long-dormant metaphors, and
show that language functions as a medium for interpreting what is going on" (p.1221).
"Dead" metaphors can be revived to their "live" status if they can again be made "mentally provocative" (p. 1221). Teachers can show that scientists too struggle for words to convey their ideas and often rely on figurative language to help in development of their theories. Students may use their own imagery to convey meaning as they struggle to assimilate scientific concepts.

**Students Can Learn to Avoid Pitfalls in Analogical Thinking**

Young adults can improve their facility with analogical reasoning within the scientific domain, so that it becomes a tool for them as it is for professional scientists. Teachers can promote such development through use of analogy in their own teaching and use of analogies in their students' learning activities. Yet this approach should be avoided when too much student knowledge makes an analogy trivial, or insufficient student knowledge makes an analogy incomprehensible (Zeitoun, 1983). Student misconceptions can be reduced through teacher guidance (Holyoak & Thagard), bridging analogies (D. E. Brown & Clement, 1989), multiple analogies (Spiro, Feltovich, Coulson, & Anderson, 1989), and identification of the limitations of a single analogy (Holyoak & Thagard). Students should be encouraged to find and explicitly state the connections between the analog and target, and identify where the analogy breaks down (Harrison & Treagust, 1993; Holyoak & Thagard, 1995). Teens can improve their facility with analogies and learn to avoid most of the pitfalls of analogical thinking. They can learn to use their metaphorical voices to explore the natural world as scientists have done (Sutton, 1993).

**Developmental Issues in Analogical Thinking**

**Young Child**

What do researchers in childhood development say about children's ability to identify similarities and to think analogically? L. B. Smith (1989) claims that the young child first
addresses similarity globally, then gradually acquires the perceptual and conceptual ability to identify similarity and dissimilarity along the line of dimensions such as higher and lower. When asked the color of an object, a very young child may answer any color at all as long as it fits within the global concept of color. A very young child is engaged in moving from global similarity to dimensional similarity, and therefore, not ready for analogical thought.

But it is not long before some ability in this area begins to develop. Research by Ortony (1983) shows that young children, four to six years of age, possess the ability to process similes if they possess relevant knowledge of the domains. The simile includes the term "like" which cues the child to make some sort of comparison. Children's difficulty with interpretation of metaphor may be due to their lack of awareness that their language would permit them to say something in words that conveys some other meaning, then what actually is said. Even young children may understand and enjoy metaphors, if these are not too complex and involve domains with which the children are familiar (Ortony, 1983).

Vosniadou (1989) agrees that children's ability to understand analogy depends on their knowledge base, thus the adult, having a larger knowledge base to draw upon, will handle a greater range of analogies. She argues against Gentner's (1988) assertion that young children, while capable of mapping relations, will tend to map object attributes; while adults favor mapping at the relations level. Vosniadou would argue that children's mapping of relations is simply limited by their smaller knowledge base.

B. Ross (1989) counters Gentner's claim that adults will always seek out relational mapping as opposed to attribute mapping. He has conducted research with adults who were novices in solving probability problems. The novices tended to use superficial
similarities in aspects to help solve the problems, rather than relying on the less salient structural similarities. So the issue of identification of surface versus deep features seems to relate as much to an individual's domain knowledge as to age.

**Middle Elementary Child**

Education researcher Rudden (1995) studied the ability of middle elementary students to interpret *Sylvester's Magic Pebble* metaphorically. While young children deal well with metaphors that rely upon domains very familiar to them, the middle elementary child seems to withdraw from the metaphorical form, almost insisting on the literal. Rudden's research relied on teacher probing to help the 8- to 10-year-olds continue to develop their analogical skills that are so active in earlier years. She claims that "It creates an opportunity to respond to text on a deeper level, reawakens their imaginations, and draws on their delight in wordplay" (p. 362).

**Middle School Child to High School Youth**

Solomon's (1985) study of yet older students, in sixth through eighth grade, revealed that many of these young people had a difficult time explaining why they agreed or disagreed with a simile that related to electricity. They were often unable to identify the point of comparison. This may be explained by the abstract nature of the concept of electricity. Students may have "experience" with electricity, but not in a way that makes it easy to understand the physics of it. For example, students familiar with the flowing property of electricity were able to make a connection between a river that flows and electricity. Students without this knowledge rejected the simile because they knew that one should never mix water and electricity.

High school students are receptive to learning through analogies. Harrison and Treagust (1993) studied a successful tenth-grade optics lesson in refraction that relied
on their modified version of Glynn's Teaching-with-Analogies Model (1991). A case study of four experienced chemistry teachers' use of analogy also suggests that analogies can be very helpful in explaining the concepts of science to students and may increase student motivation to learn chemistry (Thiele & Treagust, 1993).

Zeitoun's (1983) claims that students at the level of formal operations possess correlational reasoning, a requirement for comprehension of analogies. According to Piaget's theory of cognitive development, high school students would be expected to be capable of such abstract thought. But it is possible that students operating at a concrete level may benefit because "Most analogies have a concretizing function: they render unobservable attributes of the abstract topics (e.g., atom) perceptible by comparing them with concrete, imaginable "analogs" (e.g., solar system) (p. 9). This researcher agrees with B. Ross (1989) that it is prior knowledge and not "formal reasoning ability" or age that enables higher order thinking—an idea that fits well with a human constructivist theory of learning.

Implications of the Child Developmental Factor on Analogical Ability

The ability to think analogically develops early in a child's life (Holyoak & Thagard, 1995; Ortony, 1983; Vosniadou, 1989), yet during the mid-elementary school years, young people favor literal representations and, without encouragement of analogical thought, many seem to abandon metaphorical representations (Rudden, 1995). As students enter middle school and high school, analogical thinking again takes on greater importance (Harrison & Treagust, 1993; Thiele & Treagust, 1993; Solomon, 1985). Yet these students may still need encouragement and guidance to tap their creative analogical skills. Always the ability of an individual child or adult to benefit from an analogy is dependent on that individual's knowledge of the analog and target domains.
(Ortony, 1983; Vosniadou, 1989). The salience of the surface versus deep properties will also vary with familiarity with a domain regardless of the age of the individual (Ross, 1989). Acquisition of domain knowledge is a lifelong process for each person and this knowledge acquisition is achieved through active construction.

**Constructivism**

**Construction Zone and Zone of Proximal Development**

Constructivism, a major educational psychology tradition that helped shape this study, places active students in the center of a learning zone, and recognizes the importance of context and culture within this zone. This zone is a safe place for sharing ideas and interacting among people as their conversations lead to greater understanding and cognitive change. On this "common ground," students and teachers are free to exchange views with respect given to all.

The "construction zone" [is] a magic place where minds meet, where things are not the same to all who see them, where meanings are fluid, and where one person's construal may preempt another's. (Newman, Griffin, & Cole, 1989, p. ix)

Eventually, this interpersonal and interpsychological activity may lead to appropriation of each other's understandings.

This "construction zone" is similar to psychologist Vygotsky's "zone of proximal development" (Cole, M. et al., [Eds.] 1978, p. 84). In Vygotsky's ZPD, students work on tasks that may be beyond their individual development, but they attempt these tasks with support of an adult or peers (Dixon-Krauss, 1996). The idea of a construction zone or the ZPD brings "into our talk about instruction that slight aura of fuzziness and
confusion that is always a backdrop to real communication among people” (Newman, Griffin, & Cole, 1989, p. xii).

This kind of atmosphere is necessary if students follow Lemke’s (1990) advice to talk science with one another in class discussions and in small groups, and to practice writing science in many different ways, not just in a formal scientific way. Lemke advises teachers to “help students understand that science is a way of talking about familiar and unfamiliar experiences that enables us to relate them to each other in new ways” (p.176). Lemke’s words seem particularly applicable to this study’s focus on students talking science via metaphorical language. Scientific meaning conveyed through figurative forms is not immediately apparent. Students must tolerate ambiguity and uncertainty as they engage in complex cognitive activity of finding meaning in the analogical words. Constructivists add that cognitive functioning level of individuals is highly content dependent (Gunstone, 1988), so analogical reasoning about science concepts may add to the students’ challenge.

The constructivist approach also correlates with Latour’s (1987) differentiation of “science in the making” from “ready made science” (p. 13). Students need exposure to more of the former and as well as to the latter if they are to understand that the “construction of facts. . . is a collective process” (p. 29). This is true in science as in any other realm. Let young people think, research, debate, analyze, communicate, observe, problem solve, evaluate, analogize and engage in all the various activities of people doing science. It is just as important for them to learn about the process of science, as it is for them to learn the knowledge of science.

Students’ constructions may be accurate, inaccurate, incomplete, sketchy, potentially useful, or misleading, but such is the nature of “facts” during the making of
science. Scientists know this. This approach does not mean that a teacher need abandon students to relativism. There is an accepted base of knowledge in science that educators try to help students comprehend. With teacher guidance, input, and postanalogizing feedback, these group analogical activities can be safe catapults for student learning in science.

Teaching Within a Constructivist Framework

A variety of teaching strategies may be used within a constructivist framework: one-on-one interactions, interactive guided class activities, and small group activities. Students exchange ideas with peers as well as with the teacher (Nodding, 1990). Cooperative learning has support in Vygotsky's (1934) theories of the importance of social interactions in development of mental function. Through exchange of ideas within a child's community, the individual child is pushed to question her reasons, positions, and thoughts to ultimately experience an internal transformation in her conceptualizations.

Constructivism places new pedagogical demands upon teachers. Teachers must give up some control and allow for a looseness in lessons. The unexpected will surely happen. For example, in one investigation into a learning cycle for electricity with third and fourth graders, Newman, Griffin, and Cole (1989) found that "the metaphorical richness of the electricity concepts meant that we, and the teachers, had insufficient on-line control of the task to get the 'electricity lessons' to work as problem isomorphs" (pp. 27-28). Constructivist teachers are flexible.

Within a constructivist framework, a teacher avoids the traditional inequality inherent in a student-teacher relationship within a classroom. Instead, she promotes an open environment to empower her students. She does not rely too often on triadic dialogue that only appears to maximize students' participation. She appreciates the importance
of "joint construction of meaning in all social and scientific inquiry" (Roman & Apple, 1990, p. 38).

The teacher acts as guide. "Constructivist educators provide only as much assistance as the pupil requires. The child is allowed to work to the edge of his potential. This places a burden upon the teacher for 'interactive assessment' throughout the learning activity" (Newman, Griffin & Cole, 1989, p. 80). The teacher checks often on the progress of students working in small groups and assists them if they are getting "lost". Each group may be working toward the same goal, but the paths taken may be very different. The nature of analogical work, as in this study, may increase the potential for different paths for each group. Holyoak and Thagard (1995, p. 7) explain the dynamic nature of analogizing:

To propose an analogy, or simply to understand one, requires taking a kind of mental leap. Like a spark that jumps across a gap, an idea from the source analog is carried over to the target.

**Constructivist Perspectives**

Researchers view constructivism from different perspectives including--personal, contextual, radical (Cobum, 1991), and human (Mintzes & Wandersee, 1997). All place emphasis on construction of knowledge from experience. The construction zone may be visited from a personal constructivist perspective "in terms of an individual's developmental history" and from a contextual constructivist perspective "in terms of the support structure created by the other people and cultural tools in the setting" (Newman, Griffin, & Cole, 1989, p. 61).

This study focused on individual development of analogical thought through student participation in a series of analogical learning activities, and on the support provided by each cooperative learning group and by the teacher. The individual, society, setting, and
materials available to work with were parts of students' complex ecology for learning. This researcher explored students' meaning making as both personal and social experiences within the context of their biology class.

Radical constructivist von Glasersfeld (1990) states: "'Knowledge' is the conceptual means to make sense of experience, rather than a 'representation' of something that is supposed to lie beyond it" (p. 27). "Cognition serves the subject's organization of the experiential world, not the discovery of an objective ontological reality" (p. 23). This researcher agrees with von Glaserfeld's emphasis on the primacy of experience in knowledge construction and the lack of perfect correspondence between our knowledge representations and the natural world. Yet the scientist is bound to ever seek knowledge representations that better describe and better correspond to the natural world, and a science educator is bound to assist her students in their search for such knowledge of the natural world.

Perhaps human constructivism best captures the spirit in which this research was conducted. Mintzes and Wandersee (1997) identify three major tenets of this framework:

- Human beings are meaning makers... The goal of education is the construction of shared meanings... Shared meanings may be facilitated by the active intervention of well-prepared teachers. (pp. 47-50)

This researcher respected the student participants as capable meaning makers who, with teacher support, could construct better meaning through shared experience of the analogical activities.
METHODS

Research: Focus, Site, and Participants

Introduction

This study focused on student development of analogical thought through participation in a series of research-based analogical learning activities targeting science concepts, and on the support provided by each cooperative learning group and by the teacher. The individual, society, setting, and materials available to work with were parts of students' complex ecology for learning. This researcher explored students' meaning making as both personal and social experiences within the context of their biology class. Emphasis was placed on how students develop analogical thought as they participate in analogical activities, and the effects of such participation on meaningful biological learning, on the quality of student interactions within learning groups, and on the quality of teacher-student interactions.

It was anticipated that the use of these research-based set of analogical activities with students in a Biology I class would result in development of students' analogical thought, qualitatively better learning by students, improvement in quality of student interactions, and improvement in quality of teacher-student interactions.

Research Questions

Major Research Question for This Study Was:

How do high school biology students develop analogical thought as they proceed through a year-long sequence of research-based analogical activities?

Subquestions for This Study Were:

1. How does students' dependency on the teacher change as they participate in the sequence of analogical activities?
2. How does students' biology learning change as they participate in the sequence of analogical activities?

3. Are there any parallels between the students' development of analogical thought and their learning of biology content?

4. How does the quality of biology classroom interactions of these students compare to an equivalent biology class? (See Appendixes A and B for overviews of study.)

The High School Research Site

Magnet School Requirements for Students

The research site was an academic magnet public high school in an urban Afro-American neighborhood. To be admitted to this school, students must have earned a 2.5 average and scored at least a 5 stanine on reading and math standardized tests, and they must continue to maintain a 2.5 average. Students from the northern end of the parish may enroll in the regular magnet program. Students from all over the parish may enroll in the engineering magnet program. The engineering magnet students are required to maintain at least a grade point average of 3.0 and score a 7 stanine or better on a standardized achievement test in both math and reading. During the school year 1996-97, more females than males were enrolled in the school; but more males than females were enrolled in the engineering magnet within the larger academic magnet.

School Enrollment Profile

The 1996-97 enrollment was 856 students. Afro-Americans (502) composed 54% of the student body. The other 46% of the study body was composed of Euro-Americans (356) and Asian-Americans (37). Two Euro-Americans were Hispanic. Females (539) represented 63% of the student body, while males (317) represented
37% (see Appendix C). Students varied in their socioeconomic circumstances. There were 161 students eligible for free school meals and 76 students qualified for reduced price school meals (Davis, personal communication, October 29, 1996). These 237 students of lower economic means represented 28% of the student body.

**School Faculty Profile**

The faculty of 55 teachers (44 full-time and 11 part-time) reflected to some degree the diversity of the student body. Three-fourths of the faculty were female. The percentages of Afro-American and Euro-American female teachers was close to parity. One female teacher was Asian-American. The male teachers represented about one-fourth of the faculty. Of these male faculty members, one-third were Afro-American and two-thirds were Euro-American. Of the full-time faculty members, 33 held a Master degree and three held Ph.D. degrees. The pupil to faculty ratio was 28:1. Three counselors coordinated the guidance program.

**Peace, Diversity, and Problems too**

The typical school day was busy and noisy, yet peaceful in the sense that there were few student conflicts. Student diversity was an asset at this school, helping to prepare the students for the multicultural, complex real world. These magnet students were not immune to the problems of the larger society such as divorce, depression, stress, drugs, alcohol, smoking, teenage sexual activity, academic difficulties, and so forth. School counselors, community advisors, faculty, and administrators worked together to assist troubled students.

**School Logistics**

Students used school buses or personal cars for transportation to and from school. Few students walked to school. Classes began at 8:30 a.m. and ended at 3:30 p.m.
Each school day, students attended five classes. The only break from classes in the school day was a half-hour lunch period. Once a week, on Wednesdays, an activity period was scheduled during first or seventh hour. First- and seventh-hour classes met every day for one hour. All other class periods met three times a week for 90 minutes. This schedule allowed students to take seven courses. Students made their own course requests based on school requirements, personal interests, and abilities; but assignments to specific classes were made by counselors with computer assistance.

Biology Courses

Biology I was a science requirement for all students. Approval from an academic magnet student's physical science teacher was required for admittance to honors level, but all engineering magnet students were required to take honors level. Advanced Placement Biology was an optional course for juniors and seniors. Class size for Biology I averaged 30 students. Biology I curriculum covered the nature of science, cell biology, genetics, evolution, classification, the five kingdoms, human anatomy and physiology, and ecology.

Each of three biology teachers had teaching assignments for five periods, one planning period, and one duty period. The biology teachers aimed for depth as well as breadth of coverage. These teachers took advantage of adequate class and lab space plus science equipment to emphasize hands-on learning.

Student Participants in Research Study

Student Profiles of Honors Biology Classes

The 91 students enrolled in honors level biology for 1996-97 were placed in one of three classes (see Appendixes D and E). Of these 91 students, 38 enrolled in
Engineering Honors Biology I and 53 enrolled in the Magnet Honors Biology I (see Appendixes F and G). The course names were different, but the course was the same. Most students in sixth hour were Engineering Honors Biology I students; most students in seventh hour were Magnet Honors Biology I students. One-third of Hour 5 students were Engineering Honors Biology I students and two-thirds were Magnet Honors Biology I students (see Appendixes H and I).

Fifth hour had the best balance in gender (14 females and 16 males) and ethnicity (14 Afro-Americans, 4 Asian-Americans, and 12 Euro-Americans). There was diversity by gender among Afro-American students (9 females and 5 males), Asian-Americans (2 females and 2 males), and Euro-Americans (3 females and 9 males). The selection of fifth-hour students to participate in the analogical activities was partially based on this class diversity in gender and ethnicity (see Appendix E), as well as a better balance of engineering and magnet honors students (see Appendixes H and I).

**Roles of Student Participants**

Honors Biology I students in Hour 5, 6, or 7 participated in this study. They followed the same curriculum taught by the same teacher. But students in fifth hour also participated throughout the year in a sequence of research-based analogical activities developed by this researcher with guidance from her major advisor, Professor J. Wandersee. A five-year literature search and pilot studies of some activities provided valuable insights.

Students in sixth and seventh hours participated in substitute, nonanalogical activities that related to the same topics (e.g., body systems) and were similar types of activities (e.g., poster construction). This provision was essential to the well-being of these students who would quickly notice differential treatment by the same teacher.
This was also beneficial to this study, because it allowed qualitative analysis of the effect of the analogical aspects of the activities apart from the effects of a particular type of activity or topic.

All students worked in small groups for their analogical or nonanalogical activities. Students selected their own group members, unless teacher assistance was required. This pro-choice stance was consistent with this researcher's emphasis on students' making their own decisions as they worked to develop independence. This researcher recognized that cooperative learning research (Jones & Carter, 1997) suggests careful assessment of students for assignment to collaborative groups. This advice would have been difficult to follow in terms of this research into analogical development, because it was not clear at the outset which characteristics of students would make them strong participants and which characteristics of students would make them weak participants.

Students remained in the same group throughout the year. This pro-commitment stance was consistent with this researcher's emphasis on students' developing their interpersonal skills, essential components of emotional intelligence (Goleman, 1995). Furthermore, permanent group membership was an inherent and necessary component of this research study, since each group was a focal unit. For these reasons, analogical and nonanalogical group memberships remained stable units throughout the year, rather than temporary units formed for the purpose of doing a particular task (Jennings & Di, 1996). These students had opportunities to collaborate with students, other than their group members, in nonresearch-related group activities (e.g., laboratory work, traditional worksheet assignments).
This researcher informed Honors Biology I students that they were important
participants in this study, but participation in their group activities was part of their
biology curriculum. Participation in solely research-related elements (e.g., surveys,
interviews) was optional. Students never heard the activities referred to as analogical
or nonanalogical. This researcher used a letter to inform these students' parents of
this educational research. Parents were asked to sign this information letter to
indicate their awareness of their child's participation in educational research within
their Biology I class. This letter included this researcher's telephone number for
parents to call if they had concerns (see Appendix J for copy of letter).

Teacher and Researcher

Personal Background

As the researcher and the teacher, I would like to provide a small portrait of myself
to support my qualification for this role, and to reveal some factors that contributed to
my subjectivities. I am a female United States citizen whose ancestral roots may be
traced back to several countries in Europe. I come from a large family. I have been
married for many years to my husband who is a practicing physician. I spent my early
married years at home raising our four children. Our two girls and two boys were born
within the space of five years. This intense experience of raising children has been an
asset to my professional life. At the start of the 96-97 school term, I had eleven years
teaching experience with high school students and one with middle school children. I
had earned a bachelor degree in Science Education, a master's degree in Natural
Science (M.N.S.), completed course work for a Ph.D in Biology Education, passed the
written and oral general exam, and worked on six pilot activities in preparation for this
research. Most of my teaching experience had been at the magnet high school site of

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this study. I've taught all levels of biology, environmental science, marine biology, oceanography, and chemistry in high school; and microbiology, comparative anatomy, and life science in middle school.

**Personal Philosophy Toward the Young**

My life's experiences have shaped my teaching philosophy. Don't expect perfection. Do expect the unexpected. Respect youthful opinion. Allow students to speak for themselves and be sure to listen. Keep the conversation going. Give students opportunities to be active. Enjoy. Know that you and your students will recover from your pedagogical failures and from their errors in decision making. Revise plans and try again. Give the young a push, but don't expect to control how far or where they will then go. Offer guidance more often than orders. Shape an environment that is structured enough to provide safety for all the unique individuals in your care. When really beat down, get support from your teacher friend across the way.

**Broad, Deep, Multifocal Perspective**

For this research, I was seasoned enough to have experienced many of the joys and tragedies of life which temper my idealistic philosophy. I did not make my observations through rose colored glasses because my pair broke a long time ago. I did not wear sunglasses either, as I did not want to miss out on the occasional sunbeams. One of my eyes saw better close and one of my eyes saw better far. With such vision, I gained an understanding at the scale of the whole class and also at the scales of small group and individual. This project was very demanding because important things were happening for individuals, for the groups, and for the class overall; and these were all happening at the same time. These multiple perspectives were impossible for one
person to maintain simultaneously, but through a year-long study, research that was broad, deep, and multifocal was possible.

**Analogical Activities’ Development, Description, and Pilot Studies**

**Analogical Activities**

**Introduction**

This researcher with guidance from her major professor, James H. Wandersee, developed a set of analogical activities to promote students’ analogical thought. For this study, the following question-driven generic analogical activities were paired with target science topics as follows:

1: “Is It Like It or Not?”—Biochemistry
2: “Who Will Symbolize Us?”—Nature of Science
3: “Can You Make the Connection?”—DNA Genome
4: “Can You Experience This?”—Classification of Life
5: “Can You Find a Solution in the Story?”—Tumor Treatment / Water Allocation
6: “Does a Picture Equal 1,000 Words?”—States of Matter / Cell Functions
7: “Does a Hands-On Experience Equal 1,000 Words?”—Invertebrate Phyla
8: “Can You Say It Through Pictures?”—Body Systems

Brief descriptions of these activities and identification of their research grounding follow. In the interest of clarity, more detailed descriptions are integrated into the discussion of results. During the school year 1995-96, one or more biology classes piloted some of these analogical activities. A brief discussion of these pilot studies is also included in this synopsis of the analogical activities.
**Activity 1**

Activity 1 "Is It Like It or Not?" uses similes to develop conceptual understanding of targeted concepts (see Appendix K). This technique bears resemblance to Solomon's (1987) use of similes to study middle schoolers' ability to reason analogically.

For "Is It Like It or Not?" students evaluate a set of similes which target a scientific concept. Students accept or reject each simile based on whether they can map a similarity from an analog to its target. Notice that this first activity requires students to evaluate a simile, the simplest analogical form, and map only one similarity. For this study, the similes targeted biochemistry (see Appendix L for simile statements and Appendix M for hypothetical responses). No pilot was conducted.

**Activity 2 and Pilot Study**

Activity 2 "Who Will Symbolize Us?" (see Appendix N) was loosely inspired by Tobin and LaMaster's (1995) study of the effect of choosing different metaphors to guide LaMaster through her first year as a science teacher. As her metaphors for teaching changed, so did her teaching practice. This suggests that the way a person thinks about his or her role can shape his or her actions in that role.

For "Who Will Symbolize Us?", students choose an animal as their learning group's name based on discussion of its representation of their view of science. They design a group emblem based on their animal symbol. They explain to their class how their animal signifies their vision of science. Note that for Activity 2, students map a set of similarities, rather than just one similarity, and they select their own animal analog for the target of nature of science (see Appendix O for hypothetical responses).

This activity was piloted by advanced and regular biology students. Students responded well to this activity. They felt comfortable talking about their ideas of
science and talking about animals, which they had researched. While the insights of the more advanced biology students were more developed than those of the novice biology students, all biology students were successful in relating their animal symbol to their view of science.

**Activity 3 and Pilot Study**

The activity "Can You Make the Connection?" (see Appendix P) is based on Harrison and Treagust's (1993) modification of Glynn's (1991) Teaching-With-Analogies Model. These researchers argue that it is vital to use a structured approach when using analogies in a pedagogical way. Harrison and Treagust studied a science teacher's use of this modified model to explain the concept of refraction through analogy. Students believed this approach helped them to understand refraction better.

"Can You Make the Connection?" provides a structured guide to analysis of an analogy. Steps for analysis include: defining the analog and the target, identification of similarities and dissimilarities between the analog and target, synthesis of information about the target gleaned from the comparison, and contrast of the analog and target. For Activity 3, the analogy used was "A genome (target) is like an encyclopedia (analog)." Notice that Activity 3 added the requirement for students to map differences, as well as similarities, between the analog and the target.

Prior to students engaging in this activity within groups, the teacher used the same guidesheet to guide the whole class in analysis of the analogy "Respiration is the fire of life" (see Appendix Q). This provided students with an essential model of the analysis process. This activity was, in effect, repeated just as it was piloted in the prior school year.
Honors and regular biology students piloted "Can You Make the Connection?" This activity helped students understand the concept of respiration through a guided teacher analysis of how respiration could be and could not be compared to a fire. Emphasis was placed on student understanding of the fire analog, the concept of respiration, the mapping of similarities and dissimilarities between the analog and the target, the points at which the analogy does not work, and finally on the inferences that can validly be made from the analogy. Students improved their understanding of respiration through participation in this whole class activity.

Activity 4 and Pilot Study

The activity "Can You Experience This?" (see Appendix R) is loosely inspired by Flick's (1991) study of elementary children learning about the states of matter through their experience with a sugar cube analogy. Manipulatives, verbal discussion, written expressions of students' understandings, and drawings were important components of this experience. The familiar sugar cube and its transformations improved students' understandings of the abstract molecular concept of states of matter. Flick's investigation was constructivist, emphasized personal language and experience, looked for cognitive growth, and relied on an analogical experience.

These same qualities are integrated into the activity called "Can You Experience This?". The guidesheet provides a structured guide to analysis of an experience intended to serve as an analog for a scientific target. The first part focuses on analysis of the experience itself; the second part focuses on analysis of the analogy.

For Activity 4, students in their groups classified a set of hardware items as a simulation of biological classification (Fitzsimons, class lecture, 1983). Completion of the guidesheet, "Can You Experience This?", encouraged students to deeper reflection
on their experience in classifying hardware as a simulation for classification of life (see Appendix S for hypothetical responses). This guidesheet bears resemblance to "Can You Make the Connection?" in that students map similarities and dissimilarities between the analog and the target. In "Can You Experience This?", the analog is actually an analogous experience rather than simply a stated analogy, but the basic analytical approach is again based on Harrison and Treagust's (1993) modification of Glynn's Teaching-with-Analogies Model.

The 1996 pilot study of "Can You Experience This?" was similar to Activity 4. Honors and regular biology students participated. In doing this activity, the honors students showed a greater independence than the regular students. Participation seemed to help students understand biological classification, but some students had difficulty with the analytical aspects of this assignment.

Activity 5 and Pilot Study

The activity "Can You Find a Solution in the Story?" (see Appendix T for guidesheet) is directly related to the research of Gick and Holyoak (1980). These researchers used a story to serve as an analog for a problem within another story, which college students were asked to solve. Many students used analogical thinking to connect the analog story of a general's successful attack on a fortress to find a solution to the problem of how to destroy a patient's cancer. Gick and Holyoak found that students were more successful in using the analog story for inspiration if they were told explicitly that the fortress story could help them solve the patient's problem.

"Can You Find a Solution in the Story?" guides analysis of both an analog story and target story through identification of: problem, goal, resources, possible actions, restrictions, plan, and outcome. This basically shapes explicit mapping of a system of
correlations between the analog story and the target problem contained within another story.

For Activity 5, students groups used the guidesheet “Can You Find a Solution in the Story?” to help members devise a solution to a problem posed in a story by tapping an analogous story in which a similar problem was solved. They were told that the story could help them solve the problem. The students were given the same challenge and the scenarios provided by Gick and Holyoak to college students (see Appendixes U for modified stories and Appendix V for hypothetical responses). With potential assistance from an analogous story about peanut allocation, they also tried to solve a second problem of water allocation posed within a story (see Appendix W for stories). Notice students worked with systems mapping of analogical relationships and used their analogical thinking to solve problems.

In the pilot study, Gick and Holyoak’s two scenarios were used. All participants were told that the fortress story could be helpful to them in solving the tumor treatment problem. Many students transferred at least some aspects of the fortress story to help them come up with solutions. The students responded well to the story element and the challenge of problem solving.

**Activity 6 and Pilot Study**

The activity "Does a Picture Equal 1,000 Words?" (see Appendix X for guidesheet) is based on Hurt’s (1985) study of the cognitive benefits of literal illustrations versus analogical illustrations. Hurt found that analogical illustrations helped college students improve their understanding of abstract information; while literal representations were helpful to students in gaining realistic knowledge, such as that related to physical traits.
“Does a Picture Equal 1,000 Words?” challenges students to match analog pictures to appropriate target concepts. Students first define the target concept and evaluate the analog pictures for potential mappings between each picture and the target concept. They explain the basis for each of their choices. Notice this activity involves students in mapping properties, relations, and even a system signified within a picture analog for a scientific target.

For Activity 6, student groups worked with Fortman’s (1993) realistic picture analogs for states of matter. Students explained states of matter through analogical mappings from the picture analogs (see Appendix Y for hypothetical responses). They also worked with abstract pictures that signified cell functions. They matched each abstract cell symbol to a cell function based on their definitions of cell functions and their recognition of analogical similarities.

In the pilot, Fortman’s (1993) picture analogs for states of matter were used to review students’ understanding of states of matter. The pictures helped students review their knowledge of states of matter, particularly as solids, liquids, and gases compare to one another. Students liked the pictures and the familiar scenes depicted.

**Activity 7**

“Does a Hands-On Experience Equal 1,000 Words?” (see Appendix Z for copy of guidesheet) has a relationship to an activity developed by Vandas (1992) to teach about wetlands through students’ manipulation of concrete object metaphors. “Does a Hands-On Experience Equal 1,000 Words?” relies on a series of hands-on activities to serve as analogical reminders of properties of a target concept. The guidesheet directs students to map each activity to a particular property of a target concept.
Notice that this activity uses a series of mini-experiences as a set of analogs to signify properties of a target concept.

For Activity 7, students engaged in mini-activities that could serve as analogs for properties of organisms categorized in specific invertebrate phyla. Students went to each phylum's lab station to engage in mini-activities and to record analogical connections between each mini-activity and a property of organisms in that phylum (see Appendix AA for hypothetical responses for the digestive system). No pilot was conducted.

Activity 8

"Can You Say It Through Pictures?" (see Appendix BB) is inspired by Salay's (1992) assignment to her college students to construct a collage of analogical pictures to convey information about the integumentary system and to explain each pictures's significance. No pictures with literal meaning for the integumentary system were permitted. Salay recommends stressing the "art of collage [as] interpretive and symbolic" because "science students ... are steeped in the concrete aspects of science" (p. 102).

"Can You Say It Through Pictures?" directs students to construct a collage of metaphorical pictures which portray a targeted concept and record their interpretations for each picture. To accomplish this task, students first research the target science topic. Notice that Activity 8 involves students in selecting their own analogs and explaining their own mapping for each picture. They transform scientific information into an interpretive collage, a metaphorical vision.

For Activity 8, students' groups worked to construct a metaphorical collage of their assigned body system (see Appendix CC for hypothetical responses). Group members
presented their collage to their class and explained the analogical significance of each picture on their poster. No pilot study was conducted.

**Analogical Activities: Pilot Studies**

**Pilot Studies Support and Influence Research Study**

The experiences of student participants with pilots of Activity 2,3,4,5, and 6 influenced the plan for this study. Student benefits and problems accrued with participation in these analogical activities. These benefits and problems were identified through researcher observations of and participation in student experiences, researcher content analysis of student guidesheet responses, and student responses on optional Student Perceptions Survey (see Appendix DD for copy) for pilots of Activities 2, 3, 4, and 6.

**Benefits of Pilot Analogical Activities and Implications**

During 1996 spring pilot activities, student-participants experienced these benefits: active involvement, good motivation, some success with learning, practice with scientific processes (e.g., classifying, problem solving, analyzing, analogizing), and personal and communal construction of meaning. The formats (e.g., story, lab experience, pictures) of the analogical activities varied, and the processes (e.g., drawing, analysis, discussing) required for each activity varied. This variation provided appeal for all types of learners. The hands-on learner thrived classifying hardware; the artistic visual learner enjoyed constructing a group emblem; the verbal learner was intrigued by the story activity; the analytical thinker seized the opportunity to find meaning in an analogy; the creative learner felt affirmation in open-ended responses; and structured learners felt secure with the guidesheets. Most students learned from a
mix of approaches. In view of these apparent benefits, further investigation was justified.

Problems of Pilot Analogical Activities and Implications

Some students expressed alternative conceptions while learning through analogies (D. E. Brown & Clement, 1989; Holyoak & Thagard, 1995). For example, some students were misled by the analog pictures for states of matter. Variation in the size of people depicted in each analog picture reinforced a common alternative conception that atoms or molecules in a gas are smaller than in a liquid or solid. Understanding this problem, this researcher standardized the size of the people in the three analog pictures for use in Activity 6. Pilot experiences sensitized this researcher to notice alternative conceptions expressed by participants during this study.

During pilot activities, students often did not express their ideas fully in written form, as warned by Harrison and Treagust (1993). For example, some students talked about the analog or the target, then did not explicitly relate the two. The pilots confirmed the importance of urging students to clearly and explicitly write the connections they have made between the analog and the target. During the pilots, students expressed their ideas more completely in talking. This suggested a need to audiotape group interaction for this study of student meaning making.

The pilot of Activity 6 showed that energy was a difficult concept for students to retrieve from memory when explaining states of matter. Priming students to consider energy might have helped. For example in the pilot of Activity 3, priming students to recall concepts relevant to fire helped students use the fire analog
to understand respiration. Pilots highlighted the importance of priming student knowledge of both analog and target to promote success with these analogical activities (Glynn, 1991).

Pilot Activities Suggest Some Influential Variables

The pilots of analogical activities revealed the teacher serving multiple roles including: traditional didactic instructor; group manager; vigilant guide who points the way and intervenes when necessary; resource person who advises and provides material resources; and enthusiastic supporter of independent thought and work. Students' abilities and the difficulty of the activity dictate teacher roles. To attempt the pilot analogical activities, students required very specific oral instructions, in addition to written guidelines. Teacher modeling of each activity was most beneficial. Often students needed help with one or more processes (i.e., selection, mapping, inference, and evaluation) that are part of analogical thinking. Students responded to encouragement and validation of their thought.

For the pilots, students formed their own learning groups. Six members proved to be too many for useful work. Some groups' members worked as a unit to reach a consensus. In other groups, members did not form a functioning unit. What were pilot group interactions really like? Without a way to track each group's meaning making, it was not possible to fully answer this question. For this study, student audiotapes of group interactions provided the necessary data. To encourage student independence, students formed their own groups for this study.

The pilot of "Can You Find the Solution in the Story?" suggested gender as a factor in that activity. Female groups showed more unanimity in their responses and gave more detailed and complete solutions for treatment of the patient. While full
exploration of gender as a factor is beyond this study's scope, this researcher tried to be mindful of gender in her analysis.

Pilots showed that students vary in their ability to handle analogies, regardless of labels of regular or honors biology student. The honors students did handle the analogies better, but some regular students did just as well. Regardless of biology level, all students needed help in learning through analogical thought. Possibly participation in analogical activities could help develop students' analogical thinking.

How to Study the Analogical Construction Zone

Qualitative Research and Constructivism

Noddings (1990) asserts that an investigation of student cognitive constructions demands a research method that matches theory. Qualitative research and constructivism are a good match. Qualitative research is situated, specific, particular, contextual, holistic, personal, and inclusive of culture—qualities that are also incorporated into the theory of constructivism. Qualitative researchers try to understand the person or persons in the process of making meaning. Through this study, this researcher tried to understand students' construction of meaning. Qualitative methods provided means for investigating students perceiving, thinking, setting goals, analyzing, using intuition, and interacting in their learning group community.

Quality in Qualitative Research

Importance of Context and Natural Setting

Sherman and Webb (1988) note that there are shared concerns in all qualitative research. Qualitative research does not try to eliminate variables, but instead, pays close attention to their contribution to the overall context of the human experience.
Gender, race, personality, age, relationships, environment, and so forth are all factors that play a role in student learning. This educational researcher tried to remain mindful of the many contextual factors that affected the student participants. Qualitative inquiry should be conducted in a natural setting. This research was conducted with biology classes that had not been artificially composed in any way. The analogical group activities were simply incorporated into the students' biology curriculum.

**Holistic Experience and Personal Meaning-Making**

"Qualitative researchers want those who are studied to speak for themselves" (Sherman & Webb, 1988, p. 5). Student participants in this study expressed their own ideas and made their own meaning of the analogies. Qualitative research should focus on the "whole" experience. This researcher was also teacher to the student participants in this study. This duality promoted my understanding of students' experiences holistically, throughout the whole school year.

**Situation as Personal and Familiar**

This research shared a "familiar" thread with Grumet's (1990) work. Grumet uses autobiographical stories to help her students grow in understanding of philosophical ideas, and for her to grow in understanding of her students. One of her students enthusiastically states that "As a new student in an unfamiliar situation I appreciated the use of personal, familiar materials to mediate the learning experience" (p. 118). Just as a student's autobiographical narrative draws upon prior life experiences, student's work with metaphorical thinking draws upon prior life experiences that determine the "familiar" for each student.

Also notice that Grumet's (1990) student uses the term "situation" to refer to her particular experience within Grumet's class. Curriculum theorists Pinar and Grumet

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(1988) explain that situatedness places the individual at the center of the "field for action." The field's "horizon is lodged within this actor's perception and its meaning spans the distance between his/her history and imagination" (p. 98). They emphasize that students do not relate to school as an "educational environment" but rather as "our situation" (p. 98). A researcher must recognize the centrality of the individual student to his or her learning, and remember that each student will perceive the educational moment in a unique way.

**Teacher as Inquirer**

The good teacher is attuned to the individual student and to the interpersonal relationships of the student within his or her world. This appreciation of the situatedness of students can help the educator carry out the role of inquirer within her particular class. Grumet (1990) gives an affirmation for the teacher as educational researcher by her recognition that the world and human relationships must be incorporated into the method of educational exploration:

> But teaching, as I have tried to show, is both art and science. And we must study teaching as teachers. For teaching is research and research is teaching and daffodils often come before the swallow dares. (p. 119)

Yet, it is a big challenge to balance the demands of research study, active teaching and productive student learning (Newman, Griffin & Cole, 1989). It is a challenge because "Teaching simultaneously performs the connection of art and practices the so-called abstention of science" (Grumet, 1990, p. 102). The teacher must maintain the connectedness and relatedness of the artist to his world, yet be able to step back for reflection, interpretation, analysis, and evaluation. Demands of both subjectivity and
objectivity must be met. This researcher tried to meet both demands during this study.

**Judgment**

Sherman and Webb (1988) associate judgment with qualitative research. "Judging is an *appraisal* of the qualitative situation, the relation of the parts and whole, and an indication of the potentialities that can be sought from the actualities" (p. 7). Not all qualitative researchers would agree that judgment should be part of their inquiry. Evaluation is avoided by social anthropologists, yet it is essential to the role of the curriculum critic (D. Ross, 1988). Such evaluation "can be determined only in a qualitative context—a real, direct, specific, explicit, and problematic context" (Sherman & Webb, 1988, p. 8). Such evaluation was essential to this educational research, which focused on the process of learning biology through analogical reasoning, developmental changes in students’ analogical thought processes as they engaged in interactive class activities throughout the year, and effects on the quality of learning group interactions and teacher-student interactions.

**Qualitative Techniques**

**Triangulation**

"Data are both the evidence and the clues" (Bogden & Biklen, 1992, p. 106). They rescue the researcher from "unfounded speculation" (p. 106) and entice her to deepen analysis. Triangulation is a strategy that bases analysis on data collected using a variety of methods. Such a rich data set is needed to capture the complexity of a real situation (Borg & Gall, 1992). Using diverse data collection methods reduces bias and provides the researcher with an abundance of information (Hutchison, 1988). This researcher collected data: fieldnotes, student artifacts, taped group interactions,
student interviews, and student survey responses. With this rich data set, this researcher was positioned to use triangulation in her analysis. This documentation allowed this researcher frequent revisits to students' experiences.

**Participant - Observer and Fieldnotes**

A participant-observer combines the role of reflective detached observer and the role of an empathetically involved participant. Such researchers try "to learn from the subjects, but not necessarily be like the subjects. They may participate in their activities, but on a more limited basis" (Bogden & Biklen, 1992, p. 79). For this study, this researcher was also the teacher. This duality provided the opportunity to participate with students in their activities, but not as one of them.

Respect for and recognition of this duality also seemed to require shifts from third person to first person in the writing of this document. Use of first person when speaking of this researcher's experiences as teacher, particularly within activity narratives, makes clear this researcher's involvement in her students' world as their teacher. This connectedness and subjectivity must be recognized by words, in a study that places such high value on words. The following paragraph demonstrates the importance of occasional breaks from the traditional "detached" third person of scientific studies.

The students were aware of my research role, but firmly looked to me as their teacher. I honored the primacy of my teaching role, yet this had benefits for my role as observant inquirer. Immersion in my teaching experience facilitated observation in terms of quantity and quality. My situatedness facilitated the building of trust with my students. It did limit the time during school in which to record fieldnotes, so most were recorded at home. This was a disadvantage of my dual roles.
"These are fieldnotes: the written account of what the researcher hears, sees, experiences, and thinks in the course of collecting and reflecting on the data in a qualitative study" (Bogden & Biklen, 1992, p. 107). Fieldnotes should be rich in description and rich in thoughts. They should vividly depict the place, people, interactions, and events; and record observer feelings, reflections, and questions. This researcher recorded notes about students (e.g., physical appearance, personality, class behaviors, science fair projects), school (e.g., physical site, events, external influences, changes), analogical activities (e.g., student behaviors, interruptions, group locations), and reflections (e.g., baseline assessment, personal feelings, responses to tapes). These fieldnotes provided important reminders and insights throughout analysis, which extended well beyond data collection.

Merging the roles of researcher and teacher for this study made it all the more important to follow Roman and Apple’s (1990) advice to recognize personal subjectivities, the many personal factors that influence a researcher’s understanding of the relations that he or she studies. Explicit acknowledgement of these factors permits open inspection and recognition of bias, which leads to further self-questioning and ultimately better understanding. If a researcher must make judgments, then awareness of personal subjectivities is essential when making such judgments.

Content Analysis

The method of content analysis may be applied to all forms of communication including written, graphic, gestural, musical, and verbal (transcribed). Content analysis may involve quantification of simple variables in terms of frequency, but it may also involve quantification of more complex variables which places more responsibility on the researcher for interpretation, inferences, and coding data. Content analysis has
been used in educational research to obtain descriptive information. This method usually results in summary of data as frequency or descriptive statistics (Borg & Gall, 1989).

For this study, many student artifacts (e.g., written guidesheet responses, transcriptions of taped group interactions, projects) were collected for analysis. When appropriate, the method of content analysis was used to enhance description of these artifacts. In most cases, this researcher engaged in sophisticated advance analysis to reach the stage whereby quantification was possible and useful.

**Interviews**

Interviews can yield rich descriptive data of participants' interpretation of their own situation and experiences. In cases where the researcher is also a participant, many informal moments of conversation between researcher and participants provide insights. Nevertheless, it can be valuable to arrange formal interview sessions to address specific topics (Bogden & Biklen, 1992). This researcher met with selected students for two or three formal interviews to learn more about these students as persons and about their experiences with the analogical activities.

Interviews range from highly structured to fully open-ended. Structure insures that research concerns are addressed. Open-endedness insures that participants have an opportunity to talk freely about their concerns. Depending on the interview purpose, researchers may shape their interviews anywhere along the continuum from structured to open-ended (Bogden and Biklen, 1992). This researcher prepared a set of questions for initial and exit interviews. Initial interview questions elicited personal descriptions and early responses to participation in the analogical activities (see Appendix EE). Exit interview questions elicited student evaluations of their activity experiences (see
Appendix FF. Questions in an intermediate interview focused on student responses to particular analogical activities and varied with the interviewee. All interviews were conducted flexibly to give the students a role in shaping the interview and to allow this researcher to seek clarification or explore topics raised within the interview.

A record of the interview may be retained as notes or as a tape recording. While note-taking may be adequate for recording responses to factual questions, tape recording is advisable when an interview involves more complex issues. The tape recorder provides a permanent record of the entire interview, which allows the researcher to listen again and again to the actual words of the subject to gain additional insights (Borg & Gall, 1992). This researcher recorded and transcribed all student interviews.

Surveys

Surveys enable a researcher to collect information from many subjects of an investigation (Jaeger, 1988). For this study, these important persons were the student participants. Survey questions must be “clear, unambiguous, and appropriate to the survey researcher’s purpose” (p. 315). Jaeger deems it appropriate for some surveys to list a set of alternative answers and allow the respondent to choose, as long as the list includes the range of possible answers.

For this study, all student participants were given an option to complete a Student Perceptions Survey (see Appendix DD) for each analogical activity. These surveys provided insights into how students perceived their analogical or nonanalogical activities. For two sections of the survey, students selected from a set of alternative responses. Comparison of class perceptions was facilitated through calculation of percentage frequencies of selection. In another section, students used a rating scale to evaluate
their activity in 10 areas. Comparison of class perceptions was facilitated by calculation of class mean ratings. One section allowed students to make free response comments.

**Quantitative Techniques Within Qualitative Research**

The problem should determine the method (Shulman, 1988), and for this study, qualitative methods best addressed the problem. But this ignores the complexity of the issue, because there are many research methods that can provide worthwhile information to any problem (Eisner & Peshkin, 1990). Prior discussion of qualitative methods of content analysis and survey identified quantitative techniques within these methods. In addition a one-way analysis of variance of pre- and posttest scores provided statistical comparison of students who did or did not engage in the analogical activities.

Furthermore, researcher evaluations of students' expressed analogical development were roughly captured by calculation of SMILE scores. The rubric SMILE developed by Hackney and Wandersee stands for: (S) selection of analog, (M) mapping of analog and target, (I) inference from the analogy, (L) level of analogical development, and (E) evaluation of analogy. This evaluation instrument includes guidance standards for rating each step in analogical thinking (selection, mapping, inference, and evaluation). A rating from 0 to 5 is assigned for each step (S, M, I, and E), and a student's overall level (L) is calculated by averaging the scores for the four steps. This SMILE score indicates a student's expressed analogical development. (See Appendix GG for a copy of this SMILE rubric and guidance standards for ratings; see Appendixes HH & II for copies of two student's work on one pilot analogical activity with an explanation of their SMILE ratings.)
Chronology of Research Study

Weeks 1-6 of 1996-97: Establishment of Baseline

Building Relationships. The first six weeks of the school year did not include any analogical or nonanalogical activities. Since some students transfer during the early weeks of any school year, time was allotted to ensure that class rolls were set. During this period, teacher and students became familiar. This wait period avoided the novelty of a new school year affecting student performance and quality of teacher observations. This wait period gave students time to build relationships within the context of their biology class.

Biology achievement pretest. The 1986 NABT biology achievement pretest was taken by all honor biology students, with the exception of a group of students transferred after administration of this test on 9-10-96.

Researcher observations and fieldnotes. This researcher made observations and recorded fieldnotes. These early notes captured the situation as it existed in the Honor Biology I classes prior to students' participation in their group activities.

Weeks 7-36 of 1996-97: Student Participation in Analogical Activities or Nonanalogical Activities that Target Biology

Context of the activities. The analogical and substitute nonanalogical activities were included as part of the curriculum and were related to specific scientific topics. Students received credit for participation, but were not graded on the value of their responses or products. This eliminated some of the pressure to get the "right answer" and provided students with a safe environment in which to explore biology. Students received feedback to assist learning. This researcher carefully evaluated student responses for research and teaching purposes.
Students' written responses on guidesheets or worksheets. Students participating in the analogical activities followed guidesheet instructions and gave written responses. Students participating in the nonanalogical activities followed worksheet instructions and responded in writing. Within their groups, students conferred on responses to guidesheet or worksheet questions. This researcher retained students' written responses.

Tapes of student group interactions. Students made tape recordings of their verbal interactions during analogical or nonanalogical group activities. This researcher listened to all tapes, transcribed all fifth-hour tapes, transcribed selected interactions of sixth- and seventh-hour groups, and wrote a supplemental synopsis of each group's interactions in these two classes. The tape recordings made possible multiple revisitations to each group's experiences.

Group projects. Learning groups constructed some projects. Project artifacts were saved by the researcher for documentation and later analysis.

Student perceptions surveys. Some student participants completed an optional Student Perceptions Survey for analogical activities or nonanalogical activities. This survey included: (a) Section 1—selection of adjectives to describe activity; (b) Section 2—selection of the processes engaged in during activity; (c) Section 3—selection of a rating for 10 different categories; and (d) Section 4—additional comments (see Appendix DD for Student Perceptions Survey). This researcher emphasized to students the value of honest responses for research.

This researcher made quantitative transformations of survey results from fifth-hour and from combined sixth and seventh hours. These transformations involved: calculation of frequency of selection of particular adjectives in Section 1; calculation of
frequency of selection of particular processes in Section 2; calculation of mean ratings for each category in Section 3; and counts of tone of comments for Section 4.

**SMILE ratings.** This researcher used a rubric (SMILE) to guide her evaluation of some fifth-hour student's expressed level of analogical development during analogical activities. The SMILE instrument relies on researcher assessment of a student's performance. SMILE simply provides a tool for capturing very complex descriptive data in a general way via a SMILE score. (See Appendix GG for a copy of this SMILE rubric and guidance standards for ratings; see Appendixes HH and II for copies of two student's work on one pilot analogical activity and their SMILE ratings.)

**Researcher fieldnotes.** The major research question and subquestions guided this researcher as she recorded her observations and analytical ideas in fieldnotes.

**Weeks 7-36 of 1996-97: Student Performances in Other Biology Classroom Activities**

**Student essay responses on unit biology tests.** Throughout the year, students responded to one essay question on most unit biology tests. This researcher analyzed these open-ended questions for signs of student use of analogical thought. Transcripts of selected student answers to the free response item of unit biology tests were made.

**Researcher fieldnotes of student comments and behaviors.** This researcher recorded in fieldnotes some occasions when a student's spoken word (comment, response, question) seemed relevant to the research questions. Transcripts were made of these selected student comments.

**Interviews with selected students.** Using prepared questions, this researcher interviewed selected students in fifth hour. Interviewees described themselves, their learning styles, and their families. They talked about the first analogical activities and
about their groups. Note that even during these optional interviews the activities were not called "analogical." Some of these interviewees gave a second optional interview, which focused on specific analogical activities. These interviews were free flowing and varied with each student. Transcripts were made of all interviews.

**Weeks 34-36 of 1996-97: Final Data Collection**

**Exit interviews with selected students.** This researcher used prepared questions for optional exit interviews, but also allowed for free expression. The selected fifth-hour students explained their experiences with the analogical activities. They also participated in a mini-exploration of their recall of cellular concepts and ability to use a metaphor to explain these concepts.

**NABT biology achievement posttest.** On 5-26-97, Honors Biology I students took the 1986 NABT biology achievement test, which most had taken as a pretest. An individual student's pretest score was subtracted from her or his posttest score. Each student was assigned an identification number and variables recorded included grade point average, gender, race, engineering or honors classification, and year in high school. A one-way analysis of variance was done.

**Fall 1996 – Spring 1999: Researcher Analysis**

**Grounding of analysis.** Researcher analysis was grounded in the situation as experienced by students and researcher as teacher. Collection of much descriptive detailed data provided a base for analysis. Multiple viewpoints enriched analysis. This process began with the 1996 school term, but continued well beyond. Meaning evolved over this extensive period of reflection. This researcher analyzed relevant data to evaluate the effectiveness of the year-long sequence of analogical activities in
developing analogical thinking in biology, in improving biology learning, and in improving the quality of classroom interactions.

**Researcher content analysis.** Student artifacts available for content analysis included: student responses to guidesheets or worksheets; student products from activities; transcripts of relevant oral student responses to class questions and relevant student questions; transcripts of selected student answers to a free-response item on unit biology tests; audiotapes and transcripts of all fifth-hour group interactions, and selected excerpts from sixth- and seventh-hour tapes plus a synopsis of their interactions; student performances on NABT biology achievement pre- and posttests; audiotapes and transcripts of interviews of selected students; and student responses to Section 4 of the Student Perceptions Surveys. Researcher fieldnotes augmented this analysis, as did SMILE ratings for selected fifth-hour students.

**Student viewpoints.**

Hour 5 students' views of their analogical activities were captured in researcher fieldnotes, student comments, written guidesheet responses, audiotaped voices of students engaged in group interactions, student interviews, and Student Perceptions Survey responses. Fifth-hour voices were invaluable to analysis. Hour 6 and 7 students' views of their nonanalogical activities were captured in person, in their taped interactions, in their written words, and in their responses to the Student Perceptions Survey. This researcher listened attentively to the voices of these students, who did not participate in the analogical activities, for they offered continuous reality checking for this researcher's analysis. To facilitate comparison of student perceptions in different classes, quantitative transformations were made of the Student Perceptions Survey responses from Hour 5 and Hours 6 and 7.
RESULTS AND DISCUSSION

Activity 1

Activity 1: Analogical Versus Nonanalogical

Activity 1: Black and White Photo Shots

Scientific subject. During October, Bio I students faced biochemistry in lectures, note-taking, class discussion, film viewing, and lab identification of biochemicals. Biochemistry is the study of the structure and function of life's molecules. Organisms build larger molecules (polymers) from smaller molecules (monomers). For example, many molecules of glucose, a simple sugar, link together to form a polymer called starch. The tightly coiled chain structure of starch facilitates efficient energy storage in plant cells. Glucose and starch are both carbohydrates. Most biomolecules are categorized as carbohydrates, lipids, proteins, or nucleic acids.

Activity 1 descriptions. On October 15, Hours 6 and 7 students did "The Chemistry of Life" worksheet (Biology: The Dynamics of Life Study Guide, 1995, p. 28), which has true-false, categorization, and matching items. The 21 items covered some vocabulary, molecular formulas, and functions of biochemical molecules. Students audiotaped group interactions. They looked up biochemistry facts as needed. A class review of answers followed.

On October 15, Hour 5 students engaged in their analogical activity, "Is It Like It or Not?" (see Appendix K). This guidesheet directed students to analyze 36 simile statements about biochemistry (see Appendix L). Students accepted a simile based on whether or not they identified a similarity between the familiar thing and a structural or functional trait of molecules in the targeted biochemistry category (see Appendix M for hypothetical responses). For example, fifth-hour students accepted...
the simile “Lipid is like a coat” because both a coat and fat, a lipid, provide insulation. They looked up information as needed. Groups audiotaped their discussions.

How did sixth- and seventh-hours’ nonanalogical Activity 1 and fifth-hour’s analogical Activity 1 compare in quality? Class observations and general analysis of taped discussions formed the basis for this researcher’s panoramic views of these students engaged in the analogical or non-analogical Activity 1.

**Activity 1: Panoramic Photos Taken from Researcher Vantage Points**

**Nonanalogical path.** Hours 6 and 7 students recognized the format of their “Chemistry of Life” worksheet, so they quickly started their assignment. As teacher, I encouraged a few insecure students, redirected a few distracted students, and explained to a few confused students. When unsure, students checked in notes or text for answers.

These teens relished working together. With the exception of the dramatic Swans, most groups’ members worked on-task. Diligent students still laughed at silly comments, as when Nell called her group “academically challenged,” or Cole mused, “I am whiting out over white out.” Only very shy teens were uncomfortable with audiotaping.

Groups adopted styles that ranged from sequential turn-taking, to chaotic talking all-at-once, to cohesive consensus-building. Groups finished their worksheets in about 25 minutes, and a 25-minute class review revealed only a few errors for each group. Students appreciated the worksheet as a useful review of biochemical facts.

**Analogical path.** Though familiar with similes from English class, fifth-hour students were surprised that similes anchored their science activity. “Is It Like It or Not?” was strange. This oddness placed students in Vygotsky’s (1934/1996) “Zone
of Proximal Development," which challenges students to tolerate uncertainty as they try to construct meaning? In this zone, Hour 5 students did not even comprehend this new task until they actually did it. Research in text or notes helped, but students had to make their own sense of the similes in relation to biochemistry. Assurances that no one answer was expected encouraged some students to be risk-takers. Insecure students called for help. I offered praise, hints, critiques, comfort, and when needed, reprimands for unruly behavior or time-off-task.

By necessity and design, group members depended on their peers for help too. Groups adopted approaches that varied along continuums from structured to disorganized, communal to contentious, and analytical to intuitive. To some degree, group organization affected students' abilities to function effectively. Nevertheless, all Hour 5 students "talked science" (Lemke, 1990) as they tried to use similes to understand science. They experienced mixed emotions—confidence and uncertainty, frustration and elation. While no group found scientific meaning in all potentially productive similes, groups averaged success with two-thirds of the similes. All groups expressed some alternative conceptions. Students worked about two and one-half hours on Analogical Activity 1.

Activity 1: Panoramic Photos Taken from Student Vantage Points

Student evaluations. Some student expressed their views in optional evaluations. The evaluation form has four sections: (a) selection of adjectives that describe the activity, (b) identification of activity processes, (c) rating of activity in 10 categories, and (d) additional comments. The following number of students in each class completed Activity 1 evaluations: (a) 27 of 30 students in fifth hour, (b) 22 of 31 students in sixth hour, and (c) 26 of 30 students in seventh hour.
Selection of adjectives to describe activity. Section 1 of student evaluation forms instructed students to circle words that best described their activity experience. Table 1 lists the percentages of student evaluators who chose a listed adjective that was circled by at least 25% of evaluators in either the analogical or nonanalogical classes. This table is organized to promote comparison of students' general perceptions of the analogical activity and of the nonanalogical activity. Horizontal reading of this table will best exhibit points of comparison towards the top and points of contrast towards the bottom.

Table 1 indicates that most students found their Activity 1 either "comfortable" or "easy," "simple" or "clear," and many thought it was "fun." Most students in all classes felt capable of doing their activity. Sixth- and seventh-hour students tended to describe their nonanalogical activity as "okay," "well-structured," and "routine," which suggests a safe traditional learning exercise. Fifth-hour students stressed the "interesting," "creative," and "unusual" qualities of their activity, which suggests that analogical Activity 1 was a unique and intriguing learning encounter.

Identification of activity processes. Section 2 of student evaluation forms asked students to identify, from a list, all processes that were part of their activity. Table 2 lists specific processes identified by students as part of their Activity 1. Only processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed. Percentages of fifth-hour evaluator responses are listed from highest to lowest. Horizontal reading of percentages is recommended for comparison of evaluator responses for analogical Activity 1 and nonanalogical Activity 1.

Cross comparison of percentages shows a majority of reporting students identified "thinking," "communicating," "discussing," "learning," and "remembering" as part of
Table 1

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 1

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfortable</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td>Simple</td>
<td>44</td>
<td>46</td>
</tr>
<tr>
<td>Easy</td>
<td>30</td>
<td>33</td>
</tr>
<tr>
<td>Fun</td>
<td>37</td>
<td>46</td>
</tr>
<tr>
<td>Clear</td>
<td>33</td>
<td>44</td>
</tr>
<tr>
<td>Routine</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>Interesting</td>
<td>33</td>
<td>18</td>
</tr>
<tr>
<td>Unusual</td>
<td>41</td>
<td>15</td>
</tr>
<tr>
<td>Well-structured</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>Creative</td>
<td>70</td>
<td>25</td>
</tr>
<tr>
<td>Okay</td>
<td>8</td>
<td>58</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

a Only adjectives circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

b n = 27 evaluators out of 30 fifth-hour students.

c n = 48 evaluators out of 31 sixth-hour and 30 seventh-hour students.
their Activity 1. These processes are important for cooperative group learning and were part of both analogical Activity 1 and nonanalogical Activity 1. Cross comparison also points to contrasts. Hour 6 and 7 students more frequently picked "researching," which reflects the fact-finding nature of their nonanalogical work. Even though Hour 5 students also looked up facts, they placed emphasis on the thinking processes of "categorizing," "analogizing," "choosing," and "hypothesizing" required by their analogical activity.

**Rating of Activity 1 in 10 categories.** Section 3 of student evaluation forms elicited student activity ratings in 10 categories. The form gives a rating scale of: (a) 1 = bad, (b) 2 = poor, (c) 3 = okay, (d) 4 = good, (e) 5 = excellent. Calculated class means simply suggest trends. Cautious evaluation of these ratings is advised because this research was not a controlled experiment. Averages do not capture the highly particular experience of each student. Some students' opinions are missing. Furthermore, people differ in their interpretation of any rating scale.

Class rating means are listed in Table 3. Comparison of ratings show similarities and differences in students' responses to analogical Activity 1 and nonanalogical Activity 1. Students were pleased with their cooperative groups, teacher assistance, and learning. A higher motivation ratings from students engaged in the analogical Activity 1 suggests the simile activity was more engaging than the traditional worksheet. Less fifth-hour student satisfaction with time and directions makes sense in light of their encounter with a new learning activity. Desire for additional directions and more time to complete an unfamiliar activity should be expected. A lower challenge rating for analogical Activity 1 is puzzling. Perhaps, despite the challenge of higher level thinking, the simile activity had a user-friendly feel in its reliance on familiar everyday
Table 2

Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 1

<table>
<thead>
<tr>
<th>Process^a</th>
<th>Analogical^b</th>
<th>Nonanologal^c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communicating</td>
<td>100</td>
<td>85</td>
</tr>
<tr>
<td>Discussing</td>
<td>96</td>
<td>96</td>
</tr>
<tr>
<td>Thinking</td>
<td>96</td>
<td>85</td>
</tr>
<tr>
<td>Choosing</td>
<td>70</td>
<td>21</td>
</tr>
<tr>
<td>Learning</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>Remembering</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Hypothesizing</td>
<td>48</td>
<td>15</td>
</tr>
<tr>
<td>Categorizing</td>
<td>44</td>
<td>23</td>
</tr>
<tr>
<td>Analogizing</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>Researching</td>
<td>4</td>
<td>50</td>
</tr>
</tbody>
</table>

Note. Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

^a Only processes circled by at least 25 % of either Hour 5 or Hour 6 and 7 evaluators are listed.

^b n = 27 evaluators out of 30 fifth-hour students.

^c n = 48 evaluators out of 31 sixth-hour and 30 seventh-hour students.
Table 3

Comparison of Mean Category Ratings by Students for Their Activity 1

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical\textsuperscript{a}</th>
<th>Nonanalogical\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Time involved</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Age level</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Motivation</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

\textsuperscript{a}n = 27 evaluators out of 30 fifth-hour students.

\textsuperscript{b}n = 48 evaluators out of 31 sixth-hour and 30 seventh-hour students.

Note. The rating scale is 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means have been rounded to the half-decimal.
objects to learn biochemistry. Students rating the challenge of the nonanalogical worksheet may have focused more on the difficulty of biochemistry.

**Additional comments.** Section 4 of student evaluation provided space for open-ended written comments from students. For Activity 1, 13 fifth-hour students and 22 sixth- or seventh-hour students wrote comments. Student remarks focused on cooperative groups, audiotaping, learning, and overall value.

Students made pointed comments about cooperative groups. One Hour 5 student declared, "It gave me the ability to talk and communicate with my group." Omar felt that he "gained insight into the way other people in our groups [think]." Lisa in sixth hour said groups made "it is a whole lot easier." Millie learned new ways "for remembering . . . answers."

A few Hour 5 students had concerns. Helen worried that her group lost focus. Eve complained about "too many [members] but not enough input." Seventh-hour student Jonas echoed these complaints, "Some of us knew the answers, and others didn't. . . . we shouldn't have been as frivolous." Colette in Hour 6 wanted group selection changed. While most students liked cooperative groups, a few worried about equitable peer contribution, time-off-task, or group composition.

Students wrote about audiotaping. Kevin in fifth hour felt, "The tape recorder made some people not want to talk (me)." Christabel in sixth hour said, "We didn't know what to say in front of the tape recorder. . . . I found it hard to concentrate on finding the answers out loud." Three Hour 7 students commented on taping. Jonas believed, "Some of us cut up only because of the fact that we were on cassette." Zoe liked the creativity and Gus liked the novelty. Audiotaping held some significance for these students.
Fifth-hour students noticed the hard subject matter and good educational value of their analogical activity. Eve claimed, "It was hard for me because my knowledge of science is small. I learned a lot that day." Rika said, "I really enjoyed this activity, but I didn't know much about the subjects." Kevin hedged with, "boring, but I learned from doing it." Max declared it "made us think about things we had learned before."

Students praised their analogical Activity 1 as: "very creative assignment" (Helen), "kind of cool" (Jim), "very interesting and exciting" (Omar), "good" (Jack), and "very fun" (Barry). Bill said, "It breaks up the boring routine of a class day." Omar agreed, "New is good." Enthusiasm resounded in these students' words.

Student opinions from Hour 6 and 7 varied. Some linked learning to their nonanalogical Activity 1: "great review for the test!" (Millie) "helped me understand the material easier" (Kirsten); "had to research a little" (Joel), and "made me think" (Kay). Some students praised their worksheet activity as: "excellent" (Sheena), "very very challenge" (Estelle), and "fun" (Aisha). But some thought their activity was: "elementary" (Anne); "too easy" (Greg); "too systematic" (Jonas). Some wanted activities to be "more fun-filled and discussed more in class" (Juliette); "more fun, more creative, or less 'from the book'" (Jonas); and "longer" (Anne). Zoe suggested a problem solving activity "instead of getting them directly out of book." While some students liked their worksheet, some sensed something missing in their nonanalogical Activity 1.

**Collage of student viewpoints.** Students liked cooperative group learning, although a few groups lacked equitable focused member contribution. Students enjoyed audiotaping, but a few shy students felt insecure. Most students saw their Activity 1 as a moderately difficult task that helped them learn.
Hour 6 and 7 students stressed improvement in their knowledge and memory of biochemical facts. Their enthusiasm toward group work and audiotaping was not matched with the same enthusiasm for their routine worksheet assignment. Hour 5 students stressed improvement in understanding biochemistry through active debate and higher level thinking required by their novel simile activity. They were motivated by the exciting, interesting, and unique nature of their simile activity.

**Reflections on the Panoramic Views of Activity 1**

This researcher's panoramic views and the multiple viewpoints of Activity 1 student participants correlate well. Most students preferred working with peers on a challenging biochemistry assignment. Students liked taping their discussions.

Hour 6 and 7 students used their traditional "Chemistry of Life" worksheet to effectively review biochemistry facts in an efficient time period. Group collaboration and audiotaping group discourse made this review easier and more enjoyable. Students felt challenged by the scientific subject, yet very capable of doing the worksheet. They spoke confidently about what they knew or looked up. Their motivation was okay.

Hour 5 students used their "Is It Like It or Not" simile statements to catalyze discussions of their understanding of biochemistry. The intriguing challenge to find scientific meaning in the simile comparisons of ordinary things to biochemical molecules motivated these students to actively engage in discourse and to tolerate some uncertainty and confusion during their lengthy interactions. The simile activity seemed qualitatively better than the nonanalogical worksheet Activity 1 in terms of student motivation, student involvement in their own knowledge construction, and student reliance on higher level thinking.
But this researcher's argument is not to discard "The Chemistry of Life" worksheet, which helped students acquire factual knowledge. Rather it is an argument to expand the science curriculum to include the simile activity. But is this safe? This simile activity based on the "Is it Like it or Not?" guidesheet is an unfamiliar tool that one might even describe as odd. "To see one thing as if it were another creates a tension between two perspectives: the thing as itself and the thing as something else (Holyoak and Thagard, 1995, p. 9). This oddity is inherent in simile. "To resolve this tension by finding an integrated interpretation is a satisfying achievement" (p. 9). But the interpretation's shape changes with the person. Wouldn't it be wiser to keep this analogical tool in the competent hands of the teacher who shows her students only one shape? This would be less confusing than trusting students to share their interpretations and judgments. But if we move in that direction, the guidesheet begins to metamorphose back into the "tried and true" worksheet.

Given the complexity of this issue, a more thorough inquiry is necessary. It is imperative to move this inquiry to the "more real than the velveteen rabbit" teens--the 30 young persons in fifth-hour who formed six learning groups called: Pelicans, Harriers, Ferrets, Red Foxes, Snakes, and Lions. This inquiry will also involve special focus on seven students: Ed and Keisha of the Pelicans, Jonah and David of the Harriers, Eve of the Ferrets, and Kevin and Mai of the Foxes. Since neither the Snakes nor the Lions included students selected for special focus, and this exploration needs boundaries, these two groups will not be discussed in detail. These group names are a product of analogical Activity 2 and will be explained in discussion of that activity. Excerpts taken from taped dialogue are referenced by the activity number, the first letter of the group's name and the page number on the transcript.
Activity 1: Analogical Groups

Activity 1: The Pelicans

Group movie: Pelicans take flight. Five Afro-American students formed the cooperative group called the Pelicans. These fledglings included Michelle, Keisha, Ed, Randy, and Boris. Tawny skinned petite Michelle had a quiet demeanor, which belied her active mind. Keisha had a tall slender frame, golden brown skin, and an expressive face that matched her caring, outgoing personality. Ed had a lanky slender build, deep dark brown complexion, and an irresistible smile which signaled his assured and spontaneous persona. Mocha skinned Randy sported an Afro-braid hairstyle, which made him stand out despite his very short height. Randy was smart, motivated, and steady. Boris had a muscular stocky build and chocolate brown skin. He was insecure and often inattentive, yet receptive to help and encouraged by small victories.

The Pelicans were initially reluctant to fly in search of analogical meaning. Michelle was absent. The others were confused by the simile, "Lipid is like bubble packaging." Following Glynn's (1991) advice, I guided the Pelicans to explain the analog and target, and finally to identify links between the two. First, Ed described bubble packaging.

Mrs. H.: Let me ask you this? Fat is stored in what?
Keisha: \textit{Little like}. \\
Ed: Cells. \\
Keisha: Yeah. \\
Mrs. H.: That was good. Come on close enough so we can hear your thoughts. \\
Keisha: No, Mrs. H., that's embarrassing. \\
Randy: This is our grade girl. Serious girl, you better talk. Ha, ha, ha. Fats are, come on, like they store it in cells. \\
Keisha: Store, yeah, it's just like little packages. \\
Mrs. H.: Um, what do you think that does for us when we sit on it? \\
Boris: It builds up. \\
Keisha: It's like a cushion, yeah. (1: P, 1)
By the end of this exchange, the Pelicans had related the lipid fat to bubble packaging because they both cushion, and because fat is stored in cells like air is stored in the little bubbles. This team now had a model for analyzing other similes.

Ed took off with "Lipid is like a pantry. A pantry stores, and lipids are for storing energy present" (1: P, 1). Often a question from one member would lead to a solution. For example, when Randy explained that a "pop-it necklace is like beads that pop out," Keisha wondered if "protein breaks down into anything?" This led to Ed's explanation that "a pop-it necklace connects together just like chains of proteins connect together, uh amino acids" (1: P, 6). Amino acids do bond together to form a protein.

Disparity in members' knowledge did not inhibit communication, but differences in each student's knowledge base did affect comment quality. Keisha tried to look things up to augment her weak knowledge of biochemistry. Boris expressed rudimentary ideas. Ed and Randy contributed more often and with more scientifically grounded explanations.

This researcher judged groups successful in their responses if they supported their decisions adequately. Their responses did not need to match any expected response. Groups were unsuccessful if they failed to support their decision at all or failed to support their decision well. In terms of this broad definition of success, the Pelicans succeeded in analyzing 28 of 36 similes.

For example, these teens were successful when they rejected "Lipid is like a $2," because two dollar bills are rare and lipid fat is abundant. This surface difference was more salient to these students than core similarities. But, it was important to respect these budding analogizers' surface mappings as an important step in development of analogical thought (Medin and Ortony, 1989). Alternative interpretations that stress
deeper meanings can always be shared with students later. For example, the same simile may be accepted because fat provides energy required to do things, just like money is required to do things; and one gram of fat provides twice as much energy as a gram of carbohydrate.

The Pelicans sometimes failed by stopping their analogical analysis too soon, a pitfall identified by Harrison & Treagust (1993). They had trouble linking a backpack's function of carrying stuff with the function of fat. Keisha asked "What does fat carry around?", and Boris twisted it back, "You carry fat around" (1: P, 2). They finally responded, "Yes, lipid is like a backpack" in that "both are used to carry things." But what do fat molecules carry around? Missing is the explicit answer energy.

While a backpack and $2 did not remind this group of the explicit energy storage function of lipids, a safety deposit box did. The Pelicans argued that stored valuables can be taken out of a safety deposit box, and stored fat can be taken out of a body to provide energy. They found it easier to think in terms of large quantities of fat, energy, and money, than to think on the smaller scale involved in mapping a two dollar bill to energy stored in fat molecules. This example highlights the importance of saliency in analysis of analogies (Vosniadou, 1989; Ortony, 1983) and the importance of multiple analogies in developing understanding of a science concept (Spiro, et al., 1989).

Terminology added complexity, as warned by Wandersee (1985). For example, Randy used an inexact term "elements," when he meant amino acids. Ed co-opted Randy's 'elements' and replaced it with "amino acids" of a protein that are like the "different type of boxcars in a train" (1: P, 6-7). Even some names of familiar analogs
(e.g., pop-it necklace) initially puzzled the Pelicans. Students must know the analog or it will become an obstacle instead of a help (Zeitoun, 1983).

This researcher's SMILE assessments of expressed analogical ability capture a disparity in analogical abilities of members. Pelican SMILE scores were: 2.50 for Ed, 2.25 for Randy, 1.75 for Keisha, and 1.50 for Boris. Recall that a SMILE score is a rough subjective measure of expressed analogical ability. This score is compiled by averaging scores for four processes used in analogical thought: (a) selection, (b) mapping, (c) inference, and (d) evaluation. Table 4 lists subscores and SMILE scores for the Pelicans.

Table 4

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Randy</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>Keisha</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Boris</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.50</td>
<td>2</td>
</tr>
</tbody>
</table>

Each member worked individually, then all came together for discussion. Ed led democratically so that everyone shared their ideas as to how "something scientifical was similar to something in everyday life." (Ed's interview, January 27, 1997). These teens laughed often. They laughed at Keisha's mispronounced "corrugated" packaging, but laughed again when they all said, "blank packaging." They laughed when Ed declared, "A big old behind, they gonna have more cushion sitting for three hours than a little skinny guy with malnutrition, you know" (1: P, 2).
From this group focus, this researcher now switches to a close-up camera lens to capture Ed and Keisha in greater detail. Following individual students is an effective way to gather evidence of students' analogical development through year-long participation in these research-based analogical activities.

**Close-up focus on Ed.** Ed was a bright Afro-American teen whose mind worked so fast that it seemed to be leaping everywhere at once. His broad knowledge base coincided with his multiplicity of interests. Ed attributed his knowledge to hands-on experimenting, study, reading, listening, and "reviewing it in my mind." He believed, "The key is not memorization," but rather "thinking hard," and also perseverance. "If I fail one time, I keep going" (Interview, January 27, 1997).

Ed eagerly shared his ideas about 25 similes. He was first in class to volunteer analysis of the sample simile "Lipid is like coal." Ed gave an insightful analysis of the simile "Protein is a varied bead necklace that is twisted around itself and then put into a uniquely shaped box."

Protein, you know how there are different kinds of beads on a bead necklace, well protein is like different kinds of amino acids on the string of protein, and you can twist it up and put it in the cell like a package. (1: P, 6)

Ed's analytical skills and confidence made his voice persuasive. His was the dominant voice in eight well-analyzed similes.

Ed's imagination let him see similarities between most of the analogs and targeted concepts. In analyzing "Carbohydrate is like a wall," he pondered how "sugars might build up a wall." (1: P, 4). He almost made a connection to the cellulose walls of plants that are composed of sugar chains. Ed's free thinking yielded a few bewildering explanations. For "Lipid is like a piece of a puzzle," he said "like a piece of a puzzle is out of shape and distorted, oil is out of shape on the ground" (1: P, 3). Ed needed
critical voices when his openness to all possibilities led him to poor mappings, a pitfall
of analogizing (Sensenbaugh, 1989). His friends usually did not challenge his ideas.

Ed's SMILE score of 2.50 for the simile activity suggested a fairly good analogical
ability, yet he still gained from teacher and peer input. Ed rated a 1 in selection
because the similes were provided by the teacher and received by Ed. He earned a 3 in
mapping for his many contributions to his groups' similarity mappings with a little
teacher guidance. Ed's ability to expand on ideas earned him a 3 for inference. Ed
rated 2 for evaluation because, while many of his judgements were good, he erred in
accepting some frivolous or erroneous mappings.

During Ed's January 27, 1997 interview, he described Activity 1 as "cool," "fun,"
"not as hard as" doing it alone. He felt Activity 1 helped him learn because "once you
find the relation, it was more easy to understand."

Close-up focus on Keisha. Keisha was a dynamic, inquisitive Afro-American girl
with a sweet toughness that allowed her to take care of herself while caring for others.
She spoke with delightful spontaneity. Keisha described herself as a "very nice
person," "pretty smart in biology," "well rounded," "very people-person," "scientific,"
"not artistic," but "can be creative" (Interview, March 3, 1997).

Keisha's initial concern about working alone with the boys had some foundation.
When Keisha asked, "What are dumbbells?", Boris said, "You're embarrassing yourself."
Keisha responded in a good-natured way, "Shut up you thief" (1: P, 2). When Boris
chided, "She looked up the word and still don't know it," Keisha persevered and said,
"It [protein] provides immunity" (1: P, 6). Keisha did not allow herself to be bullied.

Keisha had a limited understanding of biochemistry. She helped analyze six lipid
similes, but only two carbohydrate and four protein similes. She learned during the
Once Keisha understood that a pop-it necklace breaks into beads, she inferred that if a protein is like a pop-it necklace, it should break into parts too. A protein may be broken into amino acids.

To learn, Keisha asked questions and insisted that "We have to explain." When Boris argued, "Protein is like a machine" because "it [machine] works; proteins work." Keisha flared back, "That's not good enough. We need more detail. A machine is a force" (1: P, 7), but she didn't know where to go from there. Keisha listened intently to her friends. She began to improve her vague notion of carbohydrate when Randy exclaimed, "It's an energy" (1: P, 4). She learned that carbohydrates store and release energy.

Keisha's SMILE score of 1.75 suggests she was fairly dependent in her analogizing during Activity 1. She received a 1 for selection because she worked with the listed similes. Keisha earned 2 in mapping and a 2 in inference because, while she helped map a third of the similes and showed ability to infer, she was mostly busy learning basic information. Keisha earned a 2 for evaluation because she asked probing questions, but often depended on others for judgments.

Keisha liked the analogical approach to learning "because we compared it to things we already knew about, so that's what helps you understand." Keisha also liked the group approach because, "It's better to get different peoples' opinions. It was fun to think about what other people think about what you think about. . . . It's like a debate" (Interview, March 3, 1997). Keisha evaluated Activity 1 as "comfortable," "clear," "interesting," "fun," and "creative." She rated motivation, enjoyment, and knowledge gain as "good" and challenge as "okay."
Movie review: Pelicans take flight. The Pelicans took their first flight in search of analogical meanings to improve their scientific understanding. The Pelicans faced problems associated with analogical work: surface mappings, difficulty with higher levels of abstraction, incomplete analysis, and inexplicit mappings (Harrison & Treagust, 1993; Holyoak & Thagard, 1995). But their early awkwardness did not detract from the obvious delight these students took in their flight towards independent learning. Pelican dialogue moved smoothly between scientific concepts and everyday things. Talking about science in this way made each teen feel capable.

Ed led his group gently. He showed a strong ability to make analogical connections, but needed help with critical review of his mappings. Keisha displayed her potential for analogical thinking, but her poor domain knowledge hampered her efforts. She sought help from her friends through her questions and demands for clearly stated explanations. Keisha and Ed liked learning science in a metaphorical sky with their Pelicans.

Activity 1: The Harriers

Group movie: Harriers construct their nest. The Harriers were Euro-Americans Jonah, Barry, and Bill, plus Afro-American David, and Asian-born Ton. In terms of personalities, they were "birds not of a feather flocking together." David was easy-going, tolerant, and flexible. He had a solid build, mahogany skin, and a notable Afro-hairstyle. Jonah was tall and thin, yet muscular. The countenance of his face reflected his serious nature. Ton shared Jonah's earnest temperament. In height they differed, for Ton was short, and had straight, ebony hair and golden beige skin. Dark brown hair fell wildly onto Barry's pale face as if to signal impish impulses. Barry had a
creative mind that resisted boundaries. Bill's neatly combed short brown hair suggested his moderate goal-oriented character.

The Harriers needed to build a group nest that would support and satisfy all five as they searched for analogical meaning. Their initial attempts led to confusion, arguments, and troubles. Bill and Barry drifted to sidetalk. Barry teased Ton for stuttering. David was too insecure to speak. Jonah's slow writing kept him out of pace with the others. The Harriers vacillated between acts of competency and bouts of silliness.

As their teacher, I checked on their progress. They claimed Jonah was having trouble. I teamed up with frustrated Jonah to model the analysis process for the group:

Mrs. H.: Do you think that lipid is like a seat cushion? Is fat in any way like a seat cushion? Do you sit on it?
Jonah: No.
Mrs. H.: Where's fat?
Jonah: Oh, okay, ha, ha, ha, ha. Yes, yes.
Mrs. H.: So what would you say?
Jonah: Yes.
Mrs. H.: It is like a seat cushion because?
Jonah: You sit on it. (1: P, 1)

While Jonah's statements left implicit a mapping of fat to its cushioning function, this partial success gave autistic Jonah the courage to speak directly and distinctly into the recorder. Freed of the chore of writing, Jonah became constructive. David also gained confidence when he experienced his own success with, "Lipid is like a coat, keeps you nice and warm" (1: H, 8). Guidance had helped.

While the others thought only of carbohydrates as energy, Jonah remembered a structural carbohydrate, cellulose, and connected it to protective armor. He said, "Carbohydrates in plants is like armor because they form the cell wall of the plant"
(1: H, 14-15). For analysis of "Protein is like a sentence in a special language," Jonah explicitly matched words to amino acids, sentence to proteins, and language to "larger things." (1: H, 20). A combination of amino acids forms a protein, and Jonah's "larger things" probably involved some sense of protein's roles in building body parts. Jonah recognized the potential for such systematic mapping of analogies (Gentner, 1983).

Ton impressed his friends with his explanation of why he accepted "Carbohydrate is like a money machine.":

Ton: Because put in one dollar bill, how much come out?
Boys: Four quarters.
Ton: Take carbohydrate out and use for the energy when doing playing sports, you need carbohydrates. (1: H, 15)

When Ton stated, "Lipid is biological," David added "and crisco, like in a casserole" (1: H, 11), which proved he knew oil was a lipid. David felt safest talking about lipids. He said, "Lipid is like bubble packaging because it insulates and protects and you can pop it. I don't know if you can pop it" (1: H 2). David correctly connected lipid fat with insulation and protection. Group feedback saved David from transferring a noncorresponding trait of "popping" from analog to target, a danger in analogizing (Harrison & Treagust, 1993; Holyoak & Thagard, 1995). To reestablish his credibility, he added that lipid fat serves as insulation for whales.

Using a "guided teacher strategy," one approach to teaching with analogies (Zeitoun, 1983), I helped these students decipher "Protein is like a freight train of different type boxcars." The boys talked of atoms, molecules, monomers, building blocks, 20 kinds of amino acids, and a protein chain. With coaxing, Bill finally put together this statement: "I agree because amino acids are like twenty different kinds, and that would be just like the boxcars. . . . [I'm] thinking they have to be like in a chain" (1: H, 19). Later Jonah and Bill easily rejected, "Protein is like a train of

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identical boxcars" because they recalled the 20 different kinds of amino acids which could not be called identical boxcars (1: H, 20).

Harrier debate involved some impressive analogical thinking. The five Harriers reached better interpretations as a group than any one could do alone. They were successful with 30 of 36 similes. They succeeded with 9 of 15 that were difficult for them. The Harriers faltered when they left some mappings implicit, because clear explicit statements permit critical evaluation of the simile analysis and avoids misunderstandings (Holyoak & Thagard, 1995).

Activity 1 promoted Harrier use of figurative expressions in general. Barry praised, "Ton is going to rule the world!" (1: H, 15). Barry invented a simile for Ton's fortitude in recording all their responses, "Ton is like the backup disk to the hard drive." David added, "Ton come to my house and boot up my computer" (1: H, 11-12).

SMILE scores listed in Table 5 roughly indicate the level of analogical work done by each Harrier during Activity 1. Harriers received the following SMILE scores: 2.50 for Ton and Jonah, 2.00 for Bill, and 1.75 for Barry and David.

Table 5
Researcher SMILE Scores for Harriers in Activity 1

<table>
<thead>
<tr>
<th>Harriers</th>
<th>SMILE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selection</td>
</tr>
<tr>
<td>Ton</td>
<td>1</td>
</tr>
<tr>
<td>Bill</td>
<td>1</td>
</tr>
<tr>
<td>Barry</td>
<td>1</td>
</tr>
<tr>
<td>Jonah</td>
<td>1</td>
</tr>
<tr>
<td>David</td>
<td>1</td>
</tr>
</tbody>
</table>
Ton and Jonah showed analogical abilities and some knowledge of biochemistry. There is a strong interplay between personal familiarity with the analog and the target which affects a persons' ability to benefit from a particular analogy (Ortony, 1983; Vosniadou, 1989). Often Ton's or Jonah's explanations helped the others learn from an analogy which otherwise would have remained mute for them.

The Harriers chose an unwieldy strategy of considering a simile in each category in rotation. This confusing approach inhibited synchrony of effort. Jonah and David needed a slower pace and a less chaotic strategy. The Harriers never abandoned their simile category rotation, but Ton and Bill helped members maintain focus on one simile at a time.

Humor pervaded Harrier talk. When the group finally reached a decision on their first simile, Bill joked, "We're on a roll." Jonah's pronunciation of "metabolism" made everyone laugh. David made soothing comments like "Slow and steady wins the race" (1: H, 7). Humor reduced the tension of their concentrated effort.

Harrier discourse was frenetic and bountiful as members argued whether to accept or reject a simile. Ton and Bill pulled errant members, especially Barry, back into their dialogue. Frustration passed from member to member. Jonah was upset that they would not replay the tape when he wanted. It put a great strain on Jonah, the structurephile, to tolerate his peers' loose, free-flowing interactions. Only David stayed calm throughout.

Close-up focus on Jonah. Euro-American Jonah was a gifted artist, an engineering magnet student, and a high-performing autistic person. Jonah felt his autism made it "a struggle to get through all this school work and stuff." Jonah found class lessons hard because he heard disconnected pieces of a lesson and writing was

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arduous. Jonah focused on one thing at a time. "My mind has this sort of one track memory. ... when I am told to do something I do it. I don't think about it or any other things until I've done it." He learned best from reading, personal experiences, and explanations directed to him alone (Interview, January 27, 1997).

In spite of Jonah's apprehension about interacting with group members, he gained from this experience. Jonah read to get ideas for his group. Peers pushed him to clarify his statements. Jonah was grateful to Ton for teaching him that amino acids are the building blocks of protein. Jonah had thought it was the opposite relationship. Jonah persuaded his friends that proteins are building blocks too, in that, "They build structure and carry out cell metabolism" (1: H, 16). Jonah gradually became an active, productive participant.

Jonah's achievement with the Harriers was surprising, given his introversion and distrust of his fellow members because he didn't "share their view of the world."

Another surprise was Jonah's favorable response to audiotaping his voice. He spoke slowly and distinctly for recording purposes. A third surprise was Jonah's leadership role during Activity 1. Jonah viewed himself as a follower rather than a leader, except when he had "information available to lead people on through this particular topic" (Interview, January 27, 1997). During Activity 1, Jonah moved from his early confusion and insecurity to a later clarity and assertiveness, which his friends respected.

Jonah's personal view departed from this researcher's view. He evaluated knowledge gain as "bad" and enjoyment as "poor." He rated motivation as "okay" and challenge as "good." He described Activity 1 as "hard," "boring," "confusing," "dull," and "restrictive." Jonah thought the "hardest part was figuring out if the answers
were true." Jonah was stressed by the inherent uncertainty of Activity 1 and the
strains of group work.

Jonah showed a good ability to use analogies to learn, which is reflected in his
SMILE score of 2.50. For selection, he rated 1 because he used teacher-provided
similes. For mapping he scored a 3 for the quantity and quality of his mappings. He
helped analyze 19 similes (1 lipid, 6 carbohydrate, and 12 protein) and deserved major
credit for 8 of these. Jonah rated a 3 for inference because he made a long line of
inferences in his complex analyses. Jonah's 3 in evaluation reflected his ability to judge
the simile with some help from his peers.

Close-up focus on David. David, who was Afro-American, described himself as
"shy" but "outgoing around friends." In class he was quiet, yet enjoyed his friends
drawing caricatures of him on the chalkboard. He was "fun-loving," "adventurous," and
"intelligent," but not "scientific" or "artistic." David learned best through "seeing stuff
over and over, seeing and doing," but reading was "not something I do a lot of." He
preferred individualized help or group work because they reduced stress. But his group
complicated things by "wander[ing] off on a thousand different subjects on one
taping." David felt comfortable as a follower (Interview, March 3, 1997).

David spoke about six lipid similes. Lipid as fat was salient to David because of his
personal experiences of such things as crisco, skinny men, and blubber. The analogs
were familiar things. He saw similarities because "I just thought of things that were
right off the top of my head." This sounds very similar to Rip's (1989) "raw perceptual
resemblance" (p. 51). David contributed little to carbohydrate discussion and served
as silent recorder of protein simile analyses. These similes required more complex
thought than was possible with David's spontaneous approach. David's weak
knowledge of biochemistry was another constraint that inhibited his analytical work. He did not read to help himself, but he listened intently to his friends' explanations. David described Activity 1 as "hard" but also "a lot of fun" (Interview, March 3, 1997).

David received a SMILE score of 1.75, which suggests that he was dependent on teacher and class instruction to help him comprehend the similes. His selection score was 1 as he used the teacher's similes. In mapping, David earned a 2 based on his lipid contributions. Because David relied on others for most inferences, he was assigned 2 for inference. He was dependent on others for judging the similes, and therefore, received a 2 for evaluation.

**Movie review: Harriers construct their nest.** Each young man brought a personal nest-building plan and chosen materials for the task. They all set to work assembling the nest; but the diversity of plans and some incompatibility of materials led to conflicts and ultimately difficult compromises. These students relied on their talents to pull them out of a dysfunctional state. Ultimately the creative Harriers assembled a startling nest in which analogical work was done. The distinct individuality of members helped make Harrier interactions interesting, energetic, contentious, intense, creative, and analytical. Lemke's vision (1990) of students using their own experiences to talk about science happened in the Harriers' nest with the aid of a metaphorical tool, the simile.

Jonah and David both gained from their experience in the Harrier nest where analogical thought was encouraged. David, at ease with himself and others, improved his knowledge of biochemistry, while providing a calming influence for the Harriers. Jonah, ill at ease with himself and others, improved his social skills while sharing his analytical voice.
Activity 1: The Ferrets

Group movie: Ferrets search through tunnels. Euro-Americans Eve, Paula, Mark, Jim, and Max composed the Ferrets. Paula's pale pallor and small thin body coincided with her lack of energy, frequent minor illnesses, and limited scholastic motivation. Vivacious Eve was motivated, but insecure in science class. Jim, Mark, and Max shared average height and build, but Jim was a bit taller and Mark was chunkier. Academically accomplished, Jim was quietly confident. Bright insecure Mark was a perpetual inquisitor about everything and anything. Capable Max was an erratic participant in scholastic activities and often distracted by social concerns.

The Ferrets initial efforts were hindered by desire to speed through the assignment, confusion of biochemical terms, scattered conversations, and haphazard switching of simile categories for discussion. They fended off most offers for teacher assistance. This team relied on Jim for science explanations. Jim reluctantly assumed leadership. The Ferrets reduced side-talk and restructured to focus on one set of similes at a time, which meant they repeated simile analyses already done. They rushed too fast to properly evaluate all their responses.

Jim could be too confident. He rejected, "Lipid is like a pantry" because it made no sense to him. He ignored Eve's literal connection that fatty foods are stored in a pantry. Eve's words might have helped him think of food storage function of a pantry as like an energy storage function of lipid fat. Eve held to her belief that somehow lipid was connectable to pantry. She later came up with another literal connection: "Pantry has fat and food and healthy foods in it and is lipids healthy for you?" (1: H, 9) Eve needed help to move beyond this literal thinking.
Yet the similes often resonated with Eve who liked relating science to her everyday world. Consider this discussion of, "Lipid is like a coating around wires."

Mark: Insulation, yeah cause like fat stores.
Eve: Fat is like blubber on a whale and it keeps you warm.
Jim: It will work.

Eve felt victorious as she fused Blubber, a "fat, fat, fat whale," with the function of lipids.

The Ferrets benefited from many protein similes. Max associated the "building block" analog with proteins building something. Eve explained the pop-it necklace, "It's the little pop-it beads and you stick them together. They're linked in chains." Max used this to support his idea of proteins joining to build body structures. Later Mark used another analog to explain the structure of one protein molecule. Mark explained that protein can be like a train pulling a variety of boxcars "because they're [proteins are] made up of different kinds of amino acids and they [amino acids] are linked together" (1: F, 7). Multiple analogies (Spiro et al., 1989) helped the Ferrets understand the structural complexity of proteins.

The Ferrets had many difficulties. In a few instances, students were unfamiliar with the analog (e.g., pop-it necklace). A greater hindrance identified by Vosniadou (1989) was lack of sufficient familiarity with the domain knowledge. These difficulties were partially overcome by members' willingness to clarify analogs or scientific terms for confused members. Eve explained pop-it necklace. Jim explained that the monomers of protein are amino acids.

Holyoak and Thagard (1995) warned that some irrelevant trait of the analog may be improperly transferred to the target. The Ferrets sometimes did this. For example,
Eve wondered if lipids made you strong like lifting dumbbells. Literal thinking hampered analysis. For example, Max used the literal idea that lifting dumbbells will get rid of a person's fat to justify acceptance of "Lipid is like dumbbells." Solomon (1985) found that young adolescents might think first of any connection between the analog and the target without regard to whether it was an analogical connection. Holyoak and Thagard (1995) emphasized the importance of explicit representation of analogical thought. The Ferrets left many explanations incompletely stated.

The Ferrets analysed 25 of 36 similes successfully. They had trouble with 13 similes, and 11 remained problematic. Paula did not help. Jim led, but Eve, Mark, and Max tried to help.

The Ferrets earned the following SMILE scores: 2.25 for Jim, 1.50 for Mark and Max, 1.25 for Eve, and 0.00 for Paula. Jim showed greatest independence. Mark, Max, and Eve were very dependent in their analogical thinking. Paula was a nonparticipant.

Ferret SMILE scores are listed in Table 6.

Table 6

<table>
<thead>
<tr>
<th>Ferrets</th>
<th>SMILE</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Selection</td>
</tr>
<tr>
<td>Eve</td>
<td>1</td>
</tr>
<tr>
<td>Jim</td>
<td>1</td>
</tr>
<tr>
<td>Mark</td>
<td>1</td>
</tr>
<tr>
<td>Max</td>
<td>1</td>
</tr>
<tr>
<td>Paula</td>
<td>0</td>
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</tbody>
</table>
Class behaviors did not predict these teen's group behaviors. With the Ferrets, Max was more vocal, both constructively and destructively; while Mark was less vocal and less confident. Paula's lack of motivation showed up more clearly. As in class, Eve sounded tentative, yet she took a more active role within her group. True to his nonassertive posture in class, Jim quietly led analyses and waited so that the others would contribute.

Jim stayed out of the fray when Max and Mark made remarks about Eve and Paula. Max claimed, "Our two chicks are being very difficult" (1: F, 4). He pretended to command Eve to, "Scratch my back woman" (1: F, 4). Mark and Max joked about the girls' brain power. Perhaps such talk was the boy's inept attempts at getting the girls' attention, but it had the potential to poison the Ferrets. Paula ignored the boys' jibes. Eve laughed, pretended to laugh, or protected herself from barbs with retorts such as this one, "You're acting crazy. I'm trying to get the lipid information down" (1: F, 6). Mark finally suggested a halt in teasing the girls because it was divisive to their group.

**Close-up focus on Eve.** Eve, who was Euro-American, rode a unicycle, enjoyed gymnastics, and loved kids. She was a caring young lady. She felt her science foundation was poor because her past science classes consisted of reading and doing worksheets. Her insecurity was palpable when she admitted, "I'm lost in here [in biology class]. I'm surprised I had a C in here." Eve believed she learned best from listening, visual aides, and outlines. (Interview, March 3, 1997). Eve explained in her March 3 interview that the simile activity was:

> hard for me because it is science, because I had to sit down and first figure out what a lipid was, what a carbohydrate was, and a protein. It took a while and everyone in the group helped me cause I never learned it, and then it helped me as I got the definitions.
Lipid, carbohydrate, and protein had been presented in lecture and notes, but Eve did not begin to assimilate these terms until she was working in her group. Once she "owned" the basic category terms, she was in a position to benefit from simile analysis. Eve showed analogical insight with the lipid similes. The lipid fat was familiar to her from life and even from her reading about a fat whale. Eve was open to possible mappings, which is a strength in analogical thought.

Eve did not distinguish between naming literal or analogical connections. In considering how protein might be like a "sentence in a special language" she wondered, "Umm, does it have like a subject, article and verb and a noun?" (1: F, 8). She made an analogical linkage of the storage function of a safety deposit box and storage of energy in fat.

Gendered imbalance in power within the Harriers disturbed Eve. She expected that "they [boys] are going to disagree with me because they don't think I know anything" (1: F, 9). But Eve still credited her fellow Ferrets with helping her learn. Eve admitted, "People persuade me easily" (Interview, March 3, 1997), so in a sense she was primed to learn or mislearn from the others. Eve didn't surrender her autonomy because she reassessed and challenged responses.

Eve rated a SMILE score of 1.50 for her expressed analogical development. This score suggests that she was teacher and class dependent for full understanding of scientific analogies in October, 1996. Her selection score was 1 because Eve worked with the teacher-selected similes. She earned a 1 in mapping because she made few contributions on her own. She rated a 1 for inference for her dependence in that area. She received a 2 in evaluation because she learned from others the educational value of some similes.
Eve depicted Activity 1 as "hard," "interesting," "complex," "tedious," and "unusual". She gave "excellent" ratings to enjoyment, challenge, and knowledge gain. She liked learning through debate, but her group must have gone beyond debate because Eve circled "fighting." She wanted better directions and more group supervision. Eve's criticism was appropriate. The Ferrets needed closer monitoring.

Movie review: Ferrets search through tunnels. The Ferrets searched too many empty tunnels during their discourse. They did not lack talent, but they often lacked discipline. They spent much time on extraneous matters. Two male members relied on gender stereotypes to tease the two girls. Having wasted time, they ended up rushing to complete the assignment. The Ferrets finally traveled through their underground tunnels of puzzling similes to a somewhat better understanding of biochemistry.

Eve often got lost, but she never gave up. She followed the others closely through the simile tunnels to learn everything she could. She carried extra burdens: weak knowledge of the science domain; inequitable treatment by male team members; and her self-appointed task to take care of Sarah.

Activity 1: The Red Foxes

Group movie: Red Foxes chase prey. The Red Foxes included two Asian-American girls, Mai and Rika, an Asian-American boy Ching, and two Euro-American boys Kevin and Kirk. Diminutive Mai had short straight brown hair, deep brown eyes, and slightly tan skin. Mai's strong spirit was masked by reluctance to speak to the whole class, though she readily side-talked with friends. Rika had long wavy hair, short stature, and ivory skin. Shy, kind Rika was a very bright student. Mild-mannered Ching, a very competent scholar, combed his straight dark brown hair to the side. Sensitive
Kevin had very dark brown eyes, which conveyed his intensity of purpose. He appeared relaxed in class, but was never eager to speak out. Easy-going Kirk had sandy blond hair and medium height like Kevin. All five students avoided center stage.

Search for a replacement for a faulty tape recorder delayed the Foxes' search for analogical meaning. Even with a good recorder in hand, these reserved teens hesitated to begin. I helped them analyze "Lipid is like bubble packaging." First they were confused by the analog "bubble packaging." Kevin and Rika explained it, but a sample of bubble packaging really made this analog clear. As expected bubble popping and jokes followed, such as Kevin's assertion "That was me popping my gum." Then I used guide questions to shape their analysis model. They talked about how fat might be stored in little bubble things. Kirk provided a key term "cell." Modeling continued:

Mrs. H.: How is fat stored?
Kirk: It's stored in fat cells.
Kevin: Because the fat is stored in things, in the bubble things.
Mrs. H.: And fat is stored in what?
Kirk: Fat cells.
Mrs. H.: In fat cells and do you think the bubble packaging is sort of a little like that?
Kirk: Yes.
Kevin: Cause the bubbles are the cells and the air is the fat.
(1: R, 2-3)

The Foxes had mapped a connection between bubble packaging and lipid fat cells.

The Red Foxes were ready to chase down simile meanings on their own. Ching connected fat and a coat because they "keep your body heat" (1: R, 5). Kevin linked fat to the protective coating on wires because "It protects the body like when somebody punches you" (1: R, 7). Kirk and Kevin mapped the energy in gasoline to the energy in carbohydrates (1: R, 8). Rika accepted protein as a building block because protein builds the body (1: R, 12).
Time lost to solving the tape-recorder problem hurt Fox analyses. The members rushed their decisions, and did not reexamine them. This team struggled with 20 similes. Kirk, Kevin, Rika, and Ching helped with analysis. Kirk made the most insightful comments. They stayed focused, but were successful with only 18 of 36 similes.

Earlier priming (End & Danks, 1982) can interfere with recognition of a different relationship than the one primed. Having learned that fat is stored in fat cells, Kevin rejected pantry and backpack because, "Lipid is not used to store things; lipid is what is stored in something" (1: R, 3). Later Kirk talked about using "stored energy" of fat to pick up dumbbells. Kevin's original analysis was never revised. Their earlier priming to see fat as stored prevented them from identifying an opposite and also valid relation of fat storing something.

The Foxes sometimes transferred a relation that applied to one target to a different target. Recalling the cushioning function of fats, Kevin and Rika incorrectly transferred this cushioning function to carbohydrates. The Foxes often identified literal connections, instead of analogical ones. For example, Kevin linked a pantry to lipid because "you put food in your pantry and you eat the food to get energy" (1: R 3). Kevin and Kirk linked lipids to dumbbells because you need the energy from fat to pick up dumbbells.

A few analogs (e.g., bubble packaging, pop-it necklace) temporarily confused the Foxes, but they had more trouble with biochemical terms. For example, Kirk confused protein with DNA. Incomplete expression of ideas was a common problem in Fox analyses. Recall how Kevin mapped bubble to the cell, but simply implied that air would be mapped to fat.
The Red Foxes were teacher- and class-dependent in analogical thinking. They received the following SMILE assessments: 1.75 for Kirk; 1.50 for Ching, Kevin, and Rika; and 1.00 for Mai. Subscores and SMILE levels are listed in Table 7.

Table 7

<table>
<thead>
<tr>
<th>Red Foxes</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mai</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
</tr>
<tr>
<td>Kirk</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1.75</td>
<td>1</td>
</tr>
<tr>
<td>Ching</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.50</td>
<td>1</td>
</tr>
<tr>
<td>Kevin</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.50</td>
<td>1</td>
</tr>
<tr>
<td>Rika</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.50</td>
<td>1</td>
</tr>
</tbody>
</table>

These nonrisk-takers were uncomfortable with Activity 1, but comfortable with each other's similar temperaments. Kevin and Ching kept their group focused. Kirk provided the most biochemical information. Shy Rika added her voice, but Mai was almost silent. She elected herself the group recorder.

Rika, Mai, and Ching protected one another. When Kevin and Kirk chided Mai for nonparticipation, Rika said, "Don't fuss at her. She's doing something" (1: R, 6). When Kevin marked Rika's comment as irrelevant, Mai warned, "You're chewing on Rika again" in a voice that said you better stop (1: R, 14). Ching sometimes bailed Mai out by answering a question directed to her. Kevin used gentle teasing to encourage equitable participation, "We [boys] just talk, so they [girls] won't" (1: R, 5).

No one wanted to do this hard activity alone, so four Foxes collaborated. This serious group enjoyed moments of humor as with the bubble packaging, but they also
felt the pressure of a difficult assignment. Relief was palpable in Ching’s sighed words, “We’re finished” (1: R, 15).

**Close-up focus on Kevin.** Euro-American Kevin was elusive. When asked to describe himself, he dodged, “I don’t like that question?” When coaxed to respond in just one sentence, he answered, “I have brown hair.” Relying on his good memory, Kevin learned through “reading it or looking at it.” He was “creative,” not very “scientific,” and most comfortable with “just a few people.” He became a zoo explorer because he loved animals. In class, he was content to follow. In his learning group, he was both leader and follower (Interview, March 3, 1997).

Even if Activity 1 was a “little too hard”, Kevin still learned because it helped him to remember things by remembering the similes. He believed his group “stay more on track.” Kevin described Fox strategy: “We just looked at the characteristics of each thing and found two that were alike” (Interview, March 3, 1997).

Kevin played many roles in his group including humorist, organizer, analyst, and critic. He dispensed his dry humor at will. Kevin teased that petite Mai, “doesn’t have fat in her entire body” (1: R, 5). He kept his group focused and oversaw the recording of group responses. He helped analyze the similes. Kevin’s matter-of-fact calm approach was an asset.

Kevin’s understanding of biochemistry and of analogical thought was limited in October, 1996. Sometimes he named literal, rather than analogical connections between analog and target. He rejected some potentially useful similes. He tried to help with analysis of 21 similes. He deserved special credit for three ideas that proved especially helpful, but three of his ideas misled.
Kevin's received a SMILE rating of 1.50. He earned a 1 for selection since he relied on similes provided by the teacher. His 2 ratings for mapping and inference indicate some ability, but also his need for teacher guidance and class instruction. Kevin was very weak in judging the learning potential of the similes and thus received a 1 for evaluation.

Kevin's described Activity 1 as "hard," "boring," "clear," "tedious," and "routine." This selection of terms suggests Kevin's displeasure with Activity 1, and yet he wrote, "I learned from doing it." Tape recording was most disturbing for very private Kevin. His ratings of "poor" for motivation and enjoyment may highlight this discomfort. He gave "okay" ratings to challenge and knowledge gain.

Close-up focus on Mai. Mai described herself as "short," "Vietnamese," "just a regular student," "friendly but . . . mean sometimes," a "pretty good" student but a talker in class, and very much a "people-person." She learned best through listening to teacher "stories from experience" and doing projects or labs. She found it hard to concentrate on reading and admitted that she "tends to get off track" with groups. She liked creative writing. Despite her stated career goal to be an engineer, she denied being "scientific." Her "strict parents" urged her to study (Interview, March 3, 1997).

Mai spoke during 5 simile analyses and only once to give her original thought. To the discussion of protein as energy, she added "Energy just like when you drive a car and you pump gas into it" (1: R, 14). Her analytical silence seemed to be grounded in the difficulty of the biochemistry for her and her novice understanding of metaphorical thought. Mai described the analogical mapping process as "basically like a comparison. What do the two have in common?" (Interview, March 3, 1997).
Wanting to contribute to her group, Mai wrote down group responses and occasionally read out loud a simile statement. She liked her group because they "kind of kid around so it was fun working together," but they could become serious "whenever answering the questions" (Interview, March 3, 1997). She definitely depended on her group members for these answers.

Mai could be assertive. She shooed an intruder away. She deflected Kevin's correction with "I'm sorry but I'm writing what you are saying, so you better get clear on these answers" (1: R, 5). Since she was recording responses, she absolved herself from evaluating the quality of these responses.

Mai rated a 1.00 SMILE score. She received 1s in selection, mapping, inference, and evaluation since she was teacher-dependent for each of these processes. She followed and listened during Activity 1.

Mai evaluated Activity 1 as: "hard," "boring," "complex," "creative," and "unusual." She contributed little because the activity was hard and complex for her. It could also have been boring if she didn't understand most of the discussions. Mai gave "okay" ratings for enjoyment and challenge, a "good" for knowledge gain, and "excellent" for motivation.

Movie review: Red Foxes chase prey. The Red Foxes stayed together throughout their chase for simile meanings for biochemistry. Delay at the start forced them to move too fast and this resulted in mistakes. These young people needed to consider more possibilities and reexamine their initial ideas. The Foxes caught the meaning of some similes, but many escaped their grasp.

Kevin showed potential for using analogies to better understand science, but he needed to perfect his skills. He shared responsibilities with his peers. Mai recorded the
analogical thinking of her Fox peers, but did not appear to grasp the process so that she could contribute. She also seemed weak in her knowledge of biochemistry.

**Activity 1: Snakes and Lions**

This researcher’s discussion will not focus on the Snakes and the Lions. The experiences and perspectives of students in these groups are captured in this researcher’s panoramic view of analogical groups and in student panoramic views. Only space limitation dictates omission of their personal stories so full of meaning.

**The Snakes.** The Snakes consisted of Afro-Americans Omar, Tina, and June and Euro-Americans Helen and Jack. Members of this team were compatible, calm deliberators who contributed on an equal basis. They especially liked relating science to everyday things like Arnold Schwarzenager, granola, fat babies, and the need for breakfast. They succeeded with 18 of 24 similes, but ran out of time to do the 12 protein similes. Snake analyses sometimes involved surface mappings or incompletely expressed mappings.

**The Lions.** The Lions were really lionesses with distant roots in Africa. This group included Sandra, Crystal, Sarita, Letitia, and Treasure. This team often broke into smaller factions. Three girls—Crystal, Sarita, and Treasure—worked equitably to reach a consensus on each decision. Their talk integrated their knowledge of nutrition and biochemistry. Two members, Sandra and Letitia, were less productive. The Lions succeeded with their analyses of 21 of 36 similes. Sometimes insufficient or entangled biochemical information blocked their path. They lacked familiarity with a few analogs and some biochemical information. They sometimes made surface mappings or inexplicit mappings.
Activity 1: Summary

How did participation in analogical Activity 1 affect student learning of biology, student development of analogical thought, the quality of group interactions, and the quality of teacher-student interactions? How did student experiences in fifth-hour compare to the counter experiences of sixth- and seventh-hour students?

Activity 1: Learning Science

For nonanalogical Activity 1, students completed a traditional worksheet "The Chemistry of Life." With satisfaction students recalled, or in comfort looked up information to enhance their knowledge of biochemistry facts. All students worked at the same learning level. Hour 6 and 7 students gave 90 to 100% correct answers. The biochemistry test grade mean for Hour 6 and 7 students was 78.5%.

For analogical Activity 1 "Is It Like It or Not?", students analyzed 36 similes for scientific meaning. These similes served as magnifying glasses to focus students' attention on biochemical concepts. In deciding to accept or reject a simile, students recalled or researched information to build support for their positions. Hour 5 students interwove nutrition issues with their debate of how familiar things might be seen in one way as like a targeted biochemical concept. Comparison of analyses of different similes promoted synthesis of isolated facts into more integrated systems, and helped dispel some conceptual confusion. The challenging work of analysis promoted individualized learning. As recognized in Glynn's (1991) model for learning from analogy, some basic familiarity with target terms was essential. Students lacking this requisite knowledge tried to acquire it by asking their peers to explain terms or by looking up information in their notes or text. More prepared students clarified and
disentangled concepts; and advanced students reached for more abstract conceptual understanding.

All groups succeeded in analyzing some similes acceptably: Pelicans - 80%, Harriers - 83%, Ferrets - 67%, Red Foxes - 50%, Snakes - 50%, and Lions - 75%. Recall tape recorder trouble reduced the Fox work time, and the Snakes worked too slowly to have time for the protein similes. These percentages are not test measurements of knowledge, but are subjective assessments of student success with higher level thinking. The biochemistry test grade mean for Hour 5 students was 79.5%.

Activity 1: Development of Analogical Thought

Only fifth-hour’s Activity 1 promoted analogical thought through students’ work to derive scientific meaning from the similes. These young people knew that a simile involved a comparison by which meaning unfolded through recognition of a similarity between two things. They appreciated the difference between more open interpretations of literary similes and domain-restrained interpretation of scientific similes. They took comfort from talking with expertise about ordinary object analogs, but they were challenged to think through scientific similes on their own. Teacher and peer assistance promoted students’ attempts to find a similarity in structure or function between a familiar analog and an unfamiliar biochemical target. Personality traits which facilitated simile interpretation included: imagination, tolerance of the tension of uncertainty, risk-taking in sharing one’s ideas, flexible thinking, ability for complex manipulation of concepts, and patience to judge value of ideas.

Students encountered obstacles to analogical thought including: identification of a literal rather than analogical connection between the analog and the target (Zeitoun, 1983); inappropriate transfer of a characteristic of the analog to the target (Holyoak &
Thagard, 1995); failure to explicitly state the analogical mapping (Harrison & Tregust, 1993; Holyoak & Thagard, 1995); lack of saliency of the analogy (Ortony, 1983; Vosniadou, 1989); lack of saliency of the analog (Zeitoun, 1983), surface mappings (Gentner, 1988; Medin & Ortony, 1989); reluctance to move from simple to more complex understandings (Holyoak & Thagard, 1995); confusion by complexity of domain terminology (Wandersee, 1985), interference with new conceptualization by earlier priming (End & Danks, 1982), and inappropriate transference of a relation from one target to a different target. Students who knew too little about the target domain (Vosniadou, 1989) or too much (Zeitoun, 1983) were not positioned to benefit as much as other students from Activity 1.

This lengthy list of impediments to analogical thought makes fifth-hour students' accomplishments seem remarkable. Yet this list of actual student missteps also highlights the novice status of these analogizers in October, 1996.

Activity 1: Quality of Group Interactions

Comfortable with a familiar worksheet format, Hours 6 and 7 students enjoyed audiotaping their group collaboration on a science review. While biochemistry was difficult, they remedied any insufficiency in knowledge by referencing biology text or notes. Little discord occurred during the hour of Activity 1. Organizational style had little effect on the ultimate success of all groups.

Most fifth hour students enjoyed their group work and liked audiotaping their group discourse. They enjoyed the freedom of speaking science on their own terms. Students derived comfort from doing a difficult task collaboratively for two and one-half hours. Each Hour 5 group adopted working styles that varied in functionality. Friendly Pelicans and compatible Snakes chose an effective consensus-building
approach. Individualistic Harriers engaged in energetic debate, but also peppery arguments. Distracted Ferrets relied too much on their strongest member to guide them. Loquacious Lions split apart to engage in vivid dialogues.

Each fifth-hour team faced their own mix of problems. These problems involved dysfunctional organization, lack of leadership, nonparity in member contribution, gendered conflicts, and personality conflicts. To begin to solve their group problems, students worked on developing their interpersonal skills. Students made progress toward functional group unity, but much work remained.

Activity 1: Teacher-Student Interactions

Sixth- and seventh-hour students accomplished their traditional Activity 1 with independence. Teacher-student interactions involved friendly exchanges, gentle persuasion, helpful science hints, and a few commands to get to work.

Fifth-hour students worked with some independence, but they also depended on the teacher for considerable help with their strange Activity 1. Fifth-hour students requested and received teacher input in the forms of analysis modeling, repetition of instructions, praise, hints, urgings to focus, guidance, validation of students' thought, and collegial conversation. These longer and more individualized interactions were beneficial in building trust and communication between teacher and students and beneficial to establishment of a safe environment in which students would risk sharing their thoughts. Slowly, students assumed responsibility to figure things out for themselves.

Activity 1: Analysis Implications

"The Chemistry of Life," nonanalogical Activity 1 provided students with an effective review of biochemistry facts. Students worked in their comfort zone with a
traditional worksheet and peer support to review a challenging scientific subject. This
traditional exercise had value in terms of student learning.

Hour 5 students worked in their less predictable "zone of proximal development."
The actual biochemical facts reviewed by these students varied with the group. In
particular, their Activity 1 promoted analogical development through students'
evaluation of the learning potential of assigned similes in terms of one connection
which the students identified between each everyday object analog and the targeted
biochemical concept. Participation in "Is It Like It or Not?" catalyzed students: to
become more involved in their individual learning, to develop interpersonal skills, to
develop analogical thinking, and to interact with their teacher more as guide rather
than disseminator of knowledge. In these aspects, analogical Activity 1 seemed
qualitatively better than nonanalogical Activity 1. These benefits support the
argument that an activity such as analogical Activity 1 should be included in a biology
curriculum.

**Activity 1: Reflections on Specific Students**

A tenuous balancing of the specific and the general must shape analysis of fifth-
hour students' diverse experiences with Activity 1 "Is It Like It or Not? A brief review
of the experiences of the students selected for special focus may provide support for
the broad view stated above, while reminding the reader of the uniqueness of each
student's responses to analogical Activity 1.

**Pelicans: Ed and Keisha**

Ed gently led his Pelicans. Biochemistry did not intimidate him. He had a
reasonable knowledge base and read to learn more. He played with the similes to find
possible connections between an analog and a target. This open-mindedness helped
his analogizing. Ed was dependent on the teacher and peers for their critical review of his simile analyses. Ed learned more about biochemistry from Activity 1, delighted in his group's interactions, in audiotaping, and in analogical thought. He earned a 2.50 SMILE score.

Keisha's knowledge of biochemistry was rudimentary, but she worked hard to learn by reading and talking with her group peers. She helped with simile analyses as often as she could, but overall was dependent on teacher and peer guidance. Keisha responded enthusiastically to group work, to audiotaping her voice, and to using familiar things to learn biochemistry. She gained confidence as she contributed and earned the Pelican boys' respect. She received a 1.75 SMILE score.

**Harriers: Jonah and David**

During Activity 1, Jonah moved from refusal to participate, to guarded contribution, to confident participation. A reprieve from writing down responses, one-on-one teacher guidance, peer pressure and peer encouragement helped him overcome his insecurity. Oddly, audiotaping Harrier discourse helped autistic Jonah to feel more comfortable speaking out within his learning group. He read to find support for his ideas. Jonah's friends filtered out some of his unfocused comments so that he could utilize his analytical strength to interpret the similes. Jonah proved to be very good at seeing analogical meanings in the similes. He relied on teacher and peers for critical feedback when his imagination led him far astray from useful learning connections. Jonah gained as much in social development as he did in analogical development and learning of biochemistry. Despite these benefits, Jonah was uncomfortable with the uncertainty inherent in an activity that allowed for open-ended responses. Jonah rated a 2.50 SMILE score.
David faced the challenge of Activity 1 with equanimity. He welcomed the interactions with the Harriers and tape recording his voice. David's tendency to say the first thing that occurred to him impaired his attempts to analyze the similes. He helped analyze the lipid similes because he had concrete life experiences to help him understand. His weak domain knowledge made him dependent on his peers and teacher for help in analyzing many of the similes. Socially skilled David helped smooth out conflicts among the Harriers. David rated a 1.75 SMILE score.

**Ferret: Eve**

Eve found Activity 1 hard because of her weak knowledge of science, inexperience with analogical thought in science class, and strife among her Ferrets. With strength of character, Eve worked to improve her knowledge and asserted herself in spite of male Ferrets' discouraging comments. She made a few worthy contributions to simile analyses, but usually had to depend on her peers for analogizing. She did not discriminate between literal and analogical connections. Eve was uncomfortable with so much responsibility for her learning. Eve received a 1.50 SMILE score.

**Red Foxes: Kevin and Mai**

Kevin felt the pressures of a difficult science assignment, inequitable participation by Red Fox members, and discomfort with audiotaping his voice. Despite his insecurity, he focused on simile analysis to state a few mappings useful for learning science. He sometimes identified literal rather than analogical similarities between the everyday objects and the scientific targets. His rejected some potentially meaningful similes. He often depended on teacher and peers to find meaning in the similes, yet he believed he learned more biochemistry through Activity 1. He rated 1.50 on the SMILE assessment scale.
Mai was overwhelmed by Activity 1's assignment to use strange analogical thought to learn about a difficult scientific subject. She preferred a more straightforward learning strategy. Mai listened to her Red Fox friends' explanations of the simile meanings in terms of biochemistry. She assisted her group by writing down responses. She seemed surprised that anyone expected her to take more responsibility for her learning. Mai was very dependent on teacher and peers during Activity 1. She took refuge within her cooperative group. Mai earned a 1.00 SMILE rating.

Activity 2

Activity 2: Analogical versus Nonanalogical

Activity 2: Black and White Photo Shots

Scientific subject. The target for Activity 2 was the nature of science. By late October, 1996, all Honor Biology I students were writing research papers in preparation for doing a science fair project. This independent research project was intended to widen student's scientific horizons beyond ritual introductions in science classes. Personal experiences, movies, television, newspapers, magazines, computer networks, and much more had also molded these students' images of science.

Activity 2 descriptions. In late November, 1996, students in the three biology classes researched animals, discussed these animals in their groups, and chose an animal name for their learning group. All student groups constructed animal emblems. In class presentations, all groups reported on their animal and displayed their emblem.

Nonanalogical Activity 2 "What Animal Will Be Placed on Your Emblem?" did not provide any guidelines for choosing the group's animal name. Sixth- and seventh-hour students determined for themselves the basis upon which to select their name. They took about two and one-half hours to complete their Activity 2.
Analogical Activity 2 "Who Will Symbolize Us?" (see Appendix N) used the group naming process to develop analogical thought and promote student dialogue on the nature of science. Fifth-hour's guidesheet directed students to not only talk about animals, but to also talk about science, and identify similarities between their animal and science. They were instructed to base their choice of a group name on how the animal was a representation of the members' vision of science. The analogical group had to explain to the class how their animal represented their concepts of science. Hour 5 students took about three hours to complete analogical Activity 2 (see Appendix O for hypothetical responses).

Activity 2: Panoramic Photos Taken from Researcher Vantage Points

Nonanalogical path. Hour 6 and 7 students enjoyed researching their own animals and sharing this information. Students talked about animal anatomy, behavior, and life history. For example, Samson stressed the wolf's communal society. Monika emphasized the shared parenting of penguins. Some students made cultural connections. Cole claimed the rooster as his Chinese zodiac sign. Christabel helped her peers make paper origami cranes.

Voting without any basis for choosing an animal name placed students in a quandary. Most students voted for their own animal. Repeat voting led to groups called African Golden Cats, Kangaroos, Lions, Wolverines, Loons, Ravens, Cranes, Jaguars, Albatrosses, and Eagles. Other groups tried: secret ballot with three votes by each member (Manta Rays); drawing chance numbers (Grizzly Bears); and votes on basis of who most needed their animal to be chosen (Swans).

During class presentations, most groups gave spur of the moment explanations for their choices. Cited reasons may be placed in these categories: (a) established symbolic meaning (e.g., albatross for instilling fear); (b) ethnic pride (e.g., African golden cat); animal characteristic (e.g., fierceness of bear); no reason (e.g., kangaroo);
uniqueness (e.g., manta ray). These students belatedly tried to add meaning to their group's name.

It might be argued that students in choosing an emblem would think metaphorically of how their animal symbolized their group. But without direct instructions to do so, most individuals and most groups did not give explicit reasons for choosing their animal. Their individual and group reports focused on factual information. These students gave a rationale for their animal choice only when asked to do so during class presentations. They simply displayed their emblems.

**Analogical path.** Fifth-hour students enjoyed choosing, researching and presenting their animal. They had little trouble generating ideas about the nature of science. Their Activity 2 "Who Will Symbolize Us?" required them to select an animal to analogically represent science. This requirement enriched group talk. Each student's defense of his animal could be tentative, incomplete, trivial, or even missing; but the group's arguments in favor of their animal symbol for science tended to be fairly developed and substantial. Three groups created emblems that visually linked their animal and science.

Fifth-hour students chose the now familiar group names: Pelicans, Harriers, Ferrets, Red Foxes, Snakes, and Lions. These Hour 5 names seem similar to names chosen by the Hours 6 and 7 students. The difference lies in the metaphorical meaning discovered by the fifth-hour science students. This difference made their analogical Activity 2 more meaningful and more challenging.

**Activity 2: Panoramic Photos Taken from Student Vantage Points**

**Student evaluations.** The following number of students by class completed evaluation forms for their Activity 2: 24 of 30 fifth-hour students, 22 of 31 sixth-hour students and 23 of 30 seventh-hour students. For these evaluations, students picked adjectives to describe their activity, identified activity processes, rated their activity in 10 categories, and some students wrote additional comments.
Selection of adjectives to describe activity. Table 8 lists the percentages of student evaluators who circled a selected adjective as descriptive of their Activity 2. Horizontal reading of the chart highlights both similarities and dissimilarities in perceptions between the analogical and nonanalogical Activity 2 participants. Almost all found their Activity 2 either "comfortable" or "easy," and "simple" or "clear." A majority of all students called their Activity 2 "fun" and "creative." Similar percentages of fifth-hour and sixth- and seventh-hour students selected "open-ended," "unusual," and "interesting." More fifth-hour students circled "well-structured." Nonanalogical Activity 2 may be less well-structured in that it provides no basis for student choice of an animal group name. Students in all classes viewed their Activity 2 as an enjoyable, somewhat special, accessible activity.

Identification of activity processes. Table 9 lists percentages of evaluators who identified certain processes with their Activity 2. Comparison of these percentages may suggest similarities and differences in student perceptions of the alternate activities.

Cross comparison of percentages indicate a majority of evaluators of the analogical and a majority of evaluators of the nonanalogical Activity 2 identified these processes: "choosing," "researching," "discussing," learning," "communicating," "drawing," and "thinking." These processes were very much a part of both cooperative activities. Fifth-hour students overwhelmingly identified "thinking" with their activity. It took thought to connect an animal to science. Most fifth-hour students did not recognize this thinking as analogical.

A majority of Hour 5 evaluators chose "observing" compared to a quarter of evaluators in Hours 6 and 7. In some way, their analogical activity made them more sensitive to their visual study of animals. It is even possible that these students engaged in virtual observations of their animal in order to find links between their animal analog and their target of science.
### Table 8

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 2

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfortable</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Open-ended</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Fun</td>
<td>50</td>
<td>53</td>
</tr>
<tr>
<td>Easy</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>Simple</td>
<td>38</td>
<td>44</td>
</tr>
<tr>
<td>Creative</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td>Unusual</td>
<td>29</td>
<td>22</td>
</tr>
<tr>
<td>Interesting</td>
<td>29</td>
<td>38</td>
</tr>
<tr>
<td>Clear</td>
<td>58</td>
<td>47</td>
</tr>
<tr>
<td>Well-structured</td>
<td>38</td>
<td>18</td>
</tr>
<tr>
<td>Okay</td>
<td>67</td>
<td>46</td>
</tr>
</tbody>
</table>

**Note.** Percentages are listed vertically from most similar to most different by comparison.

- **a** Only adjectives circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.
- **b** n = 24 evaluators out of 29 fifth-hour students.
- **c** n = 45 evaluators out of 31 sixth-hour and 31 seventh-hour students.
Percentages of evaluators who selected "fighting" suggests that there may have been more conflict in some Hour 6 and 7 groups than in Hour 5 groups. It was hard for students doing nonanalogical Activity 2 to agree on an animal because they lacked criteria upon which to base their decision.

**Student rating of activity in 10 categories.** Table 10 lists class means ratings of each Activity 2 in 10 categories. Evaluators of analogical Activity 2 and nonanalogical Activity 2 gave identical ratings in many categories. These 4.0 or 3.5 ratings suggest that students were pleased with groups, activity directions, enjoyment, no basis for student choice of an animal group name. Students in all classes viewed their Activity 2 as an enjoyable, somewhat special, accessible activity and knowledge gain. They felt motivated to do Activity 2. Their view of the challenge as just "okay" seems consistent with an accessible and appealing study of animals.

Fifth-hour students gave ratings 0.5 higher than sixth- and seventh-hour students for time involved, teacher input, and age level. Perhaps some sixth- and seventh-hour students felt that too much time was spent on a simple activity that was not quite appropriate for their age. The additional requirement to relate an animal symbolically to science made analogical Activity 2 more age appropriate for high school students.

**Additional comments.** Some students added written comments. All fifth-hour comments were favorable toward their analogical Activity 2. Comments from sixth and seventh hours split equally in favor and not in favor of their nonanalogical Activity 2. Half of all comments provided overall reactions, but other comments focused on time involved, animal subject, and voting.

Three fifth-hour students judged their activity "excellent." Keisha enjoyed it and cautious Jim guessed it was "not bad." Sarita explained, "This activity was interesting because the animal we pick was my favorite and I always wanted to know something about it. It is a better way to learn."
Table 9

Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 2

<table>
<thead>
<tr>
<th>Process</th>
<th>Activity 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Analogical</td>
</tr>
<tr>
<td>Discussing</td>
<td>96</td>
</tr>
<tr>
<td>Learning</td>
<td>88</td>
</tr>
<tr>
<td>Drawing</td>
<td>88</td>
</tr>
<tr>
<td>Choosing</td>
<td>83</td>
</tr>
<tr>
<td>Researching</td>
<td>83</td>
</tr>
<tr>
<td>Communicating</td>
<td>83</td>
</tr>
<tr>
<td>Thinking</td>
<td>83</td>
</tr>
<tr>
<td>Observing</td>
<td>58</td>
</tr>
<tr>
<td>Creating</td>
<td>33</td>
</tr>
<tr>
<td>Remembering</td>
<td>33</td>
</tr>
<tr>
<td>Categorizing</td>
<td>33</td>
</tr>
<tr>
<td>Evaluating</td>
<td>17</td>
</tr>
<tr>
<td>Fighting</td>
<td>13</td>
</tr>
</tbody>
</table>

Note. Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

aOnly processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.
b\(n = 24\) evaluators out of 29 fifth-hour students.
c\(n = 45\) evaluators out of 31 sixth-hour and 31 seventh-hour students.
### Table 10

**Comparison of Mean Category Ratings by Students for Their Activity 2**

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Time involved</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Directions</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Age level</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Motivation</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

*Note.* The rating scale is: 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means are rounded to the half-decimal.

\(a_n = 24\) evaluators out of 29 fifth-hour students

\(b_n = 45\) evaluators out of 31 sixth-hour and 30 seventh-hour students.
Eight teens liked their nonanalogical Activity 2 because it was fun, interesting, good, or okay. Two students liked group independence. Aaron explained, "Sometimes a teacher supervision is OK, but this time it wasn't really necessary." Anton agreed, "We really didn't have any questions for you." The animal subject matter appealed to some. Zoe "learned about animals I've never heard of before." Juliette shared Zoe's opinion. Sharon, a dancer, thought her new knowledge of a swan would make her dance better in Swan Lake. Some Hour 6 and 7 students disagreed with their peers. Abel declared, "too childish," and Amelia said "boring and unnecessary." Victor in seventh hour suggested a lab instead.

Written complaints came only from Hour 6 and 7 students. Laurel said, "In the groups everybody voted for the animal they chose. It was kinda pointless." Jonas agreed with Laurel, then gave his reasons for choosing the opossum, "because I thought we (as a group) were like the opossum (mischievous, active, talkative)." Jonas was one of the few students in seventh hour who did use analogical thinking to support his animal candidate. Five teens wanted more time to do a better job.

**Collage of student viewpoints.** Both analogical and nonanalogical Activity 2 provided engaging educational experiences to their participants. These novice biologists found the subject of animals very appealing and within their comfort zone. They enjoyed the independence of working in cooperative learning groups. They liked the creativity required to design their group symbols. In general sixth- and seventh-hour students liked "What Animal Will Be Placed on Your Emblem?", but some felt dissatisfied. Something was missing. This traditional activity did not provide a structure for decision making, so groups chose their name serendipitously. Fifth-hour students seemed somewhat more satisfied with "Who Will Symbolize Us?" They had a structural framework for their decision-making. They liked the thinking required to explain how an animal could represent their vision of science.
Reflections on the Panoramic Views of Activity 2

Both analogical and nonanalogical Activity 2 had the attractions of cooperative group work, freedom of choice for the animal symbol, interesting subject matter, audiotaping, and the creativity of making a group emblem. Yet the analogical activity seemed in some sense "qualitatively better" than the alternate nonanalogical activity. The addition of the directive to map characteristics of a chosen animal to the characteristics of science added a tantalizing element to a traditional activity of choosing an animal to represent a biological learning group. Students engaged in higher level thinking in their decision making and analogizing. They linked their animal to science on the basis of a set of student-perceived similarities. This took their analogical thinking one step beyond Activity 1, in which one mapping was sufficient and the analogs were provided. It is time to check out this panoramic view through closer examination of interactions within fifth-hour cooperative learning groups.

Activity 2: Analogical Groups

Activity 2: The Pelicans

Group movie: How the Pelicans got their name. The team of Ed, Randy, Michelle, Keisha, and Boris carefully followed the guidesheet for "Who Will Symbolize Us?" They talked briefly about the nature of science, then confidently read researched information about a chosen animal: pelican (Randy), barn owl (Michelle), marmoset (Keisha), mud turtle (Boris), and orangutan (Ed).

This team faltered when they tried to grasp their analogical task to relate traits of their animal to characteristics of science. With my guidance, Randy compared the pelican's ability to store things in its beak to science storing things. Ed replaced "things" with the more specific "scientific information." Keisha used the social nature of her marmosets to point out that "scientists gather together to collect information."

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(2: P, 3). She linked the marmosets' good vision to keen scientific observation. She compared a marmoset's use of its front hands to a scientist holding things in his hands.

They voted to be called Pelicans. A summary of their class presentation yields the following description: Working together with other scientists or alone, an observant scientist researches, collects, and then shares information with colleagues at a conference. This statement is an amazing leap from its counterpart pelican statement: Flying alone or together in a flock and relying on good eyesight, a pelican finds, collects, and then shares food with baby pelicans in a nest.

A comparison of these two statements reveals one-to-one mappings from the pelican analog to the nature of science target. Clearly stating an analogical relationship is essential to the improvement of analogical thinking. The Pelicans explicitly mapped six pelican traits to six characteristics of science, thereby identifying either relations, or taken together, a system as defined by Holyoak and Thagard (1995).

The Pelicans concluded with display of their pale colored emblem. The fact that their emblem design included both the pelican and images from science (e.g., black scientist, math equation) with an equal sign between them indicates that these teens understood the pelican as a symbol for science. Both the depiction of the flying pelican with a fish in its mouth and the multiple visages of a scientist relate directly to their final nature of science construction. The Pelicans began with a curious scientist who brings progress and has something to do with people, environments, and nature. Thinking analogically about a pelican helped team members recall more about the nature of science. By the end of Activity 2, they had moved beyond Michelle’s initial idea that “Science has no particular definition, it’s just there” (2: P, 1) to define their own vision of science.

Pelicans received the following SMILE scores: 3.00 for Ed, 2.75 for Keisha, 1.75 for Randy, 1.25 for Michelle, and 0.50 for Boris. Subscores and SMILE levels are listed in Table 11. The group as a whole succeeded, but members differed in their
analogical ability. While Ed and Keisha seemed to have a good grasp, Boris and Michelle remained perplexed. Randy held the middle ground.

Table 11

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>Randy</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Keisha</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2.75</td>
<td>3</td>
</tr>
<tr>
<td>Boris</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0.50</td>
<td>0</td>
</tr>
<tr>
<td>Michelle</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
<td>2</td>
</tr>
</tbody>
</table>

The Pelicans interacted in supportive ways. Their final presentation was an amalgamation of their discourse. Ideas were co-opted, transferred, and transformed into their final description of the nature of science. Through participation in Activity 2, these students chose a name for their group, learned about interesting animals, practiced analogical skills, and gained confidence to express their neophyte understandings of the nature of science.

Close-up focus on Ed. Ed showed his natural affinity for analogical thought in his linkages of orangutan curiosity to science, and pelicans feeding their young to scientists sharing research at a conference. He less clearly argued that the "orangutan has a close relation to man and science has a close relation to man" (2: P, 3). Ed did not fully explore how science is related to man. Ed immersed himself in the Activity 2 experience so he was always ready to contribute and learn.

Ed's 3.00 SMILE score for Activity 2 indicates that his expressed analogical ability showed some independence. He rated a 4 for selection because the group chose the pelican. He earned a 3 for mapping pelican traits to science. His scores 2 for inference
because he needed guidance to make inferences. Ed's evaluation scores of 3 recognizes his role in judging the groups' analogies for learning.

**Close-up focus on Keisha.** Keisha's within-group presentation proved very valuable. Three connections Keisha made between her marmosets and science showed up in her group's presentation. She linked science with observing and gathering information. She also emphasized scientists working together. The group saw these traits symbolized in pelicans as well as marmosets. Keisha practiced analogical thought and improved her ability to talk about science. Keisha seemed enticed to participate because animals were familiar, even if the target was a more daunting "nature of science" which she could not describe at all at the beginning of Activity 2.

Keisha described Activity 2 as "comfortable," "interesting," "clear," "creative," and "fun." Keisha gave "excellent" ratings to motivation, enjoyment, and knowledge gain, and "good" for challenge.

Keisha's 2.75 SMILE score for Activity 2 indicates that she showed some independence in her analogical thought. She earned a 4 in selection because she helped choose the pelican for an analog. She rated a 3 in mapping for her good mappings. Her inference score of 1 was based on her dependency on the teacher for inferences. Keisha's evaluation score of 3 means she shared judgment with her peers.

**Movie review: How the Pelicans got their name.** As Pelicans often follow each other in line as they search for tasty morsels, these teenagers followed step-by-step guidelines as they searched for their name and its analogical connections to the nature of science. Ed displayed a natural talent for analogical thinking. Keisha initially had little confidence in her ability to describe science, but she easily talked about science when she relied on her marmoset or the pelican to inspire her thoughts. Ed and Keisha helped find a suitable group name and a symbol for their team's vision of science.

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Activity 2: The Harriers

Group movie: How the Harriers got their name. The learning group of Ton, Bill, Barry, Jonah, and David resisted the structural guidelines of Activity 2, "Who Will Symbolize Us?". They omitted discussion of the nature of science. Only Ton and Jonah independently wrote down ideas about science. Each student researched an animal. Presentations by Barry, Bill, and David lacked evidence of analogical thought. Barry gave a brief account of the common bat. Bill reported on muskrats. David described his polar bear and made one attempt to connect his bear to science.

Jonah described his barn owl and then talked about science. While Jonah failed to state shared characteristics in tandem, his talk about the barn owl shaped his talk about the nature of science. He spoke of the owl's "excellent night vision" and later of the need for scientists to have "keen observation and the ability to survey and note surroundings" (2: H, 1). This description seemed shaped by a vision of the owl in search of prey. Jonah noted, "The owl symbolized wisdom and intelligence," characteristics which he later assigned to scientists. Jonah implied his mappings.

Ton explicitly related his harrier to science. He mapped a harrier's keen eyesight to scientific observation and harriers' helping man hunt to scientific help to society. He implicitly linked the patience of harriers hunting to patience required for scientific work. The team chose the harrier as their symbol. Jonah presented Ton's ideas, but with Jonah's unique spin. For example, he related the observational ability of harriers to that of scientists, but then stated a literal fact that scientists don't really see as well as harriers so they need to use binoculars.

This group's artists, Jonah, Barry, and Bill, rendered emblem sketches. They chose Barry's design of a test tube and a harrier in flight over a green field against a blue circle. The test tube represented science. Jonah linked the grassy field to the many fields of scientific research. Jonah also said that the blue circle suggested dawn when both harriers and scientists are up early working. This stereotype, as well as others,
surfaced in these boys' dialogue. Bill associated science with danger as in bombing. Jonah tapped the archetype of a scientist in a white lab coat working with lab rats.

The Harriers received these SMILE scores: 3.25 for Ton and Jonah, 1.75 for Bill, and 1.00 for Barry and David. Table 12 lists SMILE subscores. Ton and Jonah showed independence in their analogizing within their peer group. Bill showed potential to analogize. Barry and David gave little evidence of ability to analogize.

Table 12

Researcher SMILE Scores for Harriers in Activity 2

<table>
<thead>
<tr>
<th>Harriers</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.25</td>
<td>3</td>
</tr>
<tr>
<td>Bill</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Barry</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
</tr>
<tr>
<td>Jonah</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.25</td>
<td>3</td>
</tr>
<tr>
<td>David</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
</tr>
</tbody>
</table>

During Activity 2, the five members of the soon-to-be named Harriers got along without dissension. Each Harrier member contributed, but not equally to analogical thought. Ton and Jonah made the important connections of their animal symbol to the nature of science. Bill helped more as he began to understand the task better, but Barry and David remained quiet. Barry liked designing their emblem. According to their evaluations, Activity 2 was "easy," "clear," "creative," and "fun."

Close-up focus on Jonah. Jonah's report on a barn owl inspired his description of science. For example, he noted owls "like and mess with small animals especially rodents." It is likely that Jonah was thinking of scientists messing with rats in
a laboratory when he explained that scientists conduct experiments and report their research. Jonah engaged in analogical thought even if he did not express it in a "just so" manner.

Jonah held on to the literal while working toward the metaphorical world. Thinking of how harriers capture rats and mice, Jonah claimed harriers helped man by removing pesky rodents. From this specific helpful role, he generalized to science being helpful to people in "other deals, other departments." Jonah walked a fine line in giving very specific instances and generalizing from analogy.

Jonah drew on strong visual images of his owl and Ton's harrier to express his ideas about science. The emblem inspired him to name other characteristics of science. This visual element and peer support gave Jonah the boost he needed to assume the role of spokesperson for his group. It was good for the often silent and withdrawn Jonah to speak with confidence before his fellows.

Jonah earned a SMILE score of 3.25 for his analogizing during Activity 2. Jonah rated 4 in selection because he helped his group select the harrier. Jonah earned a 3 in mapping because he independently but indirectly mapped similarities of a barn owl with science and explicitly mapped similarities of the harrier to science in conjunction with his peers. Jonah's inference rating of 3 was based on his many inferences. Jonah got a 3 for judging the learning potential of the analogy that science is like a harrier.

Close-up focus on David. David researched and reported on the polar bear, but he did not understand the analogical part of the task. He mapped discovery of the polar bear to a scientist engaged in discovering, but for a proper mapping the polar bear needed to discover not be discovered. David used his first salient connection, without analyzing whether it was appropriate. David mainly listened to his peers.

David thought Activity 2 was "easy," "interesting," "clear," "well-structured," and "fun." He assigned 3 to motivation and challenge, and 4 to enjoyment and knowledge gain. David claimed he learned. He probably did learn about animals, but did he learn
more about analogizing by listening to his friends? This is possible because David listened intently to what his peers said.

David scored a 1.00 SMILE for expressed analogical development. He earned a 1 for selection because he named an analog but failed to support it. David's teacher-dependent state earned him 1s in mapping, inference and evaluation.

**Movie review: How the Harriers got their name.** "Who Will Symbolize Us?" included a variety of activities, so every member experienced success with some part or parts. Jonah did it all, even assumed the role of spokesman for his group. The visual imagery element appealed to his artistic nature. David researched his polar bear. Barry designed their group emblem. These boys chose an appropriate symbol for their understanding of science, for the harrier is patient, focused, and observant in pursuit of its prey.

**Activity 2: The Ferrets**

**Group movie: How the Ferrets got their name.** The team of Max, Jim, Eve, Mark, and Paula followed the outline provided for Activity 2, "Who Will Symbolize Us?" Together they listed scientific processes. Each member proposed an animal symbol: bull frog (Jim), black bear (Mark), tiger (Eve), kangaroo (Max), and ferret (Paula).

Jim and Mark gave researched-based reports, but the others gave brief spontaneous comments. No solo member built a strong case for his animal symbol. Although Paula simply described her ferret as a "quick, small, lively, curious, furry animal," the group voted for the ferret. Jim added that science is an uncommon profession like the endangered ferret is a rare animal. He related the ferret's preying upon small animals for food to scientists sacrificing animals for their research. Notice that both of Jim's mappings are science stereotypes. Max mapped ferret intelligence and observation to scientists. Mark associated the quickness of the ferret with the fast pace of science. It took a cooperative effort to build this defense.
Their emblem design inspired a true partnership. These teens made many preliminary designs. They even looked in a wildlife book for a ferret picture. They worked collaboratively to produce an excellent emblem. A big orange question mark stood against a blue sky and green grass. One ferret with a light bulb above its head poked out of a tunnel. This ferret's mound had the words "FERRET OUT!" printed on it. Another curious ferret stood on a box to place his nose at the top of a chemical flask filled with a liquid. They put a lot of effort and creativity into their emblem.

This researcher assigned the following SMILE scores for expressed analogical development during this second analogical activity: 2.00 for Jim, 1.75 for Mark, Max, Eve, and Paula. These SMILE scores, as listed in Table 13, indicate that these five students still needed support from their teacher and additional class instruction to improve their performance in analogical activities.

Table 13
Researcher SMILE Scores for Ferrets in Activity 2

<table>
<thead>
<tr>
<th>Ferrets</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eve</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Jim</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Mark</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td>Max</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td>Paula</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
</tbody>
</table>

Jim reluctantly led individuals whose participation waxed and waned according to their moods and abilities. Tension developed as members sensed inequality of participation. Group tension lifted once they chose to be Ferrets. Paula received a
boost by her peers' vote for her ferret. This validation kept her an enthusiastic participant in group collaboration on their emblem design.

**Close-up focus on Eve.** Eve did not do research on her tiger. She described the tiger as a "big, graceful, carnivorous cat* with a camouflage fur pattern. This did not allow for many connections to science. She connected the tiger's big size to lots of scientific information. At best this is an attribute mapping (Holyoak & Thagard, 1995) of size. She related carnivorous to intelligence of scientists. But not all carnivorous animals are intelligent. She may have been thinking of a tiger's smart hunting strategies. She barely grasped her analogical task. At least Eve made an independent attempt to make these mappings. Others did not even try. Eve did not help much with analysis of the ferret as a symbol for science. She was happy helping her group construct their emblem.

While Eve described Activity 2 as "hard" and "complex," she also selected "unusual* and "creative." She gave an "okay" rating for motivation and challenge and a "good" rating for knowledge gain and enjoyment.

Eve's SMILE score of 1.75 indicated her need for teacher guidance and class instruction to improve her analogical skills in science. She earned 2 for selection of the tiger and a 2 for mapping only a few connections between her tiger and science. For inference she rated a 1 because she depended on the teacher. For evaluation she rated a 2 for her cautious judgment of a tiger as a potential symbol for science.

**Movie review: How the Ferrets got their name.** Jim, Mark, Paula, Max, and Eve chose the ferret for their name because it appealed to them on an emotional level, and because they could make connections between a ferret and science to support their choice. They found the subject of animals intrinsically interesting. They did not
form a cohesive working group for analogical analysis, but they united in making an emblem rich in meaningful images. Eve enjoyed making the emblem, but she only had minimal success with her attempt to relate her tiger to science.

**Activity 2: The Red Foxes**

**Group movie: How the Red Foxes got their name.** The cooperative learning group of Mai, Kirk, Ching, Kevin, and Rika strictly followed the steps of the guidesheet "Who Will Symbolize Us?" To define the nature of science, these students named a smorgasbord of things studied by scientists and processes associated with the scientific method. Anxious to provide satisfactory images of science, these students sounded like they were recalling scripts from other science classes.

Next each student described their animal and tried to connect it to science. Mai said her chipmunks use their cheek pouches to store food and "scientists can store [information] in their brain that they don't need right away" (2: R, 3). Mai claimed chipmunk behavior was clever like scientists are. Rika related the way her "dolphins travel in schools" to the way "scientists work in groups" (2: R, 3).

Kevin noted that white rhinoceroses travel in groups or alone as a scientist may work in groups or alone. He said that a rhino's big ears allow it to be observant even if its eyes are small. He implied a mapping to scientific observation. He superficially mapped the rhinos' habit of eating at night to scientists being able to do that as well. Ching depended on cultural images of a fox to assign intelligence and patience to scientists. Kirk laughed as he described a sloth, then eliminated his lethargic animal as a symbol choice. Serious debate resulted in selection of the red fox.

In their class presentation, members named these three characteristics shared by a fox and a scientist: intelligence, patience, and observant nature. Mai connected a fox...
chasing after prey to the way scientists attempt to find cures. Kevin described the persistence of a fox in hunting and implied that scientists are persistent. Their group emblem consisted of a red fox walking across green grass with a tree in the distance. The sky was blue with a yellow sun and two fluffy white clouds. There was no obvious symbol for science.

While each individual, except Kirk, stated at least one supportable mapping, no one developed a rich set of mappings for his or her personal animal choice. As a group they assembled a solid set of metaphorical connections between the fox and science. The power of peer exchange of ideas recommended by Nodding (1990) was evident in this group's work. Through metaphorical thought, they produced an image of an intelligent, patient, persistent, observant scientist in search of answers to problems. This enriched their group's original depiction of science.

This team received the following SMILE scores: 2.25 for Mai, Rika, Kevin, and Ching, and a 1.5 for Kirk. The Foxes showed some independence in analogical thinking, but still needed support to accomplish their task. Table 14 lists their SMILE scores.

Table 14

Researcher SMILE Scores for Red Foxes in Activity 2

<table>
<thead>
<tr>
<th>Red Foxes</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mai</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>Kirk</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>1.50</td>
<td>2</td>
</tr>
<tr>
<td>Ching</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>Kevin</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>Rika</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>3</td>
</tr>
</tbody>
</table>
The uncertain Foxes required my encouragement. They gained some sense of security from following the guidesheet and from sharing responsibility. These young people commented briefly in fairly equal rotation, since noncontributing members were noticed by their fellows. By sticking together, they accomplished their task. Not wanting to talk to the class, these teens gave a brief, succinct presentation, but failed to explain their emblem.

**Close-up focus on Kevin.** Kevin took an enigmatic approach of combining serious contributions with joking comments. For instance, he pointed out the probing nature of science and then laughed as he remarked that science begins with S. He argued for his rhino on the basis of this animal's tendency to both join groups or seek isolation which matched scientists in groups or alone. After this reasonable analysis, Kevin quipped that scientists were homy like rhinos. This schizo-approach seemed to be Kevin's way of satisfying demands of the teacher, his need to distance himself from too much responsibility for the results, and his desire to entertain his peers.

Kevin guided the group in brainstorming about the nature of science. He offered praise for good effort. He provided Mai with the word "information" which she needed to complete her mapping. Kevin defended his rhino symbol for science with a few good mappings. His arguments were forceful enough that his animal placed second in the voting process. Kevin was a definite asset to his group.

Kevin' evaluation responses of "easy," "okay," "fun," "creative," and "unusual" indicated Kevin's approval of Activity 2. He recognized the challenge in the analogical task of mapping connections between an animal and science. Kevin was at home in this domain of science because he had zoo explorer experiences. He gave a "good" rating to challenge, knowledge gain, and enjoyment. He rated his motivation as "okay."

Kevin earned a SMILE rating of 2.25. His group chose the fox with input from the teacher so he rated a 3 in selection. He rated a 2 in mapping because he made good
similarity mappings, yet still needed teacher help to go farther. He earned a 1 for
inference since he was dependent on the teacher. His 3 for evaluation was based on
his group's evaluation of the fox as a symbol for science.

Close-up focus on Mai. Mai contributed to her group's discussion of the nature
of science. She relied on her knowledge from science classes or current projects. She
tapped the familiar scientific method to say that scientists test hypotheses. Her own
science fair project about fog primed her to say that fog and atmosphere are subjects
for scientific study. As she declared science was fun, she pointed at a class bulletin
board that stated "Science is Phun." On familiar ground, Mai was confident.

Mai chose a common chipmunk, rather than some exotic animal. The image of
chipmunk cheeks filled with nuts prompted her to connect chipmunks and scientists
because both store something. Chipmunks store food; scientists store information.
Mai added that both scientists and chipmunks are clever for storing what they will
need. Her mappings were limited, but she owned them.

Her friends encouraged Mai to express her ideas. Kevin asked her for input and
praised her when she tried, "Mai said that so she used a scientific term [hypothesis]"
(2: R, 2). When it was time for her to report on her chipmunk, Kirk told her "Okay, go
for it." (2: R, 2). Rika gave her first vote to Mai's chipmunk. In a variety of ways, Mai's
friends encouraged her to participate.

Mai evaluated Activity 2 as "comfortable," "okay," "clear," "well-structured," and
"fun." Mai's ratings of 5s for motivation, enjoyment, challenge, and knowledge gain
indicated Mai had a very good experience with this activity. Mai learned about five
animals, gained courage to speak about science, and made several analogical
connections on her own. She felt good about herself.

Mai's SMILE rating of 2.25 indicated that she had shown her ability to analogize,
albeit with support from her friends and teacher. She earned a 3 for selection
because she worked with her group along with teacher input to select the fox. She received a 2 for mapping based on her two connections of her chipmunk to science. Her 1 for inference indicated her dependence on a teacher. She rated a 3 for evaluation because she helped her group evaluate the symbolic value of the fox to represent science.

**Movie review: How the Red Foxes got their name.** Kevin, Mai, Ching, Rika, and Kirk cautiously approached each step of Activity 2. These students encouraged each other to contribute because no one wanted to work alone. Mai especially gained from this environment because it brought her out of hiding and allowed her to claim her scientific voice that had been muffled. Kevin assumed leadership within his group, which he never did within a class situation. Mai and Kevin seemed inspired to analogical thought by their chosen animals. Together these shy but clever young people chose the Red Fox to represent them and their vision of science.

**Activity 2: The Snakes and the Lions**

**The Snakes.** The Snakes first chose their snake because of its beauty. Then they supported their choice with analogical connections to science. Tina mapped danger to snakes and scientists. Helen claimed that scientists were smart like snakes and supported this idea with an account of a snake that could unlock drawers to get out. Jack linked a snake's fast moving pace to the way science keeps moving and building knowledge. Omar focused on the protective posture of a snake in the area of its nest and noted that scientists protected their lab area by requiring identification for entrance. June made their emblem of a beautiful coiled cobra with its head raised.

**The Lions.** The Lions chose their symbol by guessing a number. Sandra noted lions hunt prey like scientist hunt information. Thinking of a pride of lions, Treasure stated that scientists relied on organization. She also linked the trial and error
approach of lions hunting to a similar approach used by scientists in searching for answers. Crystal compared lions who kill their prey to scientists who kill research animals. Notice this stereotype of a scientist. Sarita said both lions and scientists study nature. Letitia said lions hunt in a place and scientists work in a place, which provided no insight into the nature of science. Their emblem simply depicted a lion.

**Activity 2: Summary**

Each cooperative learning group took a unique route to name their group, yet there were shared elements among groups. How did participation in analogical Activity 2 affect Hour 5 student learning of biology, student development of analogical thought, the quality of group interactions, and the quality of teacher-student interactions? How did student experiences in fifth-hour compare to the counter experiences of sixth- and seventh-hour students?

**Activity 2: Learning Science**

Activity 2 involved students in choosing an animal name for their cooperative group. Sixth- and seventh-hour students participated in their nonanalogical Activity 2, "What Animal Will Be Placed on Your Emblem?" They enjoyed learning about animals through research about their own chosen animal and from hearing within group and class presentations about other animals. Talking about animals provided students with a respite from molecular and cellular topics of first semester Biology I.

Fifth-hour students participated in their analogical Activity 2, "Who Will Symbolize Us?" Like their peers in Hours 6 and 7, they enriched their knowledge of specific animals through individual research, within group discourse, and class presentations. In addition, they reflected on their understanding of the nature of science. More accustomed to hearing teachers define science, these teens were pressed to seriously
consider how to describe science. Each group gave a unique explanation including items relevant to such topics as scientific processes, science subjects, scientific method, characteristics of scientists, and roles of science in society. Even though their explanations were tentative, incomplete, and perhaps too much derived from science lessons from the past, they did talk about their visions of science. The analogical task to relate their chosen animal to their view of science expanded each group's first description of science, as did hearing other group's explanations.

**Activity 2: Development of Analogical Thought**

Nonanalogical Activity 2 was not designed to encourage analogical thought; and yet, choosing an animal name certainly offered a chance for students to think of choosing their animal in terms of its symbolic value. But without direct instructions to do so, few students argued for their animal as a symbol for their group. Most groups made up a reason for their animal choice during their class presentation.

Fifth-hour students moved beyond their analogical Activity 1 by selecting their own analog for the target concept and mapping more than one similarity between the analog and target. At least the target, nature of science, was more familiar to these students and the animal analogs had a natural appeal to students. While individual students usually cited only one or two reasons to support their personal animal choice, groups gave at least five supporting arguments for their chosen animal symbol. Group dialogue helped students move to more complex mappings of shared traits, whereby, science could be said to be like a specific animal in many ways.

Fifth-hour students differed in their abilities to use analogical thinking to relate an animal to science. The most capable analogizers stayed open to possibilities, subjected each potential mapping to critical judgement, and explicitly stated their mappings. Less skilled analogizers were less open to possible mappings, less critical in
evaluating their mappings, and more likely to simply imply mappings. A few students failed to make any analogical connections, or made incorrect or trivial connections.

**Activity 2: Quality of Group Interactions**

Hour 6 and 7 students were fascinated with the animal subject and comfortably talked about their chosen animals. Peer interaction was minimal as individuals presented their animal to their learning group. Without any guidelines for making a decision, members chose an animal name for their learning team in a haphazard way. Voting without a clear purpose caused tension among some groups' members.

The appeal of animals as subjects promoted a friendly interchange among fifth-hour peers. The variety of tasks that composed Activity 2, "Who Will Symbolize Us?", allowed all members to participate at some level. Equitable contribution promoted peaceful group interactions and reduced anxiety. Selection of an animal name was guided by the necessity to relate this animal to the nature of science. Students with a better grasp of analogizing helped model the process, thereby, assisting their group through this phase of Activity 2. Each cooperative group succeeded in explaining how their animal symbol represented the nature of science.

The format of Activity 2 encouraged students toward personal involvement. For example, Afro-American Pelicans depicted their symbolic scientist as black. The Lions talked about their hopes to become scientists. Artistic students were drawn to the task of emblem design. Personal affective responses were important elements of group encounters.

**Activity 2: Teacher-Student Interactions**

Sixth- and seventh-hour students independently researched their animals and presented their animal to their group. My intervention was necessary when members of a group could not agree on which animal to choose. I acted as mediator for some students who were unhappy with the outcome of their group vote.
I urged fifth-hour pupils to adhere to the Activity 2 guidelines as an important organizational tool. Fox members gained solace in following the steps, but the Harriers complicated their task by resisting the structural guidelines. Fifth-hour students tentatively discussed their ideas about science and confidently gave their animal reports. My support was most critical when students tried to connect their animal to science. Teacher or peer modeling of the process of analogizing helped some students succeed. Three groups followed a guideline to add symbols of science to their animal emblem. The Ferrets did this only after I gave them verbal directions. They produced an effective design that linked their ferret and science. Placing verbal emphasis on certain guidelines increased the likelihood that such a guideline would be followed.

**Activity 2: Analysis Implications**

Students in all classes found their Activity 2 to be enjoyable, non-text based, individualized, and not too difficult. They liked the animal subject matter, the comfort and freedom of working within cooperative groups, the right to choose a name for their group, the artistic challenge of making an emblem, and audiotaping. But student experiences with analogical or nonanalogical Activity 2 were also different.

While sixth- and seventh-hour students learned factual information and practiced their research and communication skills, they did not transform the animal information that they collected. Even deciding on their name was a popularity contest. While they liked their easy Activity 2 "What Animal Will Be Placed on Your Emblem?", some wanted a more complex and more purposeful activity.

Addition of the analogical element added quality to fifth-hour's "Who Will Symbolize Us?" Groups moved beyond the challenge of analogical Activity 1, in which students analyzed teacher-provided similes and mapped one shared characteristic per simile. During Activity 2, groups selected their own animal symbol for science and mapped at least five similarities between their animal analog and the target, nature of science. This transition to greater responsibility in analogizing was facilitated by a less alien
target as compared to biochemistry. While learning from their peers about analogizing, less skillful analogizers contributed in other ways. Some students developed a better understanding of the analogical task as they worked. Fifth-hour students worked on higher level thinking skills of analogizing, evaluating, analyzing, and decision making. Analogical Activity 2 was more challenging, required more thought, demanded complex student dialogue to arrive at a decision based on their own understandings of science.

**Activity 2: Reflections on Specific Students**

How did each student selected for close-up attention fare during Activity 2?

Brief summaries follow to describe the participation of each of these students.

**Pelicans: Ed and Keisha**

Ed was involved, open to possible analogical mappings, sensitive to visual imagery, and very knowledgeable. He was a strong contributor to Pelican efforts. He needed to express his mappings more clearly and completely. While still somewhat dependent, he maximized the benefits of teacher guidance. Ed earned a 3.00 SMILE score.

Keisha was more comfortable analogizing about animals and science than she had been with biochemistry. She learned from her peers' modeling of analogy. Thinking of her cuddly marmoset, Keisha not only identified characteristics of scientists, but was able to transfer these mappings to the group's Pelican. Keisha gained confidence as she fully participated in Activity 2. She still depended on her peers and her teacher for some guidance. Keisha earned a 2.75 SMILE score.

**Harriers: Jonah and David**

Jonah showed strong ability to think analogically through visual imagery. He expressed such thoughts by implying linkages between his barn owl and his view of science. Jonah's explicit mappings of a harrier to science suggests that Jonah learned from Tom's example of explicit mapping. Jonah added his own twist by mentioning very literal and specific examples to support his metaphorical links. Autistic Jonah gained in
terms of peer acceptance, peer appreciation of his artistic emblem design, and peer selection as the Harriers' spokesperson. Jonah earned a 3.25 SMILE score.

David researched and reported on a polar bear, but made only one analogical connection. He stated the most easily retrieved similarity and then did not assess the quality of his improper mapping. He followed his peers and teacher. David enjoyed Activity 2 and liked working with his friends. David earned a 1.00 SMILE score.

**Ferret: Eve**

Eve found it difficult to identify metaphorical links between her tiger and science. Her sense of inadequacy in the face of any scientific subject and her failure to research information about a tiger contributed to her difficulty. She made two attempts that had potential, but she did not really understand what was required to support her analogy. During Activity 2, Eve depended on her teacher and peers to help her learn more science and better understand analogizing. Eve was very sensitive to the turmoil that was often part of Ferret interactions. Eve earned a 1.75 SMILE.

**Red Foxes: Kevin and Mai**

Kevin played multiple roles of reluctant co-leader, humorist, supportive friend, and novice analogizer. He made several good mappings from his rhino to science. Kevin's love for animals and his familiarity with traditional ideas about science made Activity 2 comfortable for him, even though he recognized the complexity of analogical thinking. Kevin was reluctant to stand out from his group, and even more reluctant to speak before the whole class. Kevin earned a 2.25 SMILE.

Mai offered her enthusiastic voice during Activity 2. She had more knowledge of animals and the nature of science, than she had of biochemistry, the target of Activity 1. Mai's confidence grew as she made two connections of her chipmunk to science. She still depended on peers and teacher. Mai earned a 2.25 SMILE score.
Activity 3

Activity 3: Analogical versus Nonanalogical

Activity 3: Black and White Photo Shots

Scientific subject. The target for Activity 3 was DNA and genome. One DNA (deoxyribonucleic acid) molecule contains many genes. Each gene is a particular segment of DNA. A DNA molecule with associated proteins forms a chromosome. An organism's genes have particular locations on specific chromosomes. Genes contain coded information that controls heredity and protein synthesis. Genes determine the structure and function of an organism through their control of the proteins made in the organism's cells. An organism's entire set of genes located in the nucleus of every body cell is called a genome.

DNA is formed from the union of nucleotides. Each nucleotide is composed of a sugar, a phosphate, and one of four different nitrogen bases (adenine, guanine, cytosine, and thymine). Genetic information resides in the sequence of the nitrogen bases. Three nitrogen bases [a codon] code for one amino acid. A structural gene contains the code for specific amino acids and the specific order of linkage of these amino acids to form a protein.

Student preparation. Students in this study were familiar with genes on chromosomes in cells and that many genes are contained within one DNA molecule. They knew that genes are copied and passed on from cell to new cells and from one generation to the next (heredity), and that genes control the process by which cells make proteins (protein synthesis). To learn how a DNA controlled these processes, students listened to lectures, simulated the processes of copying DNA and making...
proteins, watched a film on DNA, and extracted DNA from a thymus gland. They did Activity 3 to solidify their knowledge of DNA, genes, and genomes.

**Activity 3 descriptions.** Hour 6 and 7 students did the nonanalogue Activity 3 paper lab, "DNA and Its Structure" (Otto, Towle, & Otto, 1981). It involves: analysis of a classic DNA experiment; labeling a paper model of DNA; making a paper model of a segment of DNA; and responding to questions about DNA's structure and function.

Hour 5 students did analogical Activity 3 "Can You Make the Connection?" (see Appendix P). They analyzed the analogy that "A genome is like an encyclopedia." Students drew on their prior experiences with Activity 1, for which they mapped one similarity between an analog and target of each simile, and evaluated the mappings.

For Activity 2, they selected their own analog and identified similarities between their animal analog and the target, nature of science. Activity 3 required identification of dissimilarities, as well as similarities between an encyclopedia (analog) and a genome (target). Noting differences helps students enrich their conceptual understanding and may inhibit transfer of analog properties that do not fit the target concept. Harrison and Treagust (1993) warn that it is important to help students avoid such improper transfers.

Activity 3's guidesheet is based on Harrison and Treagust's (1993, p. 1293) modified version of Glynn's (1991) Teaching-With-Analogies model. The guidesheet "Can You Make the Connection?" provides directives to define the target concept and the analog; identify similarities and dissimilarities between the analog and target; synthesize a statement of conceptual understanding of the target based on these like and unlike mappings; and judge the analogy for its educational benefit.

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Activity 3: Panoramic Photos Taken from Researcher Vantage Points

Nonanalogical path. Hour 6 and 7 students felt challenged by their paper lab. "DNA and Its Structure." Groups who did not recall class discussion of the cited DNA experiment had to reread a description of the experiment in order to explain it. When labeling a DNA model, some students had difficulty naming chemical bonds of DNA or had trouble pairing the correct nitrogen bases together [adenine to thymine and guanine to cytosine]. Some pupils struggled with questions related to DNA's composition and the importance of such knowledge.

Some students felt stressed. Both Cora and Kirsten lost patience with less prepared members' neediness. Some students resented repetitive questions. Webb wanted his peers to listen to him. He doubted that he needed to know DNA's structure anyway. Kay wondered, "Since we are never going to see these, what purpose do they serve?" Thinking on the tiny scale of molecules was taxing for students. Many students requested help with this third group activity. As teacher, I circulated to boost student confidence, reroute wandering members, praise good efforts, quiet noisy groups, help perplexed students, provide academic guidance, and repeat instructions.

But, most group interactions went smoothly as these teens worked cooperatively to learn and reinforce their understanding of DNA. Friends helped friends. Venus explained the experiment to Zoe, who humbly said, "Thank you for pointing that out to me. I feel like a blunderbuss." Monika energetically helped her confused Jaguars. When her grateful friends wondered how she knew so much, she teasingly pointed out that she had learned something during their two-week study of DNA.
Group success with nonanalogical Activity 3 ranged from nearly perfect papers to about 80% correct. Students took about one hour to complete this paper lab. Class review of "DNA and Its Structure" provided remediation for groups who had answered some questions incorrectly. "DNA and Its Structure" provided a useful review of DNA's molecular structure and function.

**Analogical path.** The analogical Activity 3, "Can you Make the Connection?", challenged fifth-hour students to use their knowledge of DNA and genes to analyze "A genome is like an encyclopedia." Students needed careful preparation for this daunting task. They needed a model.

Using a guided teacher strategy (Zeitoun, 1983) and the guidesheet for "Can You Make the Connections?", I guided fifth-hour class through analysis of the analogy "Respiration is the fire of life" (see Appendix Q for hypothetical responses). Students defined respiration using their text, brainstormed to describe fire, identified similarities and dissimilarities between fire and respiration, and explained their understanding of respiration based on their analysis of the analogy. Their mappings from the fire analog to the target respiration closely resembled those of students in the pilot study (Hackney & Wandersee, 1997). Of 20 students who answered whether the activity helped them learn, 17 said yes.

With guidelines in hand and experience with the class model, fifth-hour groups began analysis of their assigned analogy. First, students tried to define the targets DNA and genome. DNA was a familiar concept, and genome was an unfamiliar name for a familiar concept--that each cell of an organism contains a complete set of genes. Students wrote down DNA and genome information from their biology text. Next they described an encyclopedia.
For steps three through six, these young people identified similarities and
dissimilarities between an encyclopedia and DNA genome; and recorded their
understanding of a genome and DNA based on their comparison and contrast of the
analog and target. This analytical process required active involvement and deep
thought. Students were not always secure about their responses, but most
persevered. They talked science as recommended by Lemke (1990) and took comfort
in sharing the responsibility for analysis of the analogy. Their discussions exemplified
the fluidity of the analogical process (Hofstadter, 1995). Groups both converged and
diverged in the ways they related an encyclopedia to a DNA genome. Analogical
Activity 3 took students two and one-half hours to complete.

My guide role was very important during Activity 3. Students required group
instructions to augment class instructions. Students wanted help with the challenging
scientific target. A few groups needed help with organization. Most students seemed
focused and motivated to learn more about DNA and especially their human genomes.

Activity 3: Panoramic Photos Taken from Student Vantage Points

Student evaluations. Students' views expressed in evaluations provide
important insights into student experiences with Activity 3. From sixth hour, 30 of 31
students completed evaluations; 24 of 29 fifth-hour students completed evaluations.
No seventh-hour students completed evaluations.

Selection of adjectives to describe activity. Table 15 lists the percentage
of student assessors who circled selected adjectives to describe their Activity 3.
Horizontal reading will facilitate comparison of students' responses. A slight majority
of students in both classes found their activity "comfortable" and "okay." But this
leaves a lot of students with different opinions. In terms of comfort level and other
qualities, sixth-hour students tended to favor a different set of adjectives. More sixth-hour students than fifth-hour students described their nonanalogical activity as "interesting," "clear," "easy," "understandable," and "typical." More fifth-hour students than sixth-hour students described their analogical activity as "complex," "hard," "tedious," "unusual," and "open-ended."

These responses suggest that nonanalogical Activity 3 was a moderate challenge and a conventional, well-structured, accessible learning activity for sixth-hour students; and that analogical Activity 3 was a more difficult challenge, a nonconventional, open-ended learning experience. Students perceived both activities as rather serious academic activities, but many fifth-hour students even described Activity 3 as tedious.

Identification of activity processes. Table 16 lists percentages of evaluators who identified each process as part of their Activity 3. Horizontal reading of this table is recommended for comparison and contrast. Cross comparison of percentages indicate that a majority, or close to a majority, of evaluators of either Activity 3 identified: "thinking," "discussing," "learning," "communicating," "researching." It is interesting to note that fifth-hour students placed greater emphasis on "thinking" during their analytical activity; and sixth-hour students emphasized "learning" and "remembering" during their didactic activity.

Other identified processes further highlight disparity between the two activities. Many sixth-hour students emphasized "drawing" done to make a DNA model and "problem solving" and "choosing" needed to label a DNA model and correctly match nitrogen bases. Many fifth-hour students emphasized the "analogical" nature of their Activity 3 and the need to "evaluate" their mappings and "categorize" their mappings as similarities or dissimilarities.
Table 15

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 3

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comfortable</td>
<td>54</td>
<td>57</td>
</tr>
<tr>
<td>Well-structured</td>
<td>33</td>
<td>40</td>
</tr>
<tr>
<td>Okay</td>
<td>58</td>
<td>50</td>
</tr>
<tr>
<td>Creative</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Fun</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Interesting</td>
<td>17</td>
<td>30</td>
</tr>
<tr>
<td>Clear</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Easy</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td>Understandable</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Typical</td>
<td>38</td>
<td>56</td>
</tr>
<tr>
<td>Complex</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>Hard</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Tedious</td>
<td>38</td>
<td>13</td>
</tr>
<tr>
<td>Unusual</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>Open-ended</td>
<td>46</td>
<td>7</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

a Only adjectives circled by at least 25 % of either Hour 5 or Hour 6 and 7 evaluators are listed.

b $n = 24$ evaluators out of 29 fifth-hour students.

c $n = 30$ evaluators out of 31 sixth-hour students.
### Table 16

**Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 3**

<table>
<thead>
<tr>
<th>Process(^a)</th>
<th>Analogical(^b)</th>
<th>Nonanalogical(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking</td>
<td>96</td>
<td>73</td>
</tr>
<tr>
<td>Discussing</td>
<td>88</td>
<td>80</td>
</tr>
<tr>
<td>Communicating</td>
<td>83</td>
<td>87</td>
</tr>
<tr>
<td>Researching</td>
<td>54</td>
<td>47</td>
</tr>
<tr>
<td>Learning</td>
<td>48</td>
<td>73</td>
</tr>
<tr>
<td>Categorizing</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>Analogizing</td>
<td>42</td>
<td>3</td>
</tr>
<tr>
<td>Evaluating</td>
<td>38</td>
<td>10</td>
</tr>
<tr>
<td>Remembering</td>
<td>33</td>
<td>57</td>
</tr>
<tr>
<td>Choosing</td>
<td>29</td>
<td>60</td>
</tr>
<tr>
<td>Problem solving</td>
<td>21</td>
<td>40</td>
</tr>
<tr>
<td>Drawing</td>
<td>0</td>
<td>37</td>
</tr>
</tbody>
</table>

**Note.** Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

\(^a\)Only processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

\(^b\)\(n = 24\) evaluators out of 29 fifth-hour students.

\(^c\)\(n = 30\) evaluators out of 31 sixth-hour.
Student rating of activity in 10 categories. Table 17 lists class means of student evaluators' ratings of Activity 3 in 10 categories. These ratings are suggestive of class trends. These ratings suggest that students who rated either analogical or nonanalogical Activity 3 were very pleased with their cooperative learning groups, teacher input, and age level for activity. While still satisfied with directions and time for the activity, fifth-hour students gave a 0.5 lower rating to activity directions and activity time than sixth-hour students. Possibly the analogical activity was more demanding, even though both classes gave a 3.5 rating for challenge. Hour 5 ratings also lag 0.5 in the categories of motivation, enjoyment, and knowledge gain. Overall these ratings are okay to good, but fifth-hour students seem somewhat less satisfied.

This dichotomy can perhaps be explained by fifth-hour students' exposure to the pressure of analytical work concerning a complex subject. The complexity and limited student experience with the format of this third analogical activity may have made some students less motivated. The "okay" rating for enjoyment seems appropriate for this analogical activity since it didn't include any "fun" elements like the DNA model construction of nonanalogical Activity 3.

Additional comments. Written comments were provided by 9 fifth-hour students and 10 sixth-hour students. In general sixth-hour students' written comments were favorable, while fifth-hour students' written comments were less favorable. Student comment topics included audiotaping, group work, subject matter, directions, time involved, and overall reactions.

Ed in fifth hour praised the audiotaping for promoting reflection on group responses. "It was cool, because we were using recorders and we could play back and hear what we were saying, and think about it." Sarita, a fifth-hour pupil, appreciated
Table 17

Comparison of Mean Category Ratings by Students for Their Activity 3

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nonanalogical&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Time involved</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Age level</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Motivation</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>3.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

<sup>Note.</sup> The rating scale is: 1= bad, 2 = poor, 3 = okay, 4 = good, 5= excellent. Calculated means are rounded to the half-decimal.

<sup>a</sup>n = 24 evaluators out of 29 fifth-hour students.

<sup>b</sup>n = 30 evaluators out of 31 sixth-hour.
"the fact we get to work together with others." Several sixth-hour students shared
the same view. Aaron and Abel liked choosing their own group members.

Some fifth-hour students complained. Max and Eve wanted more directions and Eve
needed more time. Bill thought that the two days needed to do their activity
interrupted his thought and made it more difficult to answer the last questions. Jim
noted, "It just didn't have that little perk that catches my interest." Jack "felt that
the idea of categorizing things was good, but it sort of lacked interest to me
personally." Sarita was "bored" with "answer[ing] questions." Paula explained, "I just
don't enjoy or get motivated for anything at school." Michelle said Activity 3 was
good.

Sixth-hour gave comments of praise. Lynette enjoyed "having challenging things
but plenty of time to do it in." Gina "liked this project very much." Cordelia felt, "You
just use common sense to figure the problem out." Millie "learned a lot from this
particular [DNA] chapter." Colette praised her nonanalogical Activity 3 as "a good
activity. There aren't many that are interesting dealing with DNA."

Again a few students praised audiotaping and group work. Sixth-hour students
seemed satisfied, but some fifth-hour students were not. Perhaps difficult analytical
work lacked appeal for some students. Bill's complaint that the activity was
interrupted is valid. It would be better if Activity 3 could be completed in just one day.
Four Ferrets made negative comments about teacher directions, time, and interest
level. These struggling, distracted Ferrets cast blame from themselves. Responsibility
for their problems may be shared among teacher and students.

Collage of student viewpoints. Evaluators effectively captured the nature of
their Activity 3. Sixth-hour students stressed their group discourse, importance of
checking DNA related information, thinking, and learning a lot. Fifth-hour students stressed these same processes, but placed more emphasis on the thinking required for their analytical and analogical assignment.

Students liked cooperative learning groups and audiotaping. All classes faced a challenge in their DNA subject. Hour 5 students had more difficulty with their analogical Activity 3, than the students engaged in the nonanalogical Activity 3. While a majority of Hour 5 students felt comfortable with their demanding analogical task, a quarter of fifth-hour student evaluators claimed poor motivation, and some voiced complaints of tedium.

Reflections on the Panoramic Views of Activity 3

Students enjoyed the cooperative group work and seemed at ease with taping their conversations. The difficult subject led to calls for teacher help in all biology classes. Both activities were challenging. The traditional paper lab on DNA stressed knowledge, memory, and application of knowledge. Favorable student responses validate its inclusion within a biology curriculum.

Mixed student responses to "Can You Make the Connection?" point to the importance of a closer look. Analysis of a scientific analogy required students to learn and remember information, to compare and contrast traits of two things drawn from different domains, to evaluate the quality of the connections named, and to synthesize this information. Some students were not naturally inclined to such disciplined thought. They resisted. Is not some student discontent worthwhile if it leads to student growth? But was analogical Activity 3 an effective learning tool? Were students capable of difficult analytical work? To gain more insights, it is time to visit the fifth-hour groups in action with their third analogical assignment.
Activity 3: Analogical Groups

Activity 3: The Pelicans

Group movie: Pelicans dive for meaning. Boris's departure at mid-year left four Pelicans to analyze "A genome is like an encyclopedia." They followed the guidelines of "Can You Make the Connections?" First they talked about the analog (encyclopedia) and target (genome composed of DNA). Ed and Randy used their text to define DNA and genome. Keisha and Michelle described an encyclopedia.

Members identified shared characteristics of an encyclopedia and a genome—both provide organized information conveyed through symbols. The Pelicans noted these differences: an encyclopedia is alphabetically organized, while genes of a genome are ordered on chromosomes; reference information is kept in a book, but genetic information is stored within a person; many people understand an encyclopedia, but a genome makes sense inside a particular body.

The Pelicans noticed that letters form words and words form sentences in encyclopedias, and saw a similar meaning-building process at work in DNA. They mapped letters used in an encyclopedia to letters used to signify DNA's nitrogen bases. They noted that the whole alphabet is used in books, but only four letters are used to represent DNA's nitrogen bases, which in combinations of three form "words" [that "mean" or code for amino acids]. They noted that real words may be longer than three letters, but "words" in genetic language are always three "letters." They fumbled when they matched phrases or sentences directly to protein. The three letter genetic "words" combine to form the genetic code for how to assemble a protein.

How well did these high school analogizers tap the power of this well-accepted analogy used by professional biologists (Dawkins, 1986; Wilson, 1992) to explain a
genome? Gentner's qualities for effective analogies—clarity, richness, abstractness, and systematicity (Mitchell & Hofstadter, 1995)—may be used to evaluate these students' success in analogical analysis.

The Pelicans developed rich mappings of four similarities and eight dissimilarities. They stated some mappings clearly as when Keisha said, "An encyclopedia is organized alphabetically, and a genome is organized by genes on chromosomes." Other mappings were less clearly stated. Randy noted that letters are involved with both an encyclopedia and a genome. "In an encyclopedia you could have like different volumes A, U, G; and in a genome, you could have the different nitrogen bases. They are A, U, G and stuff like that." Later Brandon added, "And the words they like in an encyclopedia could be like cat or cat and CAT for the nitrogen bases" (3: P, 2).

Randy's explanation lacked clarity. He also erroneously named U for uracil, a nitrogen base in RNA, not DNA. The group referred to three nitrogen bases as a "word" without explaining that this triplet code is a "word" for an amino acid. Ed had stated it in explaining DNA, yet the team did not reiterate this point when it was needed for clarity.

DNA and genomes involve abstract molecular and cellular concepts. The Pelicans tried to relate an encyclopedia to these abstract concepts by their reference to DNA's molecular structure and to the chromosomes of a cell. They seemed to realize the danger of literal mappings. Randy wrote on his guidesheet, "It [analogy] does not work [to explain the scientific concept] when you are trying to read the 'phrases' of DNA genomes because they do not really make real sentences."

The Pelicans sometimes had problems meeting Gentner's (1983, 1986) structure-mapping standards of "one-to-one correspondence" and "systematicity." They
mapped letters to nitrogen bases, words to triplets of nitrogen bases, but then mapped both phrases and sentences to a protein. By naming phrases and sentences, two concepts, they broke the rule for one-to-one mapping. They failed to be systematic when they skipped gene and jumped to a protein as the counterpart to a sentence. A systematic mapping for sentence is to a gene’s sequence of nitrogen bases, which carries the code for a protein.

Pelicans SMILE ratings for Activity 3 were: 3.00 for Ed, 2.50 for Randy, and 2.00 for Keisha and Michelle. Ed and Randy seemed more independent in their analogical thinking than Keisha or Michelle in February, 1997. See Table 18 for subscores and SMILE levels.

Table 18

Researcher SMILE Scores for Pelicans in Activity 3

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3.00</td>
<td>4</td>
</tr>
<tr>
<td>Randy</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2.50</td>
<td>4</td>
</tr>
<tr>
<td>Keisha</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2.00</td>
<td>4</td>
</tr>
<tr>
<td>Michelle</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2.00</td>
<td>4</td>
</tr>
</tbody>
</table>

The boys assumed leadership as implied by Ed’s introduction of himself as "show host" and Randy as "show host coordinator." Michelle gave herself a humble title, "staff member," and Keisha chose to hum in the background (3: P, 1). All spoke confidently on their Pelican tape. Each member took a turn naming analogical connections.
The Pelicans viewed Activity 3 as an enjoyable, reasonable, and educational task. They believed the analogy helped them to understand more about DNA and genomes. To add a deeper dimension to this view, Ed and Keisha will again receive special attention.

**Close-up focus on Ed.** Ed described the structure and function of DNA. He correctly pronounced deoxyribonucleic acid for which DNA is an acronym. Ed prompted Randy when he faltered in his mappings. Ed said, "Genome, info, information about you, letters, AUG, nitrogen bases" (3: P, 2) to give Randy an outline to follow. Randy proceeded to associate specific letters with nitrogen bases. Probably Ed shaped the group's more abstract mappings.

With characteristic flair, Ed pretended to be a "show host" for their taped analysis. Ed clearly encouraged his group to use their taped discourse as an aide to reflection: "We could play back and hear what we were saying and think about it. Then we could change our answer if we didn't like [it]." Possibly, Ed wrote this to justify his group's recording only their final responses.

Ed preferred to audiotape only a polished performance. I respect his desire for group reflection and for a right to revise responses, yet this was possible without cutting out preliminary thoughts. Naturally as a student, he did not consider the effect of tape editing on research data collection. Ed focused on his responsibility to do this activity well.

Ed described his experience as: "comfortable," "interesting," "understandable," "fun," "open-ended," yet "well-structured." Ed received a 3.00 SMILE score for his expressed analogical thought. He used the assigned analogy to earn 1 for selection. He rated a 4 for mapping and evaluation because his group judged the analogy on the
basis of the similarities and differences and he played a key role in shaping his group’s mappings. He received a 3 for his inferences of the most abstract mappings.

**Close-up focus on Keisha.** Keisha contentedly described the familiar analog. “To me, an encyclopedia is a book that you look up information about things you don’t already know.” She explained how to look up something in an encyclopedia, “letter first, then the word, and then the phrase” (3: P, 1). Notice that inclusion of the term “phrase” later caused some of the group’s difficulty in systematic mapping. She added that reference books are divided into sections. This primed her to consider if genes are organized into sections. Randy’s mention of chromosomes in relation to genome was a helpful hint. Keisha was able to state that organization of an encyclopedia is based on the alphabet, but that genes have special locations along chromosomes [of a genome]. As the activity proceeded, Keisha’s understanding of a genome improved.

Keisha depicted her experience as “comfortable,” “interesting,” “clear,” “creative,” and “fun.” She rated motivation and challenge as “okay” and gave “good” ratings to enjoyment and knowledge gain. Keisha favored Activity 3. Keisha’s SMILE rating was 2.00. She accepted the assigned analogy and earned a 1 for selection. She rated a 2 for mapping since she was able to make one mapping on her own, but still needed more instruction on genomes. She received 1 for inference because she depended on others for inferences. She earned a 4 in evaluation for her part in her group’s judgement of the analogy for its learning potential in terms of similarities and dissimilarities.

**Movie review: Pelicans dive for meaning.** The Pelicans plunged into metaphorical waters to collect a school of similar fish and quite a few different fish. This team deserved credit for their rich nettings of similarities and differences between an encyclopedia and a DNA genome. Ed again showed particular agility in capturing...
metaphorical meaning; while Keisha continued to learn more science and develop her analogical thought through immersion in her learning group activity.

**Activity 3: The Harriers**

*Group movie: Harriers capture meaning.* To establish a foundation for their analysis of "A genome is like an encyclopedia," the Harriers defined genome and DNA. Bill and David impressed their friends with information that a human genome consists of about 100,000 genes located on a set of 46 chromosomes. The team described an encyclopedia as a set of reference books that offers information about many topics arranged in alphabetical sequence. These books differ in type, color, and size.

The Harriers identified these similarities between an encyclopedia and genome: (a) both contain information; (b) information is arranged in some order; (c) meanings are built through combination of symbolic code units; (d) letters are in an encyclopedia, and letters signify the nitrogen bases of DNA; (e) topic space varies in an encyclopedia and gene size varies in a genome; and (f) both may be duplicated.

Harriers named these dissimilarities: (a) an encyclopedia covers many topics, but a genome covers only body structure and function; (b) an encyclopedia cannot make an organism, but a genome directs the formation of an organism; (c) encyclopedias are man-made, while genomes are made by nature inside an organism; (d) an encyclopedia is made of paper, but genomes are made of DNA nucleic acids; (e) an encyclopedia uses 26 letter symbols, but only four letters relate to DNA; and (f) letters signify sounds in an encyclopedia, but letters signify nitrogen bases (e.g., A = adenine) of DNA.

They made these faulty associations: (g) there are words and phrases in an encyclopedias, and "words" or "phrases" of a genome are genes or amino acids; and
(h) there are sentences in an encyclopedia, and "sentences" of a genome are a DNA strand.

In terms of Gentner's qualities (clarity, richness, abstractness, and systematicity) for an effective analogy, how well did the Harriers tap the power of this analogy used by expert biologists (Dawkins, 1986; Wilson, 1992)? There was richness in the Harriers' analysis of "A genome is like an encyclopedia." They identified well seven similarities and five dissimilarities between an encyclopedia and a genome. Their analysis involved discussion of a genome on increasingly abstract levels from organismic to cellular to molecular.

They stated some mappings clearly, but others not so clearly. For example, when Bill noted that the letters A, C, G, T and U relate to genomes, he did not say that the letters stood for the nitrogen bases of DNA. This had been stated earlier. They struggled to systematically map letters, words, phrases and sentences to appropriate elements of a genome. They mapped letters to nitrogen bases, but then were very confused in what linked to words, phrases, and sentences. This difficult task required more expert knowledge than they possessed.

Harriers used figurative language in their own explanations. When Ton spoke of the importance of a duplication process, Barry proclaimed, "They [encyclopedia and genomes] go to the printing press" (3: H, 6). Phil spoke of genome as a "master copy" and "blueprint DNA." David said, "An encyclopedia is a hard copy." (3: H, 6), and a "hard copy of our past" (3: H, 7).

The Harriers SMILE scores were: 3.00 for Ton, 2.75 for Bill and David, 1.75 for Barry and Jonah. Table 19 lists subscores and SMILE levels for the Harriers. Ton, Bill, and David showed strong ability to use analogical thinking in the domain of science.
Barry was ill-prepared because he was absent from class for a week. Jonah did not give his full attention.

Table 1.9

<table>
<thead>
<tr>
<th>Harriers</th>
<th>SMILE</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3.00</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Bill</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2.75</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Barry</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Jonah</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>David</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2.75</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

The Harriers' intense exchange of ideas catalyzed learning. Barry said genes were the same size, but David explained that genes vary in size. When Jonah said DNA was "made of cells," Ton declared, "No, ... DNA is in the cell" (3: H, 6). Ton replaced Bill's "acids" with the more specific term "nucleic acids." When Jonah related genomes to organisms, David clarified that each genome is specific to one organism. These boys were teaching each other.

Members gave each other important messages. When Barry directly asked Jonah to help, Jonah shared his ideas. With Bill's coaxing, distracted Barry refocused. Bill praised David's use of, "figuratively." David felt he could say, "Someone help me out here." (3: H, 2). Barry assured Jonah that his [Jonah's] contribution was "Okay, that works" (3: H, 4). A conflict began when Barry gave a lopsided compliment to Ton: "cause no one is better than you [Ton], though it doesn't sound right coming out of
your mouth, sounds like cotton candy* (3: H, 10). Bill interceded to stop verbal sparring between Ton and Barry.

**Close-up focus on Jonah.** Single-mindedness was characteristic of Jonah's participation during Activity 3. Jonah said, "Well they both explains, like the encyclopedia explains topics--genes explains functions in the body" (3: H, 4). The word "explain" works if it is taken in a metaphorical sense in the case of genes. Jonah revisited and expanded on this idea three more times. Jonah also reintroduced a theme from Activity 1 in which he talked about cellulose and fiber successfully. This theme surfaced in Activity 3 in an odd tangential comment: "As books are made from trees and trees have fiber in them, we also have fiber in our body" (3: H, 4). Jonah's preoccupation with plant cells and cellulose resurfaced again when he inaccurately said that encyclopedias and DNA were "made of cells" (3: H, 6). But, paper for books is made principally from the cellulose in plant cells; and DNA is contained within cells.

Jonah seemed to be in a bad place during Activity 3. He made this strange comment: "It [encyclopedia] can rearrange your facial makeup if you beat someone up with it" (3: H, 7). He frequently retreated into isolation. I tried to break through his silence with a direct command: "Jonah, you joined this group so you have to help" (3: H, 6). As was typical of Jonah, he tried to follow this directive, but he was not very effective in helping his group.

Jonah earned a 1.75 on the SMILE scale for expressed analogical development. He earned a 1 for accepting the teacher provided analogy. He rated a 2 in mapping for the few mappings he made. He needed to escape his rut-like thinking. He was dependent for inference so he earned a 1 in that category. He was dependent on his friends and teacher for full analogical analysis so he received a 3 in evaluation. Even
with his low participation, Jonah claimed that he learned science through analysis of the analogy.

**Close-up focus on David.** David was very engaged in Activity 3. He helped define the target and the analog. He identified characteristics of an encyclopedia that proved useful in comparing the reference book to a genome. David seemed inspired by the scientific target. He was interested in DNA, genes, and genomes. DNA's "billions and billions of codes" (3: H, 7) impressed him. While he did not know everything, he did have sufficient domain knowledge to participate in every aspect of Activity 3. He helped link an encyclopedia and genome on the basis of the ordered information contained in both. He was chiefly responsible for noting the variation in size of genes of a genome and variation in topic space in an encyclopedia. David made an important point, "Genome explains only about the organism that it belongs to" (3: H, 7).

David used figurative language to explain. To describe an encyclopedia, he described it as "a hard copy of our past" (3: H, 7). When asked what he meant when he said, "It like builds up from little things to letters to like words to sentences," he explained, "I'm speaking about the encyclopedia, figuratively about the genome." He meant that a genome is built "from little units to like the entire thing" (3: H, 8). When Jonah said that an encyclopedia was a tool, David countered that a "genome can be a tool too" (3: H, 7). Unfortunately, David did not explain in scientific terms what his metaphors meant. Possibly, he used figurative language to avoid giving explanations that could be examined more critically.

David described Activity 3 as "comfortable," "okay," "fun," "understandable," and "open-ended." He gave "excellent" ratings to enjoyment and knowledge gain. He saw his motivation as "okay" and felt the assignment provided a "good" challenge to his
group. Revealing his creativity, David assumed a pseudo-serious authoritarian tone to give the Harrier recording the feel of a conversation between real scientists.

David earned a 2.25 SMILE for his expressed analogical ability. He rated a 1 for selection by his acceptance of the teacher assigned analogy. He was a strong contributor to his group's mappings so he earned a 3 in mapping. He showed some ability to make inferences although he still was dependent, so his inference score was 2. He played an important role in demonstrating the educational value of the analogy, and thus he received a 3 for evaluation.

**Movie review: Harriers capture meaning.** The Harriers as a group showed agility in swooping down to capture the meaning of "A genome is like an encyclopedia." The pace of their debate was swift and unpredictable, yet these Harriers kept their eyes on their goal of analogical analysis. They managed to solidify their understanding of DNA, genes, and genome through identification of similarities and dissimilarities between an encyclopedia and a DNA genome. David was comfortable chasing after scientific meaning hidden in the analogy. Jonah seemed unable to escape from his fixed flight patterns to adopt better strategies for grasping analogical meanings.

**Activity 3: Ferrets**

**Group movie: Ferrets search for meaning.** The Ferrets began Activity 3 in such a state of confusion that I had to guide them very carefully through the first three steps of "Can You Make the Connections?" They had gained nothing from class directions. With unnecessary commotion, they managed to define DNA, genome, and encyclopedia. Mapping similarities and dissimilarities between an encyclopedia and a genome was challenging for the Ferrets.
The Ferrets noted these similarities between an encyclopedia and a genome: (a) both provide information; (b) information is arranged in a certain order; (c) information may be duplicated. Their discussion of dissimilarities implied two other similarities: (d) an encyclopedia and a genome build meaning by combining symbols; (e) letters are meaningful in an encyclopedia and letters only stand for the meaning bearing units in a genome.

The Ferrets noted these dissimilarities between an encyclopedia and a genome: (a) an encyclopedia only contains information, whereas, a genome's information controls life; (b) an encyclopedia provides information for next generation, whereas, a genome's information determines next generation's; (c) an encyclopedia is divided into volumes, whereas, a genome is divided into chromosomes; (d) letters signify meaningful sounds in an encyclopedia; but letters only represent meaning bearing nucleotides of a genome; (e) words are in an encyclopedia and codon "words" are in a genome; (f) sentences are in an encyclopedia and gene "sentences" are in a genome; and (g) encyclopedia books are made of paper, while a genome is microscopic.

How well did the Ferrets analyze their analogy in terms of Gentner's qualities for effective analogies—clarity, richness, abstractness, and systematicity (Mitchell & Hofstadter, 1995)? The Ferrets identified five similarities and seven dissimilarities between an encyclopedia and a genome. They captured some of the expository value of the analogy. Their mappings dealt with different levels of abstraction including the organism, cellular, and molecular; but they did not really explain the abstract concepts of these mappings. For example, they did not explain why they matched 'letters,' 'words,' and 'sentences' of an encyclopedia to 'nucleotides,' 'codons,' and 'genes' respectively.
These are actually credible and systematic mappings, but without these students' explanations, it is difficult to evaluate their level of understanding. For example, they did not explain that sentence pairs with gene because both contain a completed meaning. A gene holds the meaning of how to assemble a protein from amino acids. When Paula and Max linked "phrases* to amino acids, they broke the systematic mapping of elements in an encyclopedia to different units of meaning in a DNA molecule. An amino acid is not a part of DNA, but is coded for by a codon in DNA. The Ferrets made an unsystematic matching of book paper and the microscopic size of genomes, because these concepts belong to different categories—material composition and size.

Ferrets received the following SMILE scores: 3.00 for Jim, 2.25 for Eve and Mark, 1.75 for Max, and 0.50 for Paula. Table 20 lists subscores used to calculate their levels of expressed analogical thought.

Table 20

<table>
<thead>
<tr>
<th>Researcher</th>
<th>SMILE Scores for Ferrets in Activity 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrets</td>
<td>Selection</td>
</tr>
<tr>
<td>Eve</td>
<td>1</td>
</tr>
<tr>
<td>Jim</td>
<td>1</td>
</tr>
<tr>
<td>Mark</td>
<td>1</td>
</tr>
<tr>
<td>Max</td>
<td>1</td>
</tr>
<tr>
<td>Paula</td>
<td>1</td>
</tr>
</tbody>
</table>

The Ferrets allowed distractions from outside and from within their group to impede their work. They complained of nonmember intrusions. They talked about extraneous
topics (e.g., sounds ferrets make). Max clashed with Paula. This friction had numbing effects on Paula's efforts, albeit meager, to participate. Members took turns undermining other members' attempts to focus on the task. In frustration, goal-directed Jim exerted pressure on his peers to focus on their analogy analysis. The Ferrets responded when Jim led. The other members respected Jim. As Mark put it, "Jim's the boy genius and we're normal" (3: F, 1).

Close-up focus on Eve. How did this experience work for Eve who had claimed a poor knowledge of science? Eve began Activity 3 with little confidence, but a desire to participate. I encouraged her to reread a definition of genome slowly and distinctly. Assured that she was on the right path in defining genome, she was willing to share what she had found. She helped Jim identify encyclopedia as the analog in the analogy. When Paula refused, Eve described an encyclopedia.

She was much more dependent for the analytical steps. Still she asked questions and helped her friends identify similarities and dissimilarities between an encyclopedia and a genome. For example, she matched words of an encyclopedia to codons of DNA. She understood that a codon was a "word" for a particular amino acid. She correctly informed her team that uracil was not a nitrogen base found in DNA. Eve concentrated, but was occasionally distracted by visitors and side-talk with her group members.

Eve was sensitive to being a female in her group. To protect her "sister," Eve deflected the boys' criticism of Paula's apathy. Eve refused to be categorized as a "girl" by Mark; instead, she claimed womanhood. Mark, who never really meant offense, substituted "young woman" in deference to Eve's sensibilities (3: F, 7).
Eve described her experience in these terms: "hard," "interesting," "understandable," "well-structured," and "unusual." She felt Activity 3 was hard because the science was difficult, time too short, and instructions not good. She was also disturbed by the conflict over Paula's nonparticipation. These problems explain her "poor" rating for enjoyment. She thought motivation and knowledge gain were "okay." Eve recognized "analogizing" as a process in Activity 3.

Eve's earned a SMILE rating of 2.25 for expressed analogical development during Activity 3. She received 1 for selection because she accepted a teacher assigned analogy. She earned a 3 for mapping. She was dependent on her peers for mapping similarities and dissimilarities. She earned a 1 for inference because she required teacher guidance. She earned a 4 in evaluation for full participation in her group's evaluation of the analogy in terms of how the analog was or was not like the target.

**Movie review: Ferrets search for meaning.** The Ferrets initial search for analogical meaning was conducted in a disorganized way. Distractions enticed them away from their task. Teacher intervention was absolutely essential for this team to function. Members depended too much on Jim's knowledge and leadership. The other members lacked confidence in their own abilities. The Ferrets experienced some success with analysis of the analogy "A genome is like an encyclopedia." They seemed to understand a great deal more than they managed to say in their analogical analysis. Eve gained knowledge under Jim's guidance and gained confidence in her ability to contribute to her group's meaning making.

**Activity 3: Red Foxes**

**Group movie: Red Foxes sniff for meaning.** Red Fox members defined DNA and genome, described an encyclopedia, and compared analog and target.
synthesized their thinking with this statement: "A genome is like an encyclopedia because they both hold information that can be read and they are formed of small pieces that can be held together to form the genome." "Read" applies figuratively to genome. Ching added that the information is ordered.

The Foxes named four dissimilarities: (a) encyclopedia information is based on the past, while information in a genome determines the future; (b) encyclopedia information is organized alphabetically, while genetic information is organized randomly; (c) an encyclopedia has separate volumes, and a genome has separate chromosomes; and (d) encyclopedia information is in a book, but genome information is in a cell.

Kirk disagreed with Kevin's assertion a genome is randomly ordered. I later explained that there is a sense of randomness in location of genes on a chromosome; but genes for specific traits for a species are ordered or located at specific sites on particular homologous chromosomes. This led to a discussion of homologous chromosomes, which are the same (Gk. homo) in size, shape and carry genetic information for the same traits. A picture of one human's set of 46 homologous chromosomes helped the Foxes understand. This teacher-student interaction ended with a bonus discovery that Kirk had read about the human genome project on the Internet. Kirk explained that they "have a lot of it [human genome] mapped. They had all the chromosomes listed and all the traits" (3: R, 6).

Gentner's qualities of effective analogies—clarity, richness, abstractness, and systematicity (Mitchell & Hofstadter, 1995)—serve as criteria for evaluation of analysis of an analogy. The Red Fox analysis showed richness in naming four similarities and four dissimilarities between an encyclopedia and a genome. In terms of abstractness, these teens analyzed the genome at the organismic and cellular level, but did not
discuss genes at the molecular level. They stated their mappings clearly, but in the simplest terms. Some mappings lacked explicit explanation. Most mappings systematically related to the informational and control role of genes as ordered on chromosomes within a cell.

The Foxes did not make any connections to the molecular structure and function of DNA, the molecule which contains genes. Their definition of encyclopedia did not include references to key words like "letter," "word," and "sentence," which had led other groups to think of DNA's molecular structure. This suggests the importance of students sharing many ideas about the analog. A rich description will provide many more possibilities for making connections.

The Foxes earned these SMILE scores for Activity 3: 2.50 for Ching, Kevin, and Rika; 1.25 for Kirk, and 0.50 for Mai. Mai and Kirk's low scores reflect their minimal expression of analogical thought. Ching, Kevin, and Rika contributed equally to analysis, exercised some group independence, but also relied on teacher guidance. Red Fox SMILE levels and subscores are listed in Table 21.

The insecure Foxes took comfort in strict adherence to the guidelines for Activity 3. To further alleviate their anxiety, they frequently sought and received teacher assistance. Kevin, Ching, and Rika were constructive members. While all interacted respectfully, the more active members expressed some displeasure with Kirk and Mai for their low level of participation. Kirk tried to sound productive by reading questions, telling other people to answer, and making silly comments, but he made only a few independent analytical contributions. Quiet Mai didn't even try to appear active.
Table 21

Researcher SMILE Scores for Red Foxes in Activity 3

<table>
<thead>
<tr>
<th>Red Foxes</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
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<td>Mai</td>
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<td>0</td>
<td>0</td>
<td>0.50</td>
<td>1</td>
</tr>
<tr>
<td>Kirk</td>
<td>1</td>
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<tr>
<td>Ching</td>
<td>1</td>
<td>4</td>
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<td>2.50</td>
<td>4</td>
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<tr>
<td>Kevin</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2.50</td>
<td>4</td>
</tr>
<tr>
<td>Rita</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1.25</td>
<td>4</td>
</tr>
</tbody>
</table>

Close-up focus on Kevin. Kevin contributed much to the group's analysis of "A genome is like an encyclopedia." He named both a similarity and a dissimilarity when he said "An encyclopedia is broken up into separate volumes, and a genome is broken into separate chromosomes, separated into small pieces" (3: R, 2). He synthesized his group's dialogue on similarities. He contrasted the alphabetical order of an encyclopedia with the random placement of genes on chromosomes.

Kevin felt many emotions during Activity 3. Believing that all group members should work as hard as he was, Kevin became impatient with Mai and Kirk for their lackluster performances. Kevin told Kirk to take his turn, "Why don't you give a characteristic like you are supposed to do" (3: R, 3). Kevin felt insecure. When asked to describe a genome, he pretended to elude this question with, "It's exactly like an encyclopedia," since that was written on the guidesheet. Of course, he knew it wasn't going to be that easy. At times, he was confident. Kevin explained that step 4 "means we talk about what we talked about" (3: R, 3). His summation was funny and basically accurate.
Kevin rated motivation and enjoyment with 2s, challenge with a 5, and knowledge gain with a 4. Kevin thought Activity 3 was difficult and not much fun, yet a good, challenging learning activity which involved "analogizing." His description of the activity as "boring," "complex," "tedious," and "typical" suggest that he may have thought of this assignment as very similar to worksheet assignments which required research, thinking, and writing down answers.

Kevin's SMILE score of 2.00 suggests that he was still dependent on his teacher, class instruction, and peers for assistance in analogical Activity 3. He received a 1 in selection for accepting the analogy provided. He earned a 3 in mapping for his contributions to group mappings. He rated a 1 for inference since he did not push beyond the basic statements, and relied on experts for inferences. He got a 3 for evaluation because he was very involved in the group's judgement of the learning value of the analogy.

Close-up focus on Mai. Mai passively resisted gentle requests for her to play an active role. After each request, Mai would seem to acquiesce, but actually did not. Her one helpful comment linked an encyclopedia with information. Mai chose to listen to her friends' handling of a difficult scientific subject.

Mai viewed Activity 3 as "complex" and challenging. She felt "comfortable" because she let her friends do this task. She claimed her motivation and knowledge gain were good. The evidence does not support this claim. Perhaps in Mai's view, her attentive listening correlated with good motivation to learn; and it is possible that Mai learned from listening to her more prepared peers. She was not excited about a "well-structured," but "typical" assignment involving "analogizing." For Mai, Activity 3 was like other worksheets that were hard to do.
Mai rated a SMILE score of 0.50 because she contributed so little to the group’s analogical thought. She received a 1 in selection for accepting the experts’ analogy. She received no points for mapping or for inference because she did not contribute mappings, nor did she express any inferences. She received a 1 for evaluation since she expected to be given a useful analogy to promote biological learning.

**Movie review: Red Foxes sniff for meaning.** Three Foxes cautiously searched the metaphorical woods for meaning. Ching, Kevin, and Rika combined thoughts to arrive at an adequate analogy analysis, which enhanced their understanding of genomes, genes, and chromosomes. Kevin tried hard to figure things out, and sometimes assumed leadership of his group. Mai was content to follow the path of her fellow Foxes.

**Activity 3: The Snakes and the Lions**

**The Snakes.** Tina, June, Omar, Helen and Jack interacted as a supportive goal-focused team. June urged the group not to "memorize the book" (3: S, 1), but to go beyond copied words. These teens followed her advice. The Snakes compared their definitions of DNA, genome, and encyclopedia to map the connections between the analog and target of the analogy "A genome is like an encyclopedia." They identified four shared characteristics. An encyclopedia and a genome are informational, long [on relative scales], divided into sections, and inanimate.

The Snakes identified five dissimilarities. A big encyclopedia provides information about everything, including history, and is recorded in a book; a microscopic genome provides information only about an organism and its development, reveals history of generations, and is contained in the sequences of genes. The Snakes were unique in noting that genes contain information about the history of the organism, and that
genes can be traced back through generations. Tina explained this historical characteristic, "An example of how DNA gives information, the DNA can tell you so much, . . . about generations behind you, your history, your body, or your genes" (3: S, 3). The Snakes also noted that an encyclopedia becomes inaccurate over time; whereas, DNA replication remains amazingly accurate generation after generation.

**The Lions.** The Lions worked together to identify similarities between an encyclopedia and a genome. They noted that an encyclopedia and a genome contain lengthy ordered information and letters are involved such that meaning can be "read.* They implied that both built meaning from union of symbols into larger and larger units.

They pointed out dissimilarities. Encyclopedias are organized alphabetically and into sections and volumes; a genome has a nonalphabetical but specified order of genes on chromosomes. An encyclopedia uses the whole alphabet to spell many words, but a genome uses only four letters (A, C, G, T) to convey the meaning of genes of a DNA strand. Encyclopedias are found in libraries, but genomes are found in cells.

The girls' mappings suggest that they understood quite a bit about DNA, genes, and a genome; but they needed to explain their mappings more completely. For example, they could have explained that the four letters (A, C, G, T) are used to represent DNA's nitrogen bases which carry the coded information of a gene. They responded to Activity 3 as an okay beneficial educational assignment, but not a fun one. They seemed to appreciate the analogical aspect. On her guidesheet, Sarita explained, "They [encyclopedia and genome] are not in the same families; they are not in the same town; they are not in the same state, [nevertheless], if you have a mind like me, you can see the similarities."
Activity 3: Summary

Both analogical and nonanalogical Activity 3 posed an analytical challenge. Fifth-hour's "Can You Make the Connection?" posed an analogical challenge as well.

Students approached this third group activity as a normal part of their curriculum. How did fifth hours' Activity 3 student experiences relate to learning science, development of analogical thought, quality of group interactions, and teacher-student interactions? How did these experiences compare to the experiences of sixth- and seventh-hour students with their nonanalogical Activity 3?

Activity 3: Learning Science

The nonanalogical Activity 3, "DNA and Its Structure", promoted sixth- and seventh-hour students' learning of the structure and function of DNA. These students responded favorably to an activity that challenged them to demonstrate their scientific knowledge. They liked the variety of tasks, which helped them solidify their scientific understanding. "DNA and Its Structure" was an excellent learning activity.

Analogical Activity 3, "Can You Make the Connection?" promoted Hour 5 students' comprehension of DNA and genes through their analogical analysis. This analysis relied on interpretation, application and expansion of their initial definitions of DNA and genome and encyclopedia. Attempts to find scientific meaning in an analogy led fifth-hour students to think of genes on many levels—molecular, cellular, organismic, and even generational. They integrated their prior knowledge with a novel concept (genome). Certain themes were visited by all groups including: a genome's organization, structure, informational role, and importance to life. Other themes explored by several groups included: molecular structure of DNA, duplication of DNA, and DNA as a record of the past and a determinant of the future of life.

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Alternative conceptions were part of group dialogue. Some of these alternative conceptions were challenged. Some complex scientific concepts were never clarified within groups. Students had their most difficulty understanding the relationship of genes of a genome to the synthesis of proteins. A follow-up discussion of the protein synthesis helped to clarify this issue for those in confusion. Discussion of analogical development will further elucidate this issue, as well as amplify the case for student learning.

**Activity 3: Development of Analogical Thought**

Nonanalogical Activity 3 was not designed to develop analogical thought. In response to one summary question, Hour 6 and 7 students gave brief general explanations of "blueprint of life," a metaphorical expression for DNA.

Analogical Activity 3 was designed to develop analogical thought and fifth-hour students were very aware of this emphasis on thinking. This third analogical activity required identification of shared and unshared characteristics of an encyclopedia analog and a genome target. Students learned as much from points of contrast as from comparison. They used their mappings to synthesize a statement of their understanding of genome.

Gentner's qualities of effective analogies—*clarity, richness, abstractness,* and *systematicity* (Mitchell & Hofstadter, 1995)—provide a set of standards upon which to evaluate fifth-hour students success in analysis of an effective expert analogy. These students developed a surprisingly rich collection of mappings. Groups identified 4-7 similarities, 4-8 dissimilarities, for a total of 8-12 mappings. Table 22 lists the number of similarities and dissimilarities identified by each group.
Table 22

Number of Group-Identified Mappings Between an Encyclopedia and a Genome

<table>
<thead>
<tr>
<th>Category</th>
<th>Pelicans</th>
<th>Harriers</th>
<th>Ferrets</th>
<th>Red Foxes</th>
<th>Snakes</th>
<th>Lions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similarity</td>
<td>4</td>
<td>7</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Difference</td>
<td>8</td>
<td>5</td>
<td>7</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>

Fifth-hour students made some very clear mappings, but tended to be less clear in mappings related to molecular concepts. Interestingly, some sixth- and seventh-hour students also had trouble with molecular concepts (e.g., nucleotide). All analogical groups arrived at mappings that dealt with abstract concepts (e.g., DNA, gene). It is the abstract nature of the scientific target that made analogy an appealing way to bridge the gap between what students could see and what they had to imagine.

During analysis of the analogy, "A genome is like an encyclopedia," all fifth-hour groups said that a genome carries information organized into small units. They identified these units as genes, chromosomes, or genes located on chromosomes. They emphasized that a genome's information is located within living organisms and the meaning of the genome is understood by the body and controls life. All groups, except the Snakes, implied that this meaning is built up through a combination of symbols into larger units of meaning.

The Pelicans, Harriers, Ferrets, and Lions tried to explain specifically how this meaning is constructed in a genome. This particular series of mappings from letters, words, and sentences of an encyclopedia to the structure of a gene in a genome was
very challenging. While their mappings were not perfect and were somewhat
nonsystematic, members' efforts showed that they recognized much of the analogical
potential of the encyclopedia analog.

Each group gave some unique responses in their analysis. For example, the Snakes
explained that a genome contains the history of past generations. The Ferrets and
Foxes focused on the genome as a determinant of future generations. The Ferrets and
the Harriers noted the duplication of DNA. The Snakes emphasized the accuracy of the
replication of DNA. Unique group responses highlighted the flexible creativity inherent
in analogical thought.

**Activity 3: Quality of Group Interactions**

In general, sixth- and seventh-hour group members worked well as they shared
responsibility for a complex assignment. Some students felt stressed or frustrated by
the difficulty of their nonanalogical Activity 3. Some good students resented their less
prepared peers' dependency.

Fifth-hour students organized their learning groups into functional units. The
harmonious Pelicans proudly recorded their analysis as they participated equitably
under Ed's leadership. The Snakes valued their own thoughts as they engaged in lively
discussions. The self-sufficient Lions took turns responding to guide questions. The
Harriers dialogue was charged with energy as they shared and evaluated ideas. They
overcame personal conflicts to build a consensus for their deep analysis. Red Fox
members tolerated some inequity in contribution to generate good but sparsely
worded ideas. Personality conflicts plagued Ferret work so much that this group
functioned poorly. Only Jim's leadership allowed them to develop a good analysis of
the analogy "A genome is like an encyclopedia."
Activity 3: Teacher-Student Interactions

Sixth- and seventh-hour students requested and received teacher assistance beyond class instructions. They appreciated help with their challenging Activity 3. Groups varied in their areas of difficulty with the assignment.

Four groups in fifth hour preferred independence in doing their analogical Activity 3. As teacher, I circulated from group to group to monitor progress and offer guidance, yet encourage and permit independent discourse. I helped all groups, but gave the most help to dysfunctional Ferrets and needy Red Foxes. The Ferrets received extended and individualized instructions in how to do the analysis. Teacher talk with the Foxes expanded the meaning of their own mappings so as to enhance their understanding.

Activity 3: Analysis Implications

The third nonanalogical activity "DNA and Its Structure" was an excellent vehicle for learning at the levels of knowledge, memory, and application. This traditional paper lab motivated and challenged students. It helped students improve their knowledge of DNA's structure and function. It is appropriate within a biology course. Most students gave some incorrect answers, but class review helped students identify their errors. Hour 6 and 7 students' mean grade on the DNA test was 79%.

The third analogical activity "Can You Make the Connection?" between an encyclopedia and a genome served as a catalyst for learning. Benefits of participation included: promotion of analytical and analogical thought, integration of student knowledge of a scientific domain, and promotion of cooperative team skills. Activity 3 stressed identification of both similarities and differences between an analog
encyclopedia and a target genome, followed by a synthesis of the implications of these mappings. Students worked at the level of analysis and synthesis of their knowledge.

The analogical Activity 3 was more difficult than the nonanalogical Activity 3. These students did a new activity about a difficult science subject. While they were successful in many ways, a word of caution is in order. The analytical and analogical work of Activity 3 was a real “reach” for Hour 5 students, and this difficulty decreased some students’ motivation. Perhaps this analogical activity may need to be modeled more than once for the whole class. This would make the format of the generic activity more familiar, prior to students doing Activity 3 in groups.

Another word of caution is in order. Many students’ alternative conceptions were challenged by peers or by the teacher within the format of analogical Activity 3. This researcher is concerned about unidentified conceptual confusion. This activity does not allow a review of correct answers, but some type of post-activity class review would be advisable. Hour 5 students mean grade on the DNA test was 74%.

This lower average grade is partly explained by this test addressing the very same material, molecular DNA, as the nonanalogical Activity 3; whereas, the analogical Activity 3 targeted DNA in contexts from molecules to genomes. In fact, it was the molecular DNA concepts which Hour 5 students had the most trouble with mapping from the encyclopedia. A teacher model of analysis of the analogy in Activity 3 would have helped these students, particularly with DNA molecular structure and function. Many concepts targeted by analogical Activity 3 were not included in the DNA test.

Activity 3: Reflections on Specific Students

Students varied in terms of the benefits they received from participation in this activity. Let us focus in these reflections on the students chosen for closer study.
**Pelicans: Ed and Keisha**

Ed and Keisha agreed that Activity 3 was "comfortable," "interesting," "understandable," and "fun." Ed provided his Pelicans with confident leadership and his understanding of DNA. He sometimes stated his knowledge too vaguely, as if he assumed that it was obvious information. Ed felt it was fun to discover similarities and differences between the encyclopedia and a genome. Ed earned a 3.00 SMILE score.

Keisha proudly described a familiar encyclopedia. Keisha felt comfortable analyzing with her group, rather than alone. She succeeded in mapping a similarity and a dissimilarity between an encyclopedia and a genome. She shared Ed's enthusiasm for Activity 3. She earned a 2.00 SMILE score.

**Harriers: Jonah and David**

Jonah did not thrive with Activity 3, as he had during the first two analogical activities. He needed prodding to contribute, and then he was not very helpful. He made one good point, but then repeatedly made the same point in expanded versions. He was distracted by outside concerns. At least, interactions with his Harriers kept Jonah somewhat involved. Jonah earned a 1.75 SMILE score.

David really liked Activity 3. He displayed a confidence, which was lacking in his first two analogical activities. He made valuable contributions based firmly in his understanding of genes. He pretended to speak as a scientist. This role-playing helped him focus more on science. David felt equal to his peers such that he took some risks during group interchanges. He used his own metaphorical language to explain his ideas. Usually quiet in class, he eagerly shared his thoughts with his Harriers. David earned a 2.75 SMILE score.
Ferret: Eve

Eve's difficulty with Activity 3 seemed to lie in her poor science background, poor dynamics of her Ferrets, and her assumption of too many responsibilities. Eve protected Paula, built up Mark's confidence, tried to keep her group on task, helped decipher the analogy, and tried to build confidence in her ability to learn science. I helped Eve with individualized instructions and encouragement. Jim's scientific explanations helped her too. Her affinity for figurative language was also an asset. Eve tried hard to contribute and understand the complexities of the scientific concepts of this "hard" activity. Although she described this activity as "interesting," "understandable," "well-structured," and "unusual," she rated her motivation and knowledge gain at just "okay." Eve suggested more time and better instructions in her critique. Eve earned a 2.50 SMILE score.

Red Foxes: Kevin and Mai

Though insecure, Kevin expressed his laudable thoughts, albeit in as few words as possible. His analytical points were usually well taken and insightful. During Fox dialogue, he reluctantly assumed leadership because no one else seemed to be doing it. Later he willingly relinquished this role to Ching. The group format made it difficult for him to play the quiet role he assumed in a whole class situation. Kevin earned a 2.50 SMILE score.

Shy and insecure in biology class, Mai rarely spoke during Activity 3. She cited one mapping. Rika saved her when the Red Fox boys pressured her to speak. Mai preferred to listen and learn from her friends. Mai's difficulty with English and with science concepts combined to silence her voice, which could be quite forceful within other contexts. She received a 0.50 SMILE score.
Activity 4

Activity 4: Analogical versus Nonanalogical

Scientific subject. Taxonomy is the naming and grouping of organisms. In the eighteenth century, Linnaeus proposed a system of giving each kind of organism a two-part name consisting of a genus and species epithet. For example, the human species is called Homo sapiens. Homo is a genus and sapiens is a species epithet. Through classification, each species is placed in a kingdom with many other organisms that share the same set of traits. Based again on a specified set of traits, each organism in a kingdom is placed into a subdivision of that kingdom. This subgrouping process continues until the unique species level is reached. Classification categories, listed from most inclusive to most specific, are: kingdom, phylum, class, order, family, genus, and species.

During early March, students in all three biology classes listened to lectures on biological classification, read relevant text, and did homework. Through a worksheet exercise, students practiced using a dichotomous key, summarized traits of organisms in each kingdom, distinguished between classification categories, and completed a crossword review. They did Activity 4 during the week of March 10, 1997.

Activity 4 descriptions. Activity 4 involved classification of hardware, construction of a dichotomous key, and an optional beetle classification. This assignment was the same for all biology students, except fifth-hour students also completed the guidesheet "Can You Experience This?" (see Appendix R).

For hardware classification, each team randomly picked a bag of assorted hardware. Group members chose a trait (e.g., shape) as a basis for dividing objects into two groups (e.g., "long" and "round"). As teacher, I stressed choice of traits in order of their significance. Students subdivided objects in each group on the basis of other selected traits. They repeated subgroupings until every unique item resided in its own
category. Students judged uniqueness as "identity" or "close to identity." Groups made a classification chart that named each subgrouping and depicted each hardware item in its final placement.

Students referred to their chart as they made a dichotomous key for identification of their hardware. A dichotomous key consists of a series of coupled questions and directives to guide identification. To simplify the process of making this key, I had instructed students to subdivide by two, even though in some biological classification systems more than two subgroups may be formed at any category level.

Hour 5 students worked through Activity 4 "Can You Experience This?". Using this guidesheet, students recorded the activity's subject, purpose, and instructions. Students completed an activity analysis report covering the problem, problem solution, assumptions, sources of error, and student confidence. They analyzed the analogy, "Classification of life is like classification of hardware." Students identified the analogy, analog, and target; compared and contrasted the analog and target; and evaluated the didactic effectiveness of the analogy (see Appendix S for hypothetical responses).

Classification of hardware gave students experience with a process similar to biological classification. Only fifth-hour students used a guidesheet, which encouraged student reflections on how classification of hardware is like classification of life, and how these two classifications are by necessity also different.

Activity 4: Panoramic Photos Taken from Researcher Vantage Points

Nonanalogical path. Sixth- and seventh-hour students did their Activity 4 with relative ease over two days. I assisted some groups to start their classifications or to begin making a dichotomous key. I reminded a few groups to focus on work. All groups received occasional teacher-hints, but overall students worked independently.

Without direction, many groups thought of classifying hardware as a simulation for classification of life. For example, the Loons used Latin scientific names for category and species names. The Cranes talked about mutations and natural selection. The
Loons objected to the restriction of grouping by two. They argued that biologists classify organisms into five kingdoms.

Most students enjoyed their experience. The Albatrosses creatively called their kingdom “Tinkerbolt.” The Albatrosses laughed at their subcategory names “groovy” and “not-groovy.” When the Cranes had difficulty classifying an odd object, Christabel joked, “He got an extra chromosome, he can’t help it.”

There was some discontent. The Wolverines said they were “bored” with the repetition of classification. Abel of the Eagles complained, “We still have to do that stupid chart and have to draw pictures too.” Kirsten protested that the boy Ravens did not help enough. Students objected most to doing two classifications.

**Analogical path.** With the exception of the guidesheet work, fifth-hour students’ experiences mirrored sixth- and seventh-hours’ experiences. Students labored independently, although some requested help to begin classification of hardware or construction of a dichotomous key. Groups asked about particular objects’ classifications. Fifth-hour teens enjoyed naming categories and species. They engaged in sidetalk as the activity became less exciting towards the end. Their work extended over three days.

As part of class directions, I guided students to fill in the subject, purpose and activity instructions on their guidesheet “Can You Experience This?” After their classification and key-making experiences, they independently finished this guidesheet. They easily named the problem and problem solution. They had difficulty with assumption and source of error queries because youth do not typically think in these terms. Fifth-hour students recognized the format of the analogy analysis as similar to Activity 3 guidesheet “Can You Make the Connection?”. Students named the analogy, identified the analog and target, and listed similarities and dissimilarities between the two. The guidesheet for Activity 4 helped students to move beyond their simulation experience to focus on their target--classification of life.
Activity 4: Panoramic Photos Taken from Student Vantage Points

Student evaluations. What do students’ multiple views of Activity 4 say about their experiences? The following number of students in each class completed evaluations of the fourth group activity: 22 of 29 pupils in fifth hour, 26 of 31 pupils in sixth hour, and 9 of 31 pupils in seventh hour.

Selection of adjectives to describe activity. Table 23 lists the percentages of student evaluators who selected a listed adjective. This table is organized to highlight the similarities and differences in Hour 5 and Hour 6 and 7 student evaluators’ selections of adjectives.

The majority of students in all classes viewed their Activity 4 as "easy" or "comfortable," and "clear, "simple," or "understandable." Most students felt Activity 4 was a moderate, comprehensible learning activity.

Sixth- and seventh-hour students selected "complex" and "hard" at higher percentages than fifth-hour students. Hour 5 students may have viewed Activity 4 as not that difficult relative to their hard analogical Activity 1 and 3. A majority of sixth- and seventh-hour evaluators chose "interesting" and "fun" compared to less than a quarter of fifth-hour evaluators. Sixth- and seventh-hour students seemed to have a more favorable response than fifth-hour students. This apparent affective difference may be an artifact of the particular evaluators. Of sixth- and seventh-hour evaluators, 69% were engineering magnet students compared to 36% of fifth-hour evaluators. Engineering magnet students might be biased toward an activity involving hardware.

Identification of activity processes. Table 24 lists Activity 4 processes identified by evaluators in Hour 5 and in Hours 6 and 7. Percentages are listed in order from highest to the lowest percentage of fifth-hour evaluators who selected a process as part of their Activity 4.

Cross comparison of the percentages listed in Table 24 indicates a majority of evaluators from fifth hour and a majority of evaluators from sixth- and seventh hours
Table 23

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 4

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy</td>
<td>32</td>
<td>29</td>
</tr>
<tr>
<td>Simple</td>
<td>27</td>
<td>20</td>
</tr>
<tr>
<td>Clear</td>
<td>23</td>
<td>32</td>
</tr>
<tr>
<td>Creative</td>
<td>27</td>
<td>40</td>
</tr>
<tr>
<td>Well-structured</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>Understandable</td>
<td>32</td>
<td>17</td>
</tr>
<tr>
<td>Open-ended</td>
<td>36</td>
<td>20</td>
</tr>
<tr>
<td>Comfortable</td>
<td>59</td>
<td>43</td>
</tr>
<tr>
<td>Complex</td>
<td>18</td>
<td>39</td>
</tr>
<tr>
<td>Hard</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>Okay</td>
<td>50</td>
<td>29</td>
</tr>
<tr>
<td>Unusual</td>
<td>32</td>
<td>9</td>
</tr>
<tr>
<td>Fun</td>
<td>23</td>
<td>51</td>
</tr>
<tr>
<td>Interesting</td>
<td>18</td>
<td>57</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

\( ^a \) Only adjectives circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

\( ^b \) n = 22 evaluators out of 29 fifth-hour students.

\( ^c \) n = 35 evaluators out of 31 sixth-hour and 31 seventh-hour students.
identified these processes within their Activity 4: "thinking," "categorizing,
Percentages are very similar for these processes and also for minority-identified
processes of "evaluating," "remembering," "analogizing," and "fighting." This similarity
in identified processes makes sense since the classification experience was part of the
fourth group activity for all three biology classes. The only difference was that fifth-
hour students completed a guidesheet analysis of their classification experience.

Student rating of activity in 10 categories. Class rating means for each
category are listed in Table 25. They should be considered as suggestive of trends.
Table 25 indicates evaluators from Hour 5 and evaluators from Hours 6 and 7 gave the
same good ratings to the categories of number of students, teacher input, and
challenge. For all other category ratings, fifth-hour ratings are 0.5 lower than sixth-
and seventh-hour. Fifth-hour ratings of 4 for method of group selection, and 3.5 for
time involved and directions are still "good" ratings. Fifth-hour student ratings of 3 for
motivation, enjoyment, and knowledge gain suggest a somewhat less enthusiastic
response than that of students in sixth and seventh hour.

Additional comments. From fifth hour, seven evaluators wrote additional
comments; from sixth and seventh hours, 12 evaluators wrote comments. Keeping in
mind that a minority of students wrote extra comments, the balance of sixth- and
seventh-hour comments tilt in favor of Activity 4 and fifth-hour comments tilt toward
disfavor. Most comments were overall reactions, but a few concerned learning groups.

Jack in Hour 5 wanted to select new groups because "variety is good." Bill in fifth-
hour worried that his "group spent a lot of time fighting over what details were more
important for classification and were side-tracked very easily." Bill's comments capture
his group's paradoxical intense involvement and distractibility. These two comments
corroborate the idea that it takes hard interpersonal work to make a learning group
cooperative.
Table 24

Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 4

<table>
<thead>
<tr>
<th>Processa</th>
<th>Analogicalb</th>
<th>Nonanalogicalc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking</td>
<td>95</td>
<td>80</td>
</tr>
<tr>
<td>Categorizing</td>
<td>95</td>
<td>89</td>
</tr>
<tr>
<td>Discussing</td>
<td>82</td>
<td>83</td>
</tr>
<tr>
<td>Communicating</td>
<td>73</td>
<td>77</td>
</tr>
<tr>
<td>Drawing</td>
<td>68</td>
<td>49</td>
</tr>
<tr>
<td>Choosing</td>
<td>59</td>
<td>69</td>
</tr>
<tr>
<td>Observing</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Learning</td>
<td>59</td>
<td>60</td>
</tr>
<tr>
<td>Evaluating</td>
<td>55</td>
<td>43</td>
</tr>
<tr>
<td>Remembering</td>
<td>36</td>
<td>29</td>
</tr>
<tr>
<td>Analogizing</td>
<td>32</td>
<td>26</td>
</tr>
</tbody>
</table>

Note. Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

a Only processes circled by at least 25 % of either Hour 5 or Hour 6 and 7 evaluators are listed.

b n = 22 evaluators out of 29 fifth-hour students.

c n = 35 evaluators out of 31 sixth-hour and 31 seventh-hour students.
Table 25

Comparison of Mean Category Ratings by Students for Their Activity 4

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nonanalogical&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Time involved</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Age level</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Motivation</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>3.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Note. The rating scale is 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means have been rounded to the half-decimal.

<sup>a</sup><sub>n = 21 evaluators out of 29 fifth-hour students</sub>

<sup>b</sup><sub>n = 35 evaluators out of 31 sixth-hour and 31 seventh-hour students.</sub>
Most stated overall reactions to Activity 4 were favorable. Fifth-hour students said Activity 4: "was fun" (Rika); "took a lot of think, but was pretty good" (Sarita); and "was the easiest one we've done this year" (Barry). From sixth-hour, five girls called Activity 4 "fun." Cordelia declared, "This was a unique activity and also challenged me." Colette liked that "this activity helped [her] learn how to use a dichotomous key." Sonny in seventh hour said, "It was off da Bomb!"

A student in every class claimed Activity 4 was not worthwhile. Jim in Hour 5 "wasn't really wild about any of it...I think we already understood it well enough." Daveed in Hour 6 thought it took too long. Victor in seventh hour thought it was "too tedious" and "had too much done [for] too little knowledge gain." These advanced students thought Activity 4 was unnecessary because they had already mastered the concepts. Zeitoun (1983) warned that sometimes an analogy may be unnecessary if students already understand the target concept. This warning may have been applicable to a minority of students in all three biology classes.

Collage of student viewpoints. Fifth-hour responses tracked those of sixth- and seventh-hour students who did the same Activity 4, but without the guidesheet. Completion of the guidesheet by fifth-hour students took only a small part of Activity 4 time, so their evaluations focused on the rest of Activity 4. Most students in all three classes viewed Activity 4 as a moderate challenge that was clearly delineated. Students in all classes capably identified processes involved in their Activity 4 including "drawing," "categorizing," "observing," and "choosing," as well as cooperative group processes including "discussing," "thinking," "learning," and "communicating." It is interesting that 26% of sixth- and seventh-hour evaluators joined 32% of fifth-hour evaluators to identify "analogizing" as part of their Activity 4. Even without the guidesheet to stimulate analysis of the hardware classification as an analog for biological classification, some Hour 6 and 7 students engaged in classifying hardware as if they were classifying living things.
Sixth- and seventh-hour evaluators assessed enjoyment and motivation slightly higher than fifth-hour evaluators. This disparity may be an artifact of the particular volunteer evaluators of the nonanalogical path and the analogical path. Twice as many evaluators in Hour 6 and 7 were engineering magnet students as compared to evaluators in Hour 5. It was not surprising to find "engineering" magnet students more motivated by an activity involving nuts and bolts than other-minded students. Fifth-hour students still rated their Activity 4 as "okay" with a mean score of 3.

**Reflections on the Panoramic Views of Activity 4**

Student views and this researcher's view suggest that both the analogical and nonanalogical Activity 4 provided an accessible, relaxing learning experience which helped students understand biological classification through their classification of hardware. Students also learned by making a dichotomous key. Engineering magnet students' special enthusiasm for hardware classification correlated with their interest in engineering. Since some groups in sixth- and seventh-hours assumed hardware classification was a simulation for biological classification, their path was not strictly nonanalogical. Nevertheless, only fifth-hour groups completed the special guidesheet "Can You Experience This?" designed to encourage explicit reflection on experiences with analogical foundations. Fifth-hour's Activity 4 involved such a reflection. Student evaluations did not specifically address the effectiveness of fifth-hour's guidesheet "Can You Experience This?" To evaluate the guidesheets' effectiveness and the overall value of analogical Activity 4, a closer look at fifth-hour teams in action is necessary.

**Activity 4: Analogical Groups**

**Activity 4: The Pelicans**

*Group movie: Pelicans ignore flight plans.* Ed, Keisha, Michelle, and Randy actively engaged in classifying the items in their bag. The Pelicans tried to choose a significant feature each time they subdivided hardware objects. These students first divided their metal pieces on the basis of "curve" or "no curve."
and screws from hooks. One nail was bent into a curve and so this malformed nail became an "ugly duckling" among hooks. These teens separated nails and screws into "closed head" nails and "open head" screws, but then left these very different screws in that grouping.

Once I helped them understand how to use their chart to build a key for their classification system, the Pelicans easily accomplished that task. Their dichotomous key systematically followed their classification system. Randy did a good job drawing the objects, but he drew them with the key, rather than on their classification chart. This eliminated the impact of seeing that some like objects did not cluster together on their chart. This could have given them a clue that their classification system needed refinement.

They missed many clues when they failed to complete the guidesheet "Can You Experience This?" This guidesheet directed students to consider classification experience as an analog for classification of living things. The Pelicans approached their hardware classification with little thought of how it might be like the classification of life. This failure to consider correlations between the analog and the target is an impediment to learning from analogy (Holyoak & Thagard, 1995). If they had thought in terms of classifying life's species, they would not have separated the bent nail from other nails. In a metaphorical sense, this nail was simply a deformed member of the nail group. They did not differentiate between three very different screws. If they had thought of the screws as "organisms," they might have divided them further into unique "species."

They completed the optional beetle classification, but this did nothing to encourage them to think in comparative terms of the two classifications, hardware and "life."

The Pelicans received the following SMILE scores for expressed analogical development during Activity 4: 1.50 for Ed and Randy; 1.00 for Keisha and Michelle. Table 26 lists Pelican subscores and SMILE levels.
Table 26
Researcher SMILE Scores for Pelicans in Activity 4

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.50</td>
<td>2</td>
</tr>
<tr>
<td>Randy</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.50</td>
<td>2</td>
</tr>
<tr>
<td>Keisha</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
</tr>
<tr>
<td>Michelle</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.00</td>
<td>1</td>
</tr>
</tbody>
</table>

When together, these teens collaborated, but two unanticipated events detracted from their work as a learning group. Unhappy Paula sought temporary refuge from her own Ferrets. The Pelicans welcomed her into their group, but she did little to help. Keisha and Michelle had to leave class for much of one day's work.

Close-up focus on Ed. Ed was a strong contributor to classification of hardware and beetles. He was familiar with the hardware items and that made the task of classification seem easier. He helped Randy form their dichotomous key. He only had Randy to help him for much of the time. He was motivated and comfortable with the action parts of Activity 4. He did not consider guidesheet completion to be important.

Ed's SMILE score of 1.50 basically captured Ed's failure to explicitly think analogically of his classification experiences. He received a 1 in selection because he accepted a teacher-assigned analogy. He rated 2 for mapping because his mappings were mostly implied. He was teacher dependent for inferences so he received a 1 for inference. He got a 2 for evaluation because he did not explicitly judge the analogy and required class review to solidify the analogical comparison.

Close-up focus on Keisha. Keisha played a minor role in Activity 4. She was unfamiliar with many hardware items, so she relied on the boys. Ed and Randy knew "more like when we used the screws and all those little things. . . . we [Keisha and 200
Michelle didn’t worry about things like that* (Keisha’s interview, May 27, 1997). She was content following Ed and Randy. Due to her absence from class, she did not participate in beetle classification.

Keisha’s SMILE score of 1.00 captured her nonrecognition of her classification experience as an analog for classification of life. Her class absence affected her score. She received 1 for selection, mapping, inference, and evaluation because she needed one-on-one teacher instruction to catch up with her peers who had fully participated.

Movie review: Pelicans ignore flight plans.

The Pelicans flew through their experiences with classification and dichotomous key construction, but they ignored the analogical part of the flight plans provided by "Can You Experience This?" They experienced both classification of hardware and of beetles, but did not give much consideration to how they might be alike or different. Ed enthusiastically led his Pelicans in classification, but not in reflection. Following the boys’ lead for classification, Keisha gained her hands-on experience with that process.

Activity 4: The Harriers

Group movie: Harriers fly through squalls. The Harriers classified each item of hardware. They first divided objects into "short" and "long." This was an unfortunate decision because it placed short screws and long screws on two diverging paths. The rest of their decisions led to a systematic separation of items into smaller and smaller groups. Bill’s drawings of the objects were excellent.

The Harriers built a good classification system for 18 beetles depicted in text. This task was time consuming and complicated by the two-dimensional nature of the pictures. At the start, only Bill and Ton focused on this task. Jonah was out of class. Barry’s and David’s inattention hampered their intermittent attempts to help. Once Jonah returned, all Harriers settled into a more productive phase for the rest of the beetle classification and completion of the guidesheet.
"Can You Experience This?" guidesheet encouraged these boys to think about their classification experience. They recognized that they assumed "the exterior surface of the hardware is more important" than the interior for classification purposes. They identified a source of error as "something [that] did not seem to fit." Nevertheless, they were "very confident" of their classification system, and believed Activity 4 helped them "understand more because [they] had experience with it."

The Harriers experiences with both classifications of hardware and of beetles encouraged them to think in terms of how classification of living and nonliving things are the same and yet different. They noted that both classifications require repeated divisions into smaller and smaller groups. They noted the basis for both classifications involved characteristics of size, shape, specific parts, structure; but classification of life depends on more traits including internal structure, DNA, life span, and life functions. They mapped both similarities and dissimilarities between the analog and the target, as recommended by Harrison and Treagust (1993).

They actively debated their mappings. For example, they debated use of color, size, weight, or height as classification traits. David argued against using size because it can change as a beetle grows. Barry claimed that David’s argument was "like saying a kitten is going to grow to be as big as a lion" (4: H, 12). They decided size was an acceptable criterion for classifying an organism, just as it was for classifying hardware. The Harriers based their rejection of color on their rigid interpretation of my teacher advisory to avoid the use of color as a basis for early subgroupings of hardware. Other properties may be more significant, but color is often valuable as a secondary classification trait for organisms and hardware.

Harrier analysis showed richness in similarity and dissimilarity mappings. They tended to state mappings explicitly, but some lacked clarity. For example, when they used "structure," did they mean external structure? They accepted size and shape as traits, but rejected weight. Why did they make this distinction? This did not seem to
be systematic thinking. Their experience seemed to shape this distinction. They could see size and shape, but they needed a scale to weigh objects. Since the beetles were only pictures, they couldn't even weigh them, although they considered cutting them out to weigh them. They did go beyond their hands-on experiences to consider more abstract properties such as life span and the importance of DNA to classification of life.

The Harriers received the following SMILE scores for Activity 4: 3.25 for Ton, Bill, and Jonah; and 2.25 for Barry and David. This group worked independently to map connections between the analog and the target. Ton, Bill and Jonah identified dissimilarities, as well as similarities, and were able to make inferences. Barry and David depended on the others for inferences and did not identify any dissimilarities. See Table 27 for Harrier subscores and SMILE levels.

Ton clashed with Barry and David over their poor participation. Even when these errant boys tried to help, they were chided for not knowing the information they had missed when not paying attention. Bill disliked the discord and distracting sidetalk. Eventually, Bill's moderating influence helped to unify his group. Jonah's return to his group also seemed to break the team's polarization. When all five Harriers engaged in debate, their discourse was strong and productive.

Table 27

<table>
<thead>
<tr>
<th>Harriers</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3.25</td>
<td>4</td>
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<td>Bill</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3.25</td>
<td>4</td>
</tr>
<tr>
<td>Barry</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>Jonah</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>3.25</td>
<td>4</td>
</tr>
<tr>
<td>David</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2.25</td>
<td>3</td>
</tr>
</tbody>
</table>
Race had never been a cause for tension among these boys, but racial concerns seemed to be an undercurrent during Activity 4. These teens were concerned about an impending addition of a comprehensive program for neighborhood teens to their academic magnet school program. The neighborhood was Afro-American. These new students would alter the balanced racial composition of the student body. The Harriers ended Activity 4 talking about their next year's school plans to stay or leave.

**Close-up focus on Jonah.** Once Jonah returned from a guidance session, he assumed an active role in his group. He relied on his observant artist's eyes to classify the vividly depicted beetles. He noticed legs, antennae, mouthparts, and color patterns. He used body shape and position of legs to infer which beetles were land-bound and which were water-bound. He sensitively described shapes of beetle bodies or heads with such terms as "hexagon," "ellipse shaped," and "pin needle cone" (4: H, 13-14).

Jonah eagerly helped analyze the analogy comparing classification of hardware to classification of life. He initiated discussion of the importance of structure and specific parts for both classifications. He seemed inspired by the concrete objects. Josh declared, "They [bolts] don't use life functions. [They] don't have anything to do with . . . the characteristics of life" (4: H, 18). Thus, he cited the importance of using unique traits and functions of life to classify living things. Jonah talked specifically of bolts lasting longer than beetles. Ton translated Jonah's idea into the concept of "life span." Ton and Jonah seemed to be working in the constructive atmosphere where one person's thought is co-opted and transformed by another (Newman, Griffin, & Cole, 1989).

Jonah helped map five similarities and two dissimilarities. Jonah's active participation and confident voice suggest that he was comfortable with and interested in Activity 4. Hardware manipulatives and striking pictures of beetles increased his
Jonah earned a 3.25 SMILE score for his expressed analogical development during Activity 4. He earned a 1 for selection since he accepted the teacher-selected analogy. He received a 4 for mapping similarities and differences with the help of his peers. He rated a 4 for inferences because he frequently used inference to support his ideas and to expand on his ideas. He earned a 4 in evaluation for his role in his group's analogy evaluation, which was based on similarities and dissimilarities.

**Close-up focus on David.** David's participation in Activity 4 varied from total disconnection to sporadic participation to whole-hearted involvement. He focused on hardware classification, but his concentration waned during beetle classification. David's unreliability resulted in Ton and Bill ignoring David. Unhappy with being ignored, David complained in metaphorical language that: "Ton keeps closing the door in our faces, closing a window of opportunity* (4: H, 5). David's own distractibility and rejection by his peers hampered his participation.

David tried to earn his peers respect, but he responded serendipitously rather than systematically to the beetle pictures. He exclaimed, "God man, this one almost looks like a spider." When David figuratively described the head of one beetle as the "size of a watermelon," Barry gave a more realistic assessment of "about the size of a pea." David knew quite a bit. He identified beetle mouthparts as "the little things like ants eat with" (4: H, 12). As David's participation became more consistent, his friends became more receptive to his ideas. He identified size and shape as traits used to classify hardware and life, and wondered if texture or weight could also be used. He helped map similarities, but no differences between the two types of classification.

A school change controversy, so entwined with racial issues, affected David as a magnet student and as an Afro-American. To relieve tension, David tried humor. He modified a Monkey song line to "Hey, Hey we're the beetles." He teased that the
difference between two beetles was that "One is ugly and other one is uglier" (4: H, 13). David tried to stay calm. He deflected Ton's question about smelling by responding, "I smelled this way since I was born. I am sorry" (4: H, 1). Late in the activity he said, "I'm not that black." (4: H, 17). He was struggling with the issue of who he was. The emotionally charged school atmosphere surely upset David's usual balance.

David described Activity 4 as "comfortable," "interesting," "clear," "well-structured," "fun," and a "good" challenge. He recognized "analogizing" as a process in Activity 4. His ratings of 3 for motivation and 5 for enjoyment seem contradictory. Perhaps some of his "excellent" enjoyment included his off-task activities with Barry. The stressful emotional environment of Activity 4 contributed to David's just "okay" motivation.

David earned a 2.25 score for his expressed analogical development. David received a 1 in selection for his acceptance of the teacher-selected analogy. He earned a 3 in mapping for his help similarity mappings. He rated a 2 for inferences because he depended on his group for most inferences beyond the basics. He earned a 3 for evaluation of the analogy because he was dependent on his friends for a complete analysis.

**Movie review: Harriers fly through squalls.** The Harriers flew through squalls to accomplish their goal of learning about classification of life through classification of hardware. Their group interactions were emotionally charged. During part of their journey, a schism existed between the diligent pair of Ton and Bill and the distracted pair of Barry and David. Jonah's return to his group facilitated a beneficial regrouping of the Harriers. They completed their arduous flight to better scientific understanding of biological classification. They produced a good analysis of the analogy "Classification of hardware is like classification of life" by identifying both similarities and dissimilarities.
Artistic Jonah seemed inspired by visual elements of Activity 4 to apply his analytical abilities to finding analogical connections. David liked the hands-on experience and the beetle pictures, but multiple factors hampered his concentration during a lengthy process of classifying beetles.

**Activity 4: The Ferrets**

**Movie review: Ferrets scratch the surface.** The Ferrets developed a good classification system for a highly diverse set of hardware. Their first separation depended on whether the object was placed on something or set into something. The "inset" group consisted of assorted nails, screws, eyehooks, and curtain hook insert. This left four odd objects on the "placed" category. They continued the process of separation until each item was alone. The resulting classification system was logical, systematic, and organized.

The Ferrets used their guidesheet "Can You Experience This?" to think about their experience classifying hardware as an analog for classifying life. They divided their "Metal Kingdom" into the biological categories: phyla, classes, orders, families, and genera. The Ferrets recognized that classification of both hardware and life involved separation into large groups and further separation into smaller and smaller groups, and these separations should be based on characteristics in order of their significance. They added that the processes differed because hardware lacked properties of living things.

Even though the Ferrets recognized classification of hardware as a simulation for classification of life, they gave a simplistic analysis of this analogy. They noted a similarity in the basic process of classifying. Their use of biological classification categories suggests that they recognized more similarities than they stated. They noted one obvious difference that hardware is not living, but life involves living things. The Ferrets simply did not map out all their analogical thoughts as recommended by Harrison & Treagust (1993).
This team was overconfident. On their guidesheet, they claimed no source of error for their classification system. Indeed, they did an excellent job of classifying hardware. The problem is that they did not appreciate the importance of doing an excellent job of analysis. They assumed that the similarities and differences between the two classifications were obvious. If this team had attempted a more detailed analysis, they would have faced the challenge of explicitly stating their mappings. For example, what are the properties of living things that should be used to classify? This question is still pondered by professional biologists.

The Ferrets rated the following SMILE scores for their expression of analogical thought during Activity 4: 2.00 for Jim; 1.75 for Eve, Mark, and Max; and 1.25 for Paula. Table 28 lists SMILE levels and subscores for these students.

Unhappy Paula abandoned her Ferrets to join the Pelicans for a time. Jim and Max comfortably led the rest of the team through Activity 4. Jim was an unenthusiastic leader because he was bored doing something he already understood, but Max was pleased to display his competency in a scientific activity. Mark could name the hardware but he was confused by the classifying process. With her peer members' help, Eve eagerly participated in the classification experience.

Table 28

<table>
<thead>
<tr>
<th>Ferrets</th>
<th>SMILE Scores for Ferrets in Activity 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selection</td>
</tr>
<tr>
<td>Eve</td>
<td>1</td>
</tr>
<tr>
<td>Jim</td>
<td>1</td>
</tr>
<tr>
<td>Mark</td>
<td>1</td>
</tr>
<tr>
<td>Max</td>
<td>1</td>
</tr>
<tr>
<td>Paula</td>
<td>1</td>
</tr>
</tbody>
</table>
Close-up focus on Eve. Eve was happy to work with male friends to classify hardware. Eve said, "like hardware, that's like a guy's thing, not really a girl's thing. Like they were telling us what they were all used for, like the things girls didn't know." (Interview, May 10 1997). She suggested that girls would know more about classifying makeup, and laughed at what the boys would make of her eyelash curler. She suggested school supplies as a neutral domain.

With confidence, Eve helped classify. She liked understanding something in her often difficult biology class. She was pleased to have a hands-on simulation experience to help her learn and she liked making a classification chart. Eve said that she "can think in charts and diagrams better than I can in just a regular picture" (Interview, May 1997).

Eve's depicted Activity 4 as "easy," "interesting," "exciting," "clear," "simple," "creative," "fun," and "extraordinary." Eve enjoyed a highly motivating Activity 4. She was sensitive to the analogical thinking in her activity. She believed that Activity 4 helped her understand because "you start with a broad topic and go to many specific classifications" (Eve's guidesheet).

Eve's SMILE score of 1.75 captured her still dependent state in analogical thought in March, 1997. Accepting the assigned analogy, she earned a 1 for selection. She rated a 2 for mapping of a few similarities and one dissimilarity with the help of her friends. She received a 1 for inference since she remained dependent on her teacher in this area. She rated a 3 for evaluation since she worked with her peers to evaluate the power of their assigned analogy.

Movie review: Ferrets scratch the surface. The Ferrets designed a good classification system for their rather odd assortment of hardware. They understood this experience was intended to serve as an analog for biological classification. They only scratched the surface of this analogy for the learning potential locked within. This team was capable of a deeper analysis, yet settled for less. For Eve, the classification
experience was very beneficial, because she had so much to learn even about the basics of biological classification. She felt good that she understood the simple Ferret analysis.

**Activity 4: The Red Foxes**

*Group movie: Red Foxes explore multiple trails.* The Red Foxes pretended to classify organisms as they classified the hardware items in their bag. They referred to unique objects as "species" with Latinized names such as "roundheadus." Kirk feared repetitious "headus" endings suggested that hardware items "are all the same species." Ching rebutted with a metaphorical allusion to organisms, "They can't reproduce each other" so they surely are not the same "species" (4: R, 4). Ching and Kirk argued that length was a trait that could be used to classify screws. Kevin argued that length was not relevant since it would not be used to place humans in another category: "I'm long, you're short. That makes no difference" (4: R, 5).

The Fox boys monopolized classification of hardware. Rika and Mai assumed more active roles in making a dichotomous key. With Rika's guidance, members united to make a key to identify each item of hardware. Mai drew each hardware piece.

The Foxes had proceeded carefully, so they were somewhat miffed when I pointed out a confusing term in their classification system. Kirk thought I was being too technical, but they made an adjustment and their system worked better. On their guidesheet, the Foxes wrote that they had assumed that the "words we used to describe objects meant the same to us as to other people." This statement was probably intended as a response to my citing the ambiguity of their term.

The Foxes constructed a functional classification system for their hardware and a dichotomous key that matched their system. This team's written analysis of the analogy that "Classification of life is like classification of hardware" was brief. They noted that structure was a basis for classification in both systems. Classification of hardware concerned nonliving, simple tools; whereas, classification of life concerned
complex living organisms. The Foxes' written expression of analogical thought was poor relative to the rich analogical connections implied by their dialogue.

Fox discourse implied that classification of hardware and life depend upon a similar process of dividing a large group into smaller groups and these into smaller groups until each unique item has been given a specific name. In the case of life, this specific name is a species' name. These students paid close attention to choosing significant traits to use in classifying hardware and implied that this was important to classification of life. They debated the choice of traits in terms of their value in classifying living things. They imitated biological classification by calling their largest group a "kingdom" and Latinizing terms. This team immersed themselves in analogical thought.

Red Foxes earned the following Smile scores for expressed analogical development during Activity 4: 2.25 for Ching, Kevin, and Kirk; 1.50 for Rika; and 1.25 for Mai. The boys' dialogue was rich in analogical understanding of classification of hardware as an analog for classification of life. Rika contributed a little to the group's analogical analysis. Mai remained very dependent on her peers and teacher for analogical learning. See Table 29 for Red Fox SMILE levels and subscores.

Table 29

<table>
<thead>
<tr>
<th>Red Foxes</th>
<th>SMILE</th>
<th>Reduction</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mai</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
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<tr>
<td>Kirk</td>
<td>1</td>
<td>3</td>
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<td>2.50</td>
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</tr>
<tr>
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<td>1</td>
<td>3</td>
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</tr>
<tr>
<td>Kevin</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Rika</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.50</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
This group's interactions during Activity 4 correlates with research funded by the American Association of University Women, which "indicates that boys in small groups are more likely to receive requested help from girls; girls on the other hand, are more likely to be ignored by the boys" (Wellesley College for Research on Women, 1992, p. 73). The assured boys overwhelmed the girls during classification of hardware. They ignored Mai's helpful comments and her protests. Rika acquiesced to the boys. When I interceded with the group to encourage inclusiveness, Kirk used sarcasm to defend the status quo: "We torture them, we tell them don't talk" (4: R, 5). He didn't understand or didn't choose to understand that the boys' governing attitude inhibited the girls' participation. This negative effect on girls working in mixed-gender cooperative groups was documented in the previously mentioned AAUW report (1992). When the boys became perplexed by the task of making a dichotomous key, Rika willingly guided construction of the key. Mai overcame her insecurity to provide the necessary drawings of hardware.

Overall the Foxes felt Activity 4 was in their comfort zone. They believed they learned from their challenging classification experience. They felt confident in their classification system since "most of our 'organisms' fit into categories very easily." This assured posture was a nice change from this group's more typical sense of insecurity.

**Close-up focus on Kevin.** Kevin classified hardware as if he was classifying organisms. He slipped easily back and forth between the language of hardware and the language of biology. He began by asking, "Are we doing phylogeny?" which is a biological reference to the history of a species. He used engineering terms like "inclined planes" and "wingnuts." Thinking metaphorically of the classification of people of any height as one species, he argued that length was not an important
characteristic upon which to separate screws. Kevin was motivated to classify hardware.

Kevin lost his confidence when presented with the task of constructing a dichotomous key. He insisted that I stay and explain. He learned from my modeling of the process and Rika's guidance. Kevin's insecurity showed again when he worried that my queries were going to force the Foxes to do a big overhaul of their system. He was relieved when he realized that a simple distinction between a grooved head and a nongrooved head would suffice to improve their chart. Even when praised for creativity, he claimed, "No, we're just desperate" (4: R, 9).

Kevin was proactive towards the girls. Only Kevin asked if the girls wanted to comment. Mai responded immediately to his request. Kevin chided Ching for joking that the brains of the group belonged to the boys. He warned Kirk away from off-color language. Kevin's personal sensitivity made him more aware of the girl's feelings.

Kevin earned a 2.50 SMILE score for Activity 4. He received a 1 in selection for his acceptance of a teacher assigned analogy. He earned 3 for mapping similarities between the analog and target in cooperation with his peers. He earned a 3 for inferences because of his ability to infer back and forth between hardware classification and classification of life to keep the two correlated. He received a 3 for evaluation because his group judged the learning value of the analogy in terms of similarities.

Close-up focus on Mai. Mai was quiet. But when Kevin asked for comments, Mai eagerly explained two of the hardware items, a doorstop and a lock. Mai was upset when much of what she had said was unintentionally erased. She protested, "You taped over everything I just said. Oh, my god. It's where I put my input and it's gone"
Kirk made matters worse when he told her that what she had said wasn’t "important." In a practical sense, Mai’s words did not help much, but her voice deserved respect.

Mai seemed inspired to suggest "Tree" for their kingdom name, because indeed the classification chart looked like a branching tree. Instead, the group called their kingdom "Metalstuffius." With some trepidation, Mai agreed to draw the objects. She asked Kirk for directions. To hide his own confusion Kirk responded, "Why are you asking us?" Mai angrily asked if all he expected her to do was "just doodle" (4: R, 8). Mai successfully drew the hardware items on their chart. Mai pushed herself to contribute.

Mai described her Activity 4 experience as "comfortable," "okay," "understandable," "creative," and "fun." She circled "fighting" probably in reference to her conflicts with Kirk and Ching. She gave a "good" rating to motivation, enjoyment, challenge, and knowledge gain. In spite of the adversities Mai faced during Activity 4, she was pleased with her steps toward assertiveness and believed she had learned some biology.

Mai scored 1.25 on the SMILE scale. She was still highly dependent on others for analogical thought in March, 1997. Mai received a 1 for selection for her acceptance of the given analogy. She received a 1 in mapping and inference because she made no mappings and was in need of one-on-one teacher help. She earned a 2 for evaluation because she participated up to her limited capability in the evaluation process.

Movie review: Red Foxes follow multiple trails. Red Foxes followed many trails as they classified many hardware items. The Foxes seemed to answer in the affirmative to the question "Can You Experience This?" The experience of classifying
hardware allowed the Foxes to pretend they were classifying organisms. They applied what they knew about life's classification to their task. This metaphorical experience reinforced their understanding of biological classification. It was sad that Mai's and Rika's cautious temperaments and their male peers' assertiveness placed the girls in follower roles. These roles were semi-reversed as Rika took the lead in guiding the boys through foreign terrain of a dichotomous key.

Determined to contribute, Mai drew pictures for the classification map. Mai did not seem able to experience classification of hardware as if it was classification of life. Kevin showed his affinity for analogical thought as he classified hardware as if they were organisms. He showed his determination when he forged on to learn how to construct a dichotomous key. He showed his humanity in taking up for the girls.

Activity 4: The Snakes and the Lions

The Snakes. The Snakes confidently classified their hardware items, although they protested that a plastic item among all metal objects was a "misfit." Their first subdivision, based on the presence or absence of "threads," resulted in smooth nails being separated from grooved nails too soon. The smooth nails were grouped uncomfortably with screws. While the Snakes classification system would work for identification, the logic of their system might be challenged.

This team approached their classification task as an analog experience for life's classification. This was evident in their use of biological classification terms "kingdom," "phylum," "class," "order," and "family" in proper order. The Snakes noted that classification of hardware and of life are similar processes in that both involve separation of items into orderly groupings based on external traits and abilities. They noted the two classifications differ because one involves "nonliving" hardware and the
other involves "living" organisms. For classification of life, "internal structure" is as important as the "exterior, " and traits of life, such as "growth" and "movement," must be considered. The Snakes noted similarities and differences between the analog and target.

The Lions. The Lions diligently classified both hardware and beetles and made a dichotomous key. Their hardware classification system involved an initial separation based on the presence or absence of a point. This choice had the unfortunate result of placing a hinge, smooth screws, and smooth nails together, while placing pointy screws and pointy nails in the other subgroup. For their key, they numbered questions consecutively, instead of using the proper coupled number-letter system (e.g., 1a 1b, 2a 2b). They were confused by a plastic object among all metal objects. These confusions demonstrate the challenge inherent in this deceptively simple Activity 4.

On their guidesheet, "Can You Experience This?", the Lions said that classification of both hardware and life involved systematic placement of items into smaller and smaller groups based on certain features. They realized classification systems can change because they are made by people. They noted that the basis for the two classifications differed because hardware and organisms differ in "physical structure" and the "purpose for being." They stressed the need to study the internal structure of living things. The guidesheet encouraged these girls to reflect on ways in which hardware classification was like and unlike biological classification.

Activity 4: Summary

Both analogical and nonanalogical Activity 4 required students to classify hardware as a way to better understand the process of biological classification. Each group made a dichotomous key for their own hardware identification system. Some groups also did an optional classification of beetles. In addition, fifth-hour students completed a guidesheet "Can You Experience This?" that directed students in a step-by step
analysis of the analogy "Classification of life is like classification of hardware." How did participation in analogical Activity 4 affect fifth-hour students' learning of biology, student development of analogical thought, the quality of group interactions, and the quality of teacher-student interactions? How did student experiences in fifth hour compare to the counter experiences of sixth- and seventh-hour students?

**Activity 4: Learning Science**

Students in all three biology classes gained insight into classification and dichotomous key construction through their experiences with Activity 4, "Classification of Hardware". They were challenged to think, categorize, discuss, choose, draw, observe, and learn. They were highly engaged in a hands-on learning activity, which they viewed as a clearly structured, achievable assignment. All students showed some facility with classification, but also showed their neophyte skill as classifiers when they made decisions which more expert classifiers would not have made.

Groups made critical decisions early in the classification process. Despite teacher instructions to choose significant traits as a basis for separation, some groups made poor choices. Such errors tended to occur when groups made their first sub-groupings. An early teacher check on each group's progress would provide intervention at the most opportune moment. Construction of a dichotomous key, a tool for identification of organisms and their classification, took students beyond their prior simple use of a key to identify primates. Some groups did this task easily, other groups struggled.

In addition to the described experiences, fifth-hour students also completed their Activity 4 guidesheet, "Can You Experience This?" This aid contributed to Hour 5 students' learning and development of analogical thought.

**Activity 4: Development of Analogical Thought**

Some students in sixth- and seventh-hour classes thought of their activity as a simulation for biological classification. Without directions, these bright intuitive students developed a hierarchical system using biological category names and
Latinized terms. The extra assignment to classify beetles further encouraged students
to think comparatively. But comparison of classification of life to classification of
hardware was implicit in sixth- and seventh-hours’ Activity 4. Without a prompt to
explicitly state their analogical understanding, these students did not do so.

Fifth-hour’s guidesheet “Can You Experience This?” prompted explicit student
reflection on the classification of hardware as an analog for classification of life. The
guidesheet generated student discussion of detailed points of comparison and
contrast. Like some sixth- and seventh-hour students, many fifth-hour students
incorporated their analogical thought within their simulation experience through use of
biological category names and Latinized terms; but the guidesheet encouraged fifth-
hour students to take the next step of explicitly recording their analogical thoughts.

Fifth-hour groups wrote definitive statements of how the two classifications were
alike and not alike. All fifth-hour groups noted similarity in grouping patterns and the
relevance of structure as a basis for classification. They emphasized that classification
of life requires consideration of the traits of living things, whereas, these traits do not
apply to nonliving hardware. The Harriers, Snakes, and Lions gave more detailed
explanations of traits used to classify living things. The Foxes wrote a brief analysis,
but their dialogue was rich with analogical implications. The Ferrets gave a short
analysis, and assumed details were obvious. The Pelicans did not turn in a guidesheet.

Activity 4: Quality of Group Interactions

Hour 6 and 7 students generally liked the hardware classification activity,. The
engineering students were the most enthusiastic about working with hardware. These
students approached their assignment with seriousness, but also enjoyed the creativity
of naming their groupings and individual items. Toward the end of their assignment,
students became bored with the repetition.

Most fifth-hour students easily and comfortably worked together to classify their
hardware. They felt empowered to make their own group decisions and free to have a
little fun making up category and object names. A few students came in minor conflict with their peers under the stress of a long assignment, incompatibility of personalities, and school-wide concerns. These momentary clashes occurred among the Ferrets, Harriers, and Red Foxes.

**Activity 4: Teacher-Student Interactions**

My role as teacher was basically the same in all three biology classes. I gave class instructions, and followed these with individualized instructions to each group. I encouraged students to choose the most significant characteristic as the basis for grouping. The students quickly understood the basic process of classification and worked with confident autonomy. Sometimes they were overconfident, because they did not recognize some of the pitfalls of classification. I pushed them to refine their classifications. Some groups requested and received assistance with constructing a dichotomous key. Fifth-hour students did not ask for extra help with their guidesheet, probably because the format was very similar to that used in Activity 3.

I spent more time than usual keeping fifth-hour students focused, possibly because they were distracted by registration matters for the next school year. Some students were called out of this biology class to speak with guidance counselors. These students had concerns about how their school would change the next year as it became a neighborhood school, while also remaining a parish-wide academic magnet. These worries decreased student attention to their work.

**Activity 4: Analysis Implications**

Hour 5, 6, and 7 students classified a set of hardware as an aid to learning about biological classification. This experience helped students learn about classification, a process important to science. They gained an appreciation of evaluation and decision-making in classification. The guidesheet "Can You Experience This?" encouraged fifth-hour students to consider how classifications of hardware and of life are similar and different, and to formulate explicit statements based on these distinctions. This not
only contributed to their development of their analogical skills, but also helped them to maximize their learning about life's classification from their experience with classification of hardware. The addition of the guidesheet to Activity 4 seemed to be a useful tool for promoting important learning transference from the hardware classification to the target of biological classification.

**Activity 4: Reflections on Specific Students**

Activity 4 was a different experience for each of the students selected for special focus in this research. It may be informative to look back at these students.

**Pelicans: Ed and Keisha**

Ed expertly led his group through the classification of hardware, beetles, and construction of a dichotomous key. Ed enjoyed Activity 4, even though he and Randy carried the burden for Activity 4 once the girls left. The Pelicans did not turn in their guidesheet responses, which eliminated this as a source of evidence for analogical thought. For this reason, Ed's SMILE score of 1.50 for expressed analogical ability during Activity 4 may underestimate his analogical thought.

Keisha's absence during much of Activity 4 partly explains her SMILE score of 1.00. Keisha enjoyed classifying, yet was content to let the boys lead because they were more familiar with nails and screws than she. When troubled Paula sought refuge with the Pelicans, kind Keisha welcomed her.

**Harriers: Jonah and David**

Jonah was in high spirits doing Activity 4. Concrete manipulation of objects and keen observation of the beetle pictures suited his artistic personality. These factors facilitated his well-considered verbal contributions. He made specific references to the two classification experiences as he made his points regarding how they are alike and different. Jonah showed strength and independence in his analogical thought to earn a 3.25 SMILE score.
David liked Activity 4, but had trouble concentrating. As an Afro-American, he was especially sensitive to the school-wide turmoil concerning impending changes in the student body. During the early parts of Activity 4, David sporadically tried to help his group, but without much success. When his attention improved, he was able to help his Harriers classify beetles and then analyze the analogy between the classification of hardware and of life. He noted similarities, but no dissimilarities. He earned a 2.25 SMILE score. David depended on his analytical peers to catalyze his own deeper thought. Yet, metaphorical expression permeated David's talk throughout the fourth analogical activity.

**Ferret: Eve**

Eve responded enthusiastically to Activity 4 in part because it matched Eve's preference for learning from charts and diagrams. She depended on the boys' knowledge of hardware. She appreciated the analogical nature of the classification of hardware for biological classification. She was still dependent on her peers and her teacher for enhancement of her analysis of the analogy. She rated a 1.75 SMILE score.

**Red Foxes: Kevin and Mai**

Kevin was in his comfort zone. He enjoyed classifying hardware as though he was classifying organisms. His zoo volunteer work increased his interest in biological classification. Kevin's felt less secure constructing a dichotomous key, but persevered in this task. Sensitive Kevin protected the girl foxes. He earned a 2.50 SMILE score.

Activity 4 appealed to quiet Mai so much that she spoke several times, but the boys did not validate her contributions. Pragmatically, her comments may not have added much to their discussion, but Mai needed her peers to appreciate her efforts. She gained some satisfaction from drawing the hardware objects on the Fox classification chart. She remained dependent on her peers and teacher for understanding classification of life, and for explanation of the analogy between the classification of hardware and life. She rated a 1.25 SMILE score.
HIGH SCHOOL BIOLOGY STUDENTS' PARTICIPATION IN A YEAR-LONG SEQUENCE OF ANALOGICAL ACTIVITIES: THE RELATIONSHIP OF DEVELOPMENT OF ANALOGICAL THOUGHT TO STUDENT LEARNING AND CLASSROOM INTERACTIONS

VOLUME II

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

Marcella Wichser Hackney
B.S., University of New Orleans, 1969
M.N.S., Louisiana State University, 1984
May, 1999
Activity 5

Activity 5: Analogical Versus Nonanalogical

Activity 5: Black and White Photo Shots

Introduction. Problem solving is important in science. Activity 5 challenged students to solve two problems—tumor treatment and water allocation. Since Activity 5 was not linked to a specific biology unit, student preparation depended on their knowledge of relevant topics and terminology. On April 18, 1997, all three classes began their Activity 5.

Activity 5 descriptions. Cooperative groups in all three biology classes faced the same two problems to solve. One problem involved the treatment of a patient with an inoperable tumor (Gick & Holyoak, 1980). Radiation treatment was the only option, but intense rays would harm good tissue and low level rays would be ineffective. The second problem concerned equitable distribution of annual river flood waters to poor farmers. Students read each problem text and then identified the following: problem, goal, resources, possible actions, restrictions, plan, outcome, and how they arrived at a solution. This basically describes the nonanalogical Activity 5, "Can You Find a Solution to the Problem?"

The analogical Activity 5, "Can You Find a Solution in the Story?" (see Appendix T), included a story text which solved a problem similar to one the students needed to solve. Each story text could serve as an analog to a problem text. Hour 5 students answered the same questions for the story text as they did for their problem text. The story text provided answers to all the questions, but the problem text did not include a plan for solving the problem. I urged Hour 5 students to use the story analog to help them think of solutions to their assigned problems (see Appendixes U, V, and W).

Activity 5: Panoramic Photos Taken from Researcher Vantage Points

Nonanalogical path. Hour 6 and 7 students brainstormed to solve their problems with a little teacher advice and direction. For the patient's tumor problem,
groups named the goal as removal or destruction of the tumor; resources as X-rays and doctors; and restrictions as no operation and no use of high energy radiation. Group solutions included: medium doses of radiation, chemotherapy, low dose radiation in one direction for a long time, laser inserted into stomach, and low energy rays focused on the tumor from many angles. Most groups devised solutions through debating their ideas.

**Analogical path.** While fifth-hour groups' identifications of the goal, resources, and restrictions matched those of sixth- and seventh-hour groups, this matching pattern shifted with fifth-hour groups' solutions. Some students suggested drugs, prayer, or intermittent use of high energy rays. But over half the students in fifth-hour favored using low intensity rays focused from different directions toward the tumor. These students associated their solution with the solution given in their extra story text.

In the analog story text, a general needed to attack a fort protected by mines on all roads leading to the fort. The general decided to send his men in small units along the roads to avoid the mines and arrive in full force to attack the fort (Gick & Holyoak, 1980). The general's solution influenced a majority of fifth-hour students to propose using low intensity rays to attack the tumor from many directions. Only two out of fourteen nonanalogical groups, the Loons and the Kangaroos, proposed the same solution.

**Nonanalogical path.** For the water allocation problem, sixth- and seventh-hour teams named: the goal as equal water distribution to farmers along the river as it overflowed; resources as rustic farming implements and farmers; and restrictions as no high tech machinery and little money. Group solutions included: irrigation canals, reservoirs, dams, wells, water storage tanks, and splitting the river. Several groups drew detailed maps of their irrigation plans. The students arrived at their solutions through brainstorming, discussion, and remembering lessons about irrigation.
Hour 6 and 7 students were interested in solving the two problems and enjoyed free exchange of thought. They requested teacher input, but took responsibility for their own problem solving. These students sometimes floundered in their discussions, as if they lacked a tool for shaping their discourse. They spent one hour on Activity 5.

**Analogical path.** The analogical teams responses were similar to those of the nonanalogical teams to the questions of the water problem, goal, resources, and restrictions. Fifth-hour solutions shared features with Hour 6 and 7 solutions in that they considered canals, diversion streams, reservoirs, wells, and ditches.

Fifth-hour students seemed more concerned with water rationing and community cooperation. Student focus on these concerns may have been primed by reading the analogous story text in which equitable distribution of peanuts to hungry people was the problem. The solution involved a daily lineup of people who waited to receive as many peanuts as their hands could hold. A majority of fifth-hour students felt that the peanut allocation story influenced their problem solving.

Hour 5 students enthusiastically engaged in problem solving. Some Hour 5 students found comfort in having the story text to help shape their dialogue, even though it was more work to analyze the two story texts. Hour 5 students took about two class periods to complete Activity 5.

**Activity 5: Panoramic Photos Taken from Student Vantage Points**

**Student evaluations.** The following number of students in each class provided their views of their Activity 5: 18 in fifth hour, 29 in sixth hour, and 19 in seventh hour. They completed evaluation forms.

**Selection of adjectives to describe activity.** Table 30 lists the percentages of students evaluators in Hour 5 or in Hours 6 and 7 who chose a listed adjective. Table 30 is organized to highlight a comparison of student evaluators' perceptions of the analogical and the nonanalogical Activity 5.
Table 30

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 5

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-ended</td>
<td>28</td>
<td>27</td>
</tr>
<tr>
<td>Easy</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>Interesting</td>
<td>44</td>
<td>46</td>
</tr>
<tr>
<td>Complex</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>Unusual</td>
<td>33</td>
<td>27</td>
</tr>
<tr>
<td>Typical</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td>Okay</td>
<td>50</td>
<td>42</td>
</tr>
<tr>
<td>Clear</td>
<td>44</td>
<td>33</td>
</tr>
<tr>
<td>Fun</td>
<td>39</td>
<td>52</td>
</tr>
<tr>
<td>Understandable</td>
<td>28</td>
<td>44</td>
</tr>
<tr>
<td>Well-structured</td>
<td>55</td>
<td>35</td>
</tr>
<tr>
<td>Comfortable</td>
<td>94</td>
<td>69</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

\(a\) Only adjectives circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

\(b\) \(n = 18\) evaluators out of 29 fifth-hour students.

\(c\) \(n = 48\) evaluators out of 31 sixth-hour and 31 seventh-hour students.
Table 30 shows that a majority of students in all classes found their Activity 5 to be "comfortable," "clear" or "understandable," "okay" or even "interesting." About a quarter of students in both the analogical and analogical groups called their Activity 5 "complex." A quarter of students in Hour 5 and Hours 6 and 7 selected "open-ended" to describe their Activity 5.

A larger percentage of fifth-hour evaluators chose "well-structured" compared to Hour 6 and 7 evaluators. This suggests that the analogous story texts provided additional structure to the analogical Activity 5. A larger percentage of sixth- and seventh-hour evaluators chose "creative" as compared to fifth-hour evaluators. In a sense, the nonanalogue participants had to be even more creative than the analogical participants, because they did not have the analog stories to help shape their thoughts.

**Identification of activity processes.** Table 31 lists Activity 5 processes evaluated by students as part of their Activity 5. Percentages are listed in order from highest to lowest based on fifth-hour evaluator responses. Cross comparison of processes identified for the analogical and nonanalogue Activity 5 is recommended.

A majority of evaluators of the analogical Activity 5 and a majority of evaluators of the nonanalogue Activity 5 identified the processes of "problem solving," "thinking," "communicating," "discussing," "hypothesizing," and "choosing." These processes definitely were important to both activities. Fifth-hour evaluators identified "analogizing" more than sixth- and seventh-hour evaluators (38% versus 19%). Hour 5's activity encouraged analogical thought. A larger percentage of Hour 6 and 7 students' selected "learning" and "remembering" as processes required for their nonanalogue Activity 5.

**Student rating of activity in 10 categories.** Student evaluators rated their activity in 10 categories. Class rating means are listed in Table 32. Student
Table 31

Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 5

<table>
<thead>
<tr>
<th>Process</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving</td>
<td>89</td>
<td>94</td>
</tr>
<tr>
<td>Thinking</td>
<td>88</td>
<td>98</td>
</tr>
<tr>
<td>Communicating</td>
<td>83</td>
<td>79</td>
</tr>
<tr>
<td>Discussing</td>
<td>83</td>
<td>79</td>
</tr>
<tr>
<td>Hypothesizing</td>
<td>78</td>
<td>52</td>
</tr>
<tr>
<td>Choosing</td>
<td>56</td>
<td>58</td>
</tr>
<tr>
<td>Estimating</td>
<td>50</td>
<td>29</td>
</tr>
<tr>
<td>Creating</td>
<td>44</td>
<td>53</td>
</tr>
<tr>
<td>Evaluating</td>
<td>39</td>
<td>54</td>
</tr>
<tr>
<td>Analogizing</td>
<td>39</td>
<td>19</td>
</tr>
<tr>
<td>Learning</td>
<td>33</td>
<td>67</td>
</tr>
<tr>
<td>Calculating</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td>Observing</td>
<td>28</td>
<td>21</td>
</tr>
<tr>
<td>Remembering</td>
<td>22</td>
<td>38</td>
</tr>
</tbody>
</table>

Note. Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

*Only processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

*b = 18 evaluators out of 29 fifth-hour students.

c = 48 evaluators out of 31 sixth-hour and 31 seventh-hour students.
Table 32

Comparison of Mean Category Ratings by Students for Their Activity 5

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical\textsuperscript{a}</th>
<th>Nonanalogical\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Time involved</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Age level</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Motivation</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Challenge</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

\textbf{Note.} The rating scale is 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means have been rounded to the half-decimal.

\textsuperscript{a}n = 18 evaluators out of 29 fifth-hour students

\textsuperscript{b}n = 49 evaluators out of 31 sixth-hour and 31 seventh-hour students.
evaluators of either Activity 5 gave the same high 4.5 ratings for number of students, method of group selection, and teacher input. They gave the same "good" ratings of 4 for time involved, age level, enjoyment, challenge, and knowledge gain. Fifth-hour evaluators rated their Activity 5 slightly higher with a 4.5 for directions and a 4.0 for motivation. The addition of the analogous story text made directions clearer and increased student motivation.

Additional comments. Some evaluators wrote extra comments. Most comments concerned overall favorable reactions, but a few students in sixth and seventh hours mentioned concerns.

Fifth-hour evaluators gave favorable comments about analogical Activity 5. Jim "thought it was fun. We should do things like that more often!" Paula drew a smiley face. Tina said, "I think it was kind of hard but challenging; but I like it cause it was comfortable for me." David liked "choice of drawing as an activity."

Seven students in the nonanalogical groups of Hour 6 and 7 expressed pleasure with their problem solving activity. Lynette liked that it was different. Roy described Activity 5 as "groovy and far out too." Some students in the nonanalogical groups gave mixed reviews or negative comments. Kay was okay with the first problem, but confused by the second. Anton wanted more "excitement" even though the activity was "well organized." Abel agreed with Daveed, who wanted "more time to adequately solve the second (water) problem. Jonas complained that "We fought too much and got off track."

Collage of student viewpoints. Most students in all three classes seemed to enjoy the stories and problem solving of Activity 5. They felt challenged and motivated to work cooperatively. Category ratings for both analogical and nonanalogical Activity 5 were high. The opportunity to use analogical thinking to solve problems appeared to increase the motivation of fifth-hour students. The story text
provided students with an anchor as they tried to figure out solutions. The story text provided ideas that influenced fifth-hour students' thoughts.

**Reflections on the Panoramic Views of Activity 5**

Students' views and this researcher's view suggest that both the analogical and the nonanalogical Activity 5 were motivating assignments which let students draw on their prior knowledge to propose solutions to realistic problems. All students practiced problem solving using a structured analytical approach. The analog stories gave fifth-hour students a potential analogical foundation upon which to base their decisions. Analysis of the story text provided these students with additional ideas for problem solving. It will take a closer look at fifth-hour learning groups to see how the analog story text and its analysis helped students develop their problem solving skills and their analogical thinking.

**Activity 5: Analogical Groups**

**Activity 5: The Pelicans**

*Group movie: Pelicans tell their own stories.* The Pelicans easily analyzed the story text of the general's capture of the fortress. They noted that the general's plan was to "split the troops up and send them down different roads so the mines will not go off" and the fortress can be attacked in full strength. To solve the tumor problem, the Pelicans decided "to keep the rays of low intensity, then when it is over the tumor," they will in combination be strong enough to destroy the tumor.

Responses to "Can You Find a Solution in the Story?" guidesheet helped shape the Pelican solution to the tumor problem. The Pelicans solved the tumor problem through their analogical mappings of similarities between the fortress and tumor problems. Sending a high intensity ray to kill the tumor would kill healthy tissue; just as sending all the soldiers down one mined road would kill many healthy soldiers. The story of the general sending small units of soldiers down each road to the fortress primed this team to think of sending low intensity rays toward the tumor. The low intensity rays
together would have the effect of a high intensity ray, just as the coordinated arrival of all the small soldier units gave the general a strong attack force at the fortress.

The Pelicans analyzed the story text of the allocation of peanuts to the hungry people. They noted that the people collectively decided to give a standard amount of peanuts, two handfuls, to provide all with enough food to live. To solve the water allocation problem, they recommended that people decide together on a standard amount of water, which each farmer would be allowed to take based on the size of his farm. An observer would be sent to each farm to monitor the barrels of water taken.

The Pelicans used analogical thinking when they proposed their solution to the problem of water allocation, which was similar to the solution to the story text problem of equitable distribution of peanuts. They mapped: the resource of peanuts to the river water resource; the hungry people to the farmers in need of water; and the community plan to distribute handfuls of peanuts to a community plan to provide equal amounts of water to each farm. The Pelicans believed the story text helped them solve the water problem.

The Pelicans earned the following Activity 5 SMILE scores: 2.50 for Ed and Randy, 1.75 for Keisha, and 1.25 for Michelle. Table 33 lists Pelican SMILE scores.

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Randy</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Keisha</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td>Michelle</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
<td>2</td>
</tr>
</tbody>
</table>
The Pelicans arrived at their solutions under the leadership of Ed and Randy. Keisha helped, but Michelle spoke very little. This team talked about the similarities between the story text situations and the problems they needed to solve. A closer look at Ed's role and Keisha's role will enhance understanding of Pelican problem solving.

**Close-up focus on Ed.** Ed contributed to Pelican problem solving efforts. Ed related the tumor problem and the fortress problem because "both of them had to do with how to destroy something without hurting the other." Ed wanted to use low intensity rays like the general used small units of soldiers. A combination of the soldiers or combination of the low intensity rays amount to a large force.

Ed easily identified the peanut and water problems as equitable distribution problems. He thought of the hungry people's different size hands as a symbol for the different size farms. Smaller handed people needed less food and smaller farms needed less water. The community took responsibility for monitoring water allocation so that no farmer took more than he should (Ed's interview, May 10, 1997). Ed showed strength as a planner and as an analogical thinker throughout Activity 5.

Ed described Activity 5 as "comfortable," "interesting," "clear," "understandable," "well-structured," "creative," "fun," and "extraordinary." He recognized "analogizing" as a process in Activity 5. He gave "good" ratings to motivation and enjoyment and "excellent" ratings to challenge and knowledge gain. Clearly, Ed experienced Activity 5 as a powerful experience.

Ed earned a 2.50 SMILE score for Activity 5. He accepted the provided analog so he rated a 1 for selection. He mapped many similarities with the help of his group to earn a 3 for mapping. He developed a detailed plan based on his inferences, which earned him a 3 in inference. He earned a 3 for evaluation because his team judged the value of the analogy on the basis of similarities.

**Close-up focus on Keisha.** Keisha helped, but the boys tended to dominate the conversation of how to solve Activity 5's problems. She liked having her peers to
rely on when trying to make sense. She willingly recorded the group answers on the
guidesheet, but she did not write very detailed responses. She felt okay about her
contributions to Pelican dialogue and felt responsible in her role as group recorder.

Keisha rated 1.75 on the SMILE assessment. She earned 1 for selection when she
accepted the provided analogy. She received 2 for mapping for helping her peers map
some similarities. She rated 1 for inference given her dependence in this area. She
earned a 3 for evaluation since she was able to recognize the analogous nature of the
story texts with the help of her peers.

**Movie review:** Pelicans tell their own stories. The Pelicans took the
wisdom from the story text and through analogy applied this wisdom to solving the
tumor problem and the water allocation problem. They were very good at recognizing
mappable relationships. They were less likely to notice differences that may have been
relevant to problem solving. The Pelicans used Activity 5 to develop their skills of
problem solving. They liked telling how the problem stories ended. Ed waxed eloquent
in his story telling. Keisha liked adding pieces to the stories and recording her group's
stories.

**Activity 5: The Harriers**

**Group movie:** Harriers share stories. The Harriers followed the guidesheet
"Can You Find a Solution in the Story?" to analyze both story texts and problem texts.
They wrote that the solution to the fortress problem was for the general to "dispatch
small groups and attack from all roads at the same time." Similarly, they proposed to
"zap the tumor from different directions at same time with low intensity rays" in order
to destroy the patient's tumor.

The Harriers fashioned a solution to the tumor problem that showed kinship with
the solution to the fortress attack problem. Bill even wrote that they "used the same
method as the General in the other story." Bill meant analogically "the same." Both
fortress and tumor were attacked. Small units of men and low intensity rays were
used. The soldiers moved toward the fortress on many roads; the rays moved toward the tumor from many directions. The combined soldiers won the battle and the country was freed; the combined rays killed the tumor and the patient lived. The Harriers produced a system of mappings from the analog story to the problem story. Such systematicity is emphasized in Gentner's (1983, 1986) structure mapping theory.

The Harriers competently analyzed the story text of how peanuts were distributed equitably to hungry people through a system of lining people up to receive handfuls of peanuts. They noted that the problem text also involved equitable distribution of a resource, the water from an overflowing river. The Harriers decided to use community labor to dig a reservoir to store flood water for later irrigation of upstream farms, and allow the rest of the river water to flow to the downstream farmers.

The Harriers fashioned a solution to the water distribution problem that was not directly influenced by the story about peanut distribution. Bill claimed that the solution took "creativity" and Ton claimed it took "common sense." The story text did not help them, because they confusedly answered the questions for the problem text first. When Barry clarified this issue, it was too late for the story text to affect their decision to dig a reservoir to store water. Without analogical guidance, this part of their dialogue resembled that of students in Hour 6 and 7 who did not read the analog story.

Harriers earned the following SMILE scores: 2.50 for Ton, Bill, Barry, and David; and 2.25 for Jonah. The team showed independence in analogical thought for the tumor problem solution, but they did not tap the second story analog for clues to solving the water problem. Table 34 lists Harrier SMILE levels and subscores for Activity 5.

As a team, these boys enthusiastically brainstormed solutions to the problems. Guidesheet structure shaped their organized analysis of the tumor problem. When they misread instructions in analyzing the second problem, their discourse became less organized, but maintained its interesting character. David explained how their talk
"started flowing" as each member commented. The equitable participation by all the boys improved Harrier group dynamics. What roles did Jonah and David play?

Table 3.4

Researcher SMILE Scores for Harriers in Activity 5

<table>
<thead>
<tr>
<th>Harriers</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Bill</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Barry</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Jonah</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>2.25</td>
<td>1</td>
</tr>
<tr>
<td>David</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
</tbody>
</table>

Close-up focus on Jonah. Jonah was motivated to work with his peers to solve problems. In trying to solve the tumor problem, Jonah used his recollection of a relative's radiation treatment for cancer. When I later discussed Activity 5 with Jonah, he did not think the story text helped him think of a solution, even though he could see the similarity between the story text and the problem text. "They both use lower numbers." (Interview, May 10, 1997). He insisted that he would not transfer a solution from one situation to another. "The way I think of the thing is through my head as it goes action by action."

In spite of Jonah's belief that he did not use analogical transfer to find solutions to problems, he may have implicitly used the peanut allocation approach to solve the water distribution problem. He suggested, "Everyone gets a pond [filled with water] to supply their own needs." Ponds holding water are similar to hands holding peanuts in the analog story. Jonah wanted a long ditch dug at a certain height all along the river. The water from the ditch would spill over into the ponds. The river ditch seems analogous to the line formation of the hungry people, and the flow of water from the
ditch into the ponds seems analogous to the flow of peanuts from the sack into the
hands of people in the line. Jonah's solution actually was more analogous to the
peanut allocation story than the group's solution which was to build one big reservoir.
When asked if he saw a similarity between the two stories, he agreed, "I sort of see
one, doing it at a time, letting some go at a time" (Interview, May 10, 1997). He
compared the water to peanuts.

Jonah received a 2.25 SMILE score. He earned a selection score of 1 based on
evidence that he accepted the analogs only unconsciously. He implicitly mapped
similarities from both story analogs to the problems with his peers and independently
so he earned a 4 in mapping. He worked with his teacher and peers to make inferences
so he rated a 3 in inference. He received a 1 for evaluation because he needed help to
see the analogical value of the story analogs.

**Close-up focus on David.** David was a humorous, confident problem solver
during Activity 5. He helped his team make systematic mappings from the analog
fortress story to the tumor problem story. He explained that the tumor problem
seemed "unsolvable," until he "read the story about the army general." Then he "got
it right off the bat" (Interview, May 27, 1997). David saw the general's problem and
the doctor's problem as the "same" in an analogical sense.

Even in the midst of confusing discussion of the water problem, David was a voice
of reason. He read both texts well and used them to make his points. He realized that
the group had erred in reading the guidesheet, so he told his peers, "It goes in order"
(5: H, 4). The Harriers gave David credit for their solution to the water problem. David
thought it was harder than the tumor problem. Without an assist from the analog
story, it may have been more difficult. David may have transferred ideas from real
problems that interested him. For example, David recounted how a North Dakota
community came together to build a levee to protect their town from a flooding river.
David described Activity 5 as "easy," "interesting," "simple," open-ended," and "extraordinary." David felt honored by his peer's respect for his ideas. David was highly motivated to solve "realistic" problems.

David rated a 2.50 SMILE score. He received a 1 for selection for his acceptance of the assigned analogy. He helped map similarities with his peers so he received a 3 in mapping. David expressed several inferences during Harrier debate to rate a 3 for inference. He shared a 3 with his mates for evaluation of the first analogy.

**Movie review: Harriers share stories.** The Harriers used strong analogical thinking to arrive at a solution to the tumor problem. They all agreed on the ending for the patient's story. They shared ideas about how to solve the water allocation problem. Of their many stories, David's tale made the most sense to this team. David felt proud. The Harrier's solution to the water allocation problem showed little transfer of ideas from the peanut allocation story. Jonah's solution for water allocation seemed inspired by the peanut story, even if Jonah was unaware of this influence.

**Activity 5: The Ferrets**

**Movie review: Ferrets agree on their story lines.** Using the guidesheet "Can You Find a Solution in the Story?", the Ferrets methodically analyzed the fortress story text. They described the general's plan as "divide the forces, go down different roads so you don't set off traps." In reference to the problem text, they planned to "shoot the cancer with several low intensity beams, so it will only be intense enough to kill the cancer." Jim explained that the story text helped because they "followed the general's plan to 'divide and conquer.' The individual beams weren't enough to kill the cancer, but the focal point was."

Using the same set of guide questions to shape analysis of the story text and the problem text seemed to promote correlational reasoning, which is necessary to use an analogy (Zeitoun, 1983). Just like the general used his soldiers in small units to move toward the fort along many roads, this team used radiation in small units to move
toward the tumor from many different directions. The attack by all the soldiers at once brought victory to the general; the concentration of many low intensity rays on the tumor brought a health victory to the patient. Analogical thought helped the Ferrets "save the patient."

The Ferrets analyzed the story text of the peanut distribution. They noted that food was fairly allocated by pouring peanuts into the hands of people standing in a line. They solved the water allocation problem by digging a series of wells to hold the overflow water. Farmers could come every day to take the water they needed. All Ferrets agreed that the story text helped them solve their problem.

The Ferrets definitely gained insights for solving the patient’s tumor problem from their analysis of the attack on the fortress story. Just like the general used his soldiers in small units to move toward the fort along many roads, this team used radiation in small units to move toward the tumor from many directions. The attack by all the soldiers at once brought victory to the general; the concentration of many low intensity rays on the tumor brought a health victory to the patient. Analogical thought helped the Ferrets "save the patient." Using the same set of guide questions to shape analysis of the story text and the problem text seemed to promote comparison thinking, which is necessary to use an analogy for insights.

The Ferrets followed the same systematic approach to solve the water problem. They used the story text to help them solve their problem. Max thought the peanut allocation story helped them think of the need to separate the water like the peanuts were separated. Paula wrote, "Everyone got what they could handle and got enough to satisfy them." Her note pointed out the similarity of goals--fair distribution of a vital resource. Jim and Eve saw the similarity of resources in the peanuts and water.
Eve thought of the line of people as like the long river. The idea of farmers drawing water daily from the well fits with the daily rationing of peanuts to the hungry people.

The Ferrets received the following SMILE scores: 2.50 for Eve and Jim, 2.00 for Mark and Max, and 1.50 for Paula. They showed independence in their mapping of similarities. They did not explicitly note the differences. Sarah's low score reflects the paucity of her analogical thoughts, even though she participated. See Table 35 for Ferret SMILE levels and subscores.

Table 35

Researcher SMILE Scores for Ferrets in Activity 5

<table>
<thead>
<tr>
<th>Ferrets</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eve</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Jim</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Mark</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Max</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Paula</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.25</td>
<td>2</td>
</tr>
</tbody>
</table>

The Ferrets stayed focused and in harmony during Activity 5. They still allowed extraneous talk to interrupt their thought flow. They seemed intrigued by this assignment to solve problems. Members engaged in energetic debate. The girls were accepted as equal partners. Members asked me questions pertinent to the subject like what time of year was it. Jim wrote on his evaluation, "I thought it was fun. We should do things like that more often." The story element and problem solving challenge appealed to the Ferrets. In particular, Eve responded to these elements.

Close-up focus on Eve. Eve was a strong participant in Activity 5. She played a leadership role in her group. She showed a talent for seeing connections between
the analog story and the target story. Eve claimed that the fortress story text helped her to devise a solution to the tumor problem that she thought would work better than the ones she first considered (Interview, May 10, 1997). She used real life experience with the Mississippi River to understand the water problem, but she also used the peanut story text to help devise a solution. She liked to picture everything. During the group dialogue, she painted verbal pictures. For example, "A baby has little hands cause its all he can hold for something to eat; a big man has big hands because that’s all he can eat" (5: F, 2). Eve was pleased when Jim praised her "sophisticated language" when she stated the goal "to sufficiently irrigate their plants, their crops" (5: F, 3). She added that she knew deluge was another word for flood. Eve thrived in Activity 5's story world, oral debate, and verbal pictures. She also thrived on the unusual conviviality of her Ferret group.

On her evaluation, Eve described Activity 5 as "comfortable," "exciting," "complex," "well-structured," and "extraordinary." She gave 5s to motivation, enjoyment, and challenge, and a 4 to knowledge gain. In her May 10, 1997 interview, Eve said she liked "arguing and debating" during Activity 5. She also liked drawing the river and farms for the water problem, because the pictures helped her visualize the problem.

Eve earned a 2.50 SMILE score for her expressed analogical development during Activity 5. She rated 1 point for selection because she accepted the provided analog stories. She received a 3 in mapping for her role in identifying similarities. She expanded on the analogical connections through inference so she earned a 3 in that category. Her 3 evaluation rating was based on her strong contribution to her group's analysis.

Movie review: Ferrets agree on their story lines. The Ferrets discovered the power of cooperation when their group tackled Activity 5 problems. Their gregarious behavior permitted an exchange of ideas. They also followed the guideline structure carefully, another novel behavior for the Ferrets. They used analogical
thought to develop solutions to both the tumor problem and water problem. They agreed on the story lines that solved these problems. The ferrets responded enthusiastically to the story element and the realism of the problems. Eve shared this enthusiasm for stories about realistic problems. Eve was a very competent problem solver and analogical thinker. She thrived in the unusual amiable atmosphere of her learning group.

**Activity 5: The Red Foxes**

*Group movie: Red Foxes tell very different stories.* The Red Foxes gave an okay analysis of the fortress problem. They stated the general's plan as "break up into small groups to attack." The members did not agree on the solution to the tumor problem. Ignoring the requirement to use rays, Ching planned to cure the patient with medicine. Ignoring the prohibition against high intensity rays, Rika planned to use the strongest radiation intermittently. Paying attention to both requirements and restrictions, Kirk planned for radiation to "be shot at different ways at lower levels so that it is strong when it hits the tumor."

Rika's and Ching's tumor attack solutions showed no relationship to the general's attack solution. Kirk used the story text of the fortress attack to think of his solution to use many low intensity rays directed at the tumor from many directions. Kirk knew his analogical connections from the story text helped him think of a solution.

The Foxes stated this plan for peanut allocation, "Everyone should get a fair amount or fair share of food." But this was the goal, not the plan. They simply ignored the detailed plan for peanut distribution. To solve the water allocation problem, they planned to build a dam to provide water to fill "small reservoirs with equal amounts [of water] for everyone."

The Foxes claimed that the peanut story text helped them solve the water problem. They recognized similarity in the goals of equal distribution and outcomes of sufficient
supplies of a natural resource. Yet, the influence of the peanut distribution plan on their construction of a water allocation plan is unclear.

These students' sparse use of written words on their guidesheet impeded their ability to tap the full power of analogical thought. These teen's aversion to intense dialogue also hurt. Fox brevity in spoken and written word interfered with members' ability to compare two long verbal passages to find connections. Fox discourse needed more explicit expression to facilitate analogical thought (Holyoak & Thagard, 1995).

Kevin was absent so he was a nonparticipant. Kirk showed more independent analogical thought than Ching, Rika, or Mai during Activity 5. Red Foxes received the following SMILE scores: 2.50 for Kirk, 1.25 for Ching and Rika, 1.00 for Mai, and 0.00 for Kevin. Table 36 lists Fox SMILE scores.

Table 36

<table>
<thead>
<tr>
<th>Red Fox SMILE Scores for Activity 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>SMILE</td>
</tr>
<tr>
<td>-------------------------------------</td>
</tr>
<tr>
<td>Red Foxes Selection Mapping Inference Level Evaluation</td>
</tr>
<tr>
<td>Mai 1 1 1 1.00 1</td>
</tr>
<tr>
<td>Kirk 1 3 1 2.50 5</td>
</tr>
<tr>
<td>Ching 1 2 1 1.25 1</td>
</tr>
<tr>
<td>Kevin 0 0 0 0.00 0</td>
</tr>
<tr>
<td>Rika 1 2 1 1.25 1</td>
</tr>
</tbody>
</table>

The absence of Kevin's leadership may have hurt the Foxes' ability as a group to use the analog stories to help them solve problems. Even though Kirk used the fortress analog to think of a good solution to the tumor problem, he did not convince his group. The others chose to write their own plans down on their guidesheets. The Foxes unified to solve the water problem, but their discourse was brief. The Foxes
liked and felt challenged by Activity 5, as they interpreted it to be. Close-ups on Kevin or Mai are not possible because Kevin was absent and there is a paucity of evidence for Mai's specific role.

**Movie review: Red Foxes tell very different stories.** In the absence of Kevin's leadership, four Foxes arrived at three different story solutions for saving the life of the tumor patient. Only Kirk used analogical thought to solve the tumor problem. The Foxes had minimal success using a story analog to provide insight for solving the water problem. These teens' preference for brevity in both oral and written communication hampered their ability to make connections between elements in two long story passages. For two members, English as their second language added another complication.

**Activity 5: The Snakes and Lions**

**The Snakes.** The Snakes accurately named the problem, goal, resources, possible actions, plan, and outcome for the fortress story. Their solution to the tumor problem showed no relationship to the analog fortress story. They suggested pain medicine and prayer as the only treatment for the patient with the tumor. They misinterpreted the story text to say that you could not use radiation at all to treat the patient. The Snakes did not use analogical thought to solve the first problem.

The Snakes claimed that the peanut distribution story did not help them solve the problem of water allocation to the farmers. Their solution required that canals be built to bring water to regions along the river. This solution does not seem analogically inspired. They attributed their solution to "common sense."

Interestingly, the Snakes tried to improve the solution to the peanut problem by using analogical thought based on their experience of welfare. These teens empathized with the plight of hungry people who only received enough food to eat for one day. They related the problem of peanut distribution to people on welfare rolls who receive...
"commodities." They suggested on their guidesheet that the government "gather information about the family households and distribute the food according to the amount of people."

**The Lions.** The Lions capably analyzed the story of the general's attack on the fortress. Their solution to the problem of how the doctor could attack the patient's tumor shows no relationship to the story text solution. The Lions decided to give the patient drugs as treatment. They said they relied on modern technology and the process of elimination to arrive at a solution. There was no evidence of analogical transfer from the story text.

The Lions engaged in a lengthy intense discussion of how they might solve the water problem. They thought the peanut allocation story analog helped them think of how they might distribute water so that everyone would get enough. They also drew upon their own experiences with the Bonnet Carre Spillway, study of the Incas' clay brick levee, and a Smurf cartoon episode involving a dam. They decided to build a clay brick wall which would have water-pressure induced break-through holes; but the holes could be closed off by tree trunks to regulate the water flow to each farm. This solution seems similar to the regulated flow of peanuts to each person. The Lions freely used analogical thought to solve the second problem.

**Activity 5: Summary**

For analogical and nonanalogical Activity 5, students devised solutions to the same two problems posed in story form. Fifth-hour students read another story which accompanied each problem story. This second analog story could be used as a source for insights into the solution of the problem. Students used their guidesheet "Can You Find a Solution in the Story?" to facilitate comparison of each story text to the appropriate problem text. Was analogical Activity 5 effective in promoting learning and analogical thought? What was the quality of student interactions and student-
teacher interactions during analogical Activity 5? How did student experiences in fifth hour compare to the counter experiences of sixth- and seventh-hour students?

**Activity 5: Learning Science**

Hour 6 and 7 students proposed solutions to two scientific problems described in their “Can You Find a Solution to the Problem.” They used a structured analytical approach of identification of the problem, goal, resources available, restrictions, possible actions, plan, and outcome. These students practiced solving realistic problems by drawing on their scientific knowledge, personal experiences, creativity, and a structured analytical method. As they used this analytical approach, they gained confidence in their own problem-solving abilities.

Hour 5 students were presented with the same problems (a tumor problem and a water allocation problem) and the same analytical structure in their “Can You Find a Solution in the Story?” They too tapped their knowledge of science and their life experiences to hypothesize solutions to the two problems. They learned a logical structured approach to problem analysis and increased their appreciation of the problem-solving value of a firm foundation in science and a rich experiential life.

But fifth-hour students had an additional aid for solving the two problems. Each problem text was coupled with a story text in which an analogous problem had been solved. The story text was only helpful to students if they saw the two stories as similar in some ways. Students who used the story text solution to help them solve the problem learned that analogical thinking can be used to solve problems.

**Activity 5: Development of Analogical Thought**

Sixth- and seventh-hour students designed solutions to both the tumor problem and the water allocation problem. Their discussions did not involve comparison of the
assigned problems to any analogous problems. Instead they chose from an array of brainstormed solutions.

Analogical Activity 5 promoted fifth-hour students' analogical ability to transfer elements of the solution in one situation to another situation that could be seen as similar in some ways. Activity 5's guidesheet encouraged comparison of the problems, goals, resources, restrictions, potential actions, plans, and outcomes in the two metaphorically similar stories. Sometimes students used the resolution to the problem in the story text to design a solution to the unresolved problem in the problem text.

The six analogical learning groups varied in their success in using analogical thought to solve each of the two problems. The Pelicans, Harriers, Ferrets, and Kirk of the Red Foxes developed plans to attack the patient's tumor that bore close resemblance to the general's attack on the fortress. Just as the general divided his forces into small units to approach the fortress from many directions, these groups decided to use low levels of radiation directed at the tumor from many directions. This solution was analogically inspired. The Lions, Snakes, and most of the Foxes proposed solutions unrelated to the story analog.

All fifth-hour groups traced the concepts of equitable distribution and community effort from the peanut allocation story to the water allocation problem. The Pelicans, Jonah of the Harriers, Ferrets, and Lions planned different water distribution methods, yet their methods shared many similarities with peanut distribution in the analog story. The other Harriers and the Foxes mapped only some elements, and the Snakes' water solution seemed even more distantly influenced by the peanut analog story.

The chance of analogical transfer was increased by certain student behaviors including: recording responses in similar ways for both the story analog and targeted
problem story; adhering to directions; reading texts carefully; and carefully
distinguishing the nature of each question.

**Activity 5: Quality of Group Interactions**

Sixth- and seventh-hour students liked their problem-solving activity and the story
format. They enjoyed debating how to solve each problem. Some students felt that
they lacked a way to evaluate the effectiveness of their solutions. It was hard for
some group members to agree on a solution. They seemed to want more structure in
their nonanalogical Activity 5. In this way, these students were somewhat less
motivated than Hour 5 students, who had the extra structure of analogical scaffolding.

Fifth-hour groups were motivated by the problem-solving and story elements of
analogical Activity 5. They genuinely enjoyed their peer debates. They felt
comfortable because their past experiences made the problems somewhat familiar.
They were pleased to share knowledge gained from beyond classroom walls. Activity 5
tended to promote balanced participation by group members. For many teams, the
analog stories provided an additional element of support in their problem solving and in
evaluating their solutions. Groups that used analog stories for inspiration felt
confident that their solutions would solve the assigned problems.

**Activity 5: Teacher-Student Interactions**

Students in all three biology classes wanted to solve the problems on their own, but
felt it was okay to ask me, as teacher, to clarify some points. They enjoyed bouncing
their ideas off on me, but did not seek my approval. I interceded when I thought my
questions or comments would promote deeper analysis. It was exciting for me to hear
students’ intense conversations about how they would solve the hypothetical
problems. I helped a few groups to refocus when members’ attention wandered, but
Activity 5 kept most students interested. I praised students as they shared their
creative ideas.
Activity 5: Analysis Implications

In general students in fifth-hour analogical groups and students in sixth- and seventh-hour nonanalogical groups liked the story telling and problem solving of their activities. Students practiced a structured analytical approach to problem solving. They felt good solving problems through reliance on their knowledge of science, their creativity, and their own life experiences.

Fifth-hour students had the additional benefit of their guidesheet "Can You Find a Solution in the Story?" which encouraged them to use analogical thought to help solve the problems. Fifth-hour's Activity 5 successfully promoted analogical thinking. Many fifth-hour groups' problem solutions shared similarities with the solutions used to solve the problems in the analog stories. While both analogical and nonanalogical Activity 5 seemed to be good ways to help students develop problem-solving skills, the analogical Activity 5 seemed qualitatively better because it also encouraged analogical thinking as an asset for problem solving. The analogical element also increased student motivation.

Activity 5: Reflections on Specific Students

A moment of reflection on the participation by students selected for special focus again shows the variability in student response to the analogical activities.

Pelicans: Ed and Keisha

Ed enjoyed immersing himself in problem solving through analogical thought. He led his team's discussion. The parallels between the analog stories and the problem stories seemed obvious to Ed. He earned a 2.50 SMILE score for Activity 5.

Keisha was happy to have the boy's leadership as she tried to make analogical sense of the stories. She willingly commented when she thought she had something valuable to say. Keisha's dependency showed. She earned a 1.75 SMILE score.
Harrters: Jonah and David

Jonah revealed his analogical thought even though it was out of his awareness. He developed a plan for water allocation that mapped closely the peanut allocation plan. His SMILE score of 2.25 was lowered by his conscious rejection of the analogs and his lack of recognition of their learning value. Nevertheless, he showed an ability to map connections between the analog story and problem story, as well as an ability to make inferences. He seemed comfortable working with his Harrters. He was eager to share his ideas with his group members.

David thrived in the nurturing environment of his peer group. He gave all he could give to Activity 5. David added his voice to the fast paced Harrier discourse as they mapped similarities between the fortress story and the tumor story. He definitely saw analogical similarities between these two stories. The story format and the problem solving challenges appealed to him. He used his knowledge of a real flood to help him understand a river flooding in the water problem text. He earned a 2.50 SMILE score.

Ferret: Eve

Eve’s learning style fit Activity 5. She liked reading stories, debating, solving realistic problems, and building visual images based on the story words. She liked the structured approach to solving problems, which was provided by the Activity 5 guidesheet. She was pleased by congeniality within her group. She felt confident talking about problems that she could relate to her own experiences. She was a leader in this fifth analogical activity. Her SMILE score was 2.50.

Red Foxes: Kevin and Mai

Kevin was absent for Activity 5. As a nonparticipant, he received a 0.00 SMILE score. Mai was present, but her participation level was so low and her dependency was so high that she rated 1s in selection, mapping, inference, and evaluation. She earned a 1.00 SMILE score.
Activity 6

Activity 6: Analogical Versus Nonanalogical

Activity 6: Black and White Photo Shots

Introduction. Activity 6 focused on the subjects of states of matter and cell functions. To reinforce a relevant physical science topic, biology students reviewed solid, liquid, and gaseous states of matter. During first semester of Biology I, students study the functions of the cell. These functions are vital to study of the cell, genetics, and human body systems. Targeted cell functions included: nutrition, response, reproduction, excretion, secretion, biosynthesis, digestion, respiration, and absorption. Activity 6 gave students in the three biology classes an opportunity to reinforce their understandings of states of matter and cellular functions.

Activity 6 descriptions. The nonanalogical Activity 6, "How Well Do You Remember?" required groups to list and discuss states of matter, write a paragraph about each state of matter, and give an example. They followed the same steps for their work on cell functions. When necessary, students referenced biology texts.

The analogical Activity 6, "Does a Picture Equal 1,000 Words?" (see Appendix X), required the same discussions and explanations of the states of matter and cell functions. The unique feature was nonliteral pictorial representations of the states of matter and cell functions. Fifth-hour groups matched a state of matter or a cell function with its corresponding picture analog (see Appendix Y for hypothetical responses).

The pictures used as analogs for the states of matter included: a military unit of soldiers standing at attention; people at a class reunion party with their party space ribboned off; and soccer players running within the large space of a soccer field. Each picture analog had a potential for reminding students of properties (e.g., particle spacing, particle movement, particle energy) of a corresponding state of matter. For example, the soldiers standing at attention in exactly the same way expended little
energy because they moved very little. This may suggest particles of a solid that are spaced closely together in an orderly arrangement and each particle has low kinetic energy and moves very little. People moving around within a class reunion party space may suggest that particles in a liquid are spaced further apart and have more kinetic energy for moving around and changing position, although these particles remain within a limited space. Athletes playing soccer suggest gas particles have kinetic energy for moving fast and are spaced farther apart, although they occasionally hit one another.

The symbolic analogs used to represent cell functions were composed of circles to represent the cells; arrows to designate direction of movement; chemical formulas and words to denote important substances or stimuli; line variations to convey some change; and shapes and linked shapes to denote small molecules and large molecules. For example, the symbol for response to stimuli consisted of a circle with a wavy line superimposed on it and many arrows pointing in and out to suggest change in the cell in response to listed stimuli (light, hear, pressure, and chemical) with arrows pointed toward the cell. Reproduction was represented simply by a circle with a line dividing it into two halves.

**Activity 6: Panoramic Photos Taken from Researcher Vantage Points**

**Nonanalogical path: Part 1.** During nonanalogical Activity 6, sixth- and seventh-hour students revealed what they recalled about states of matter. The bright Loons resisted this review, yet their skimpy answers showed little mastery and included a misconception. In contrast, the capable Wolverines and Albatrosses easily compared solids, liquids, and gases on the basis of shape, particle spacing, particle movement, and particle energy. The uncertain Cranes worked hard with teacher guidance to compare the states of matter in terms of how particles are spaced, move, and attract. Ravens struggled. Kirsten of the Ravens asked "What makes something solid?" and "[Do] molecules move?" Groups revealed much variation in their understanding of the states of matter.
Some students expressed alternative conceptions. The Loons and Ravens wrote that particles in a solid do not move. Probably thinking of liquid water, Kirsten made an incorrect generalization, "Liquid is liquid at room temperature." The Albatrosses overlooked colored gases to say that gases are invisible.

**Analogical path: Part 1.** Most fifth-hour groups easily related three picture analogs to an appropriate state of matter. They linked soldiers standing at attention to a solid, a class reunion party to a liquid, and a soccer game to a gas. All groups justified their choice through a comparison of the spacing of particles in a solid, liquid, and gas. Most groups also compared the states of matter in terms of particle movement. Two groups explained this movement in terms of energy of the particles in each state.

**Nonanalogical path: Part 2.** Activity 6 challenged Hours 6 and 7 students to integrate their knowledge of cell functions, which they had studied separately. They associated these functions with human body systems, a level far above the cellular level. They were forced to consider how what happens in the body depends on what happens in a single cell. For example, the Rays began to consider if DNA in different types of cells might be different, because skin cells make skin cells not heart cells. I explained that a body's cells contain the same DNA, but that as cells differentiate, only part of that DNA code is put into action in the differentiating cells. They finally said, "Cells produce exact most of the times copies of themselves to guarantee life."

Some groups recorded only book definitions, but most groups limited their use of text definitions because they preferred to use their own words, even if they were not perfect definitions. For example, Kirsten said digestion was "the way the body uses food, separate waste from needed stuff." Group dialogue promoted clarity of expression. Discourse helped the Ravens transform respiration as "breathing" to "taking in oxygen and giving off carbon dioxide," yet they still failed to associate release of energy with cellular respiration. The African Golden Cats related body
nutrition to a cell. They said, "It makes the cell healthy." Many groups truly tried to talk science.

These students requested guidance. I helped students with science concepts such as excretion and secretion. The Jaguars were confused when they read that "waste is secreted in the process of excretion." I explained that excretion involves getting rid of stuff that is useless and even harmful to the cells, but that a cell secretes substances that are useful to other cells. The nonanalogical Activity 6 required a lot of student effort and did not include any extra "fun." I discouraged some students from adding their own "entertainment." I tried to keep students focused on task.

On average, these students took one and one-half hours to complete their nonanalogical Activity 6. Hour 6 and 7 students gave acceptable descriptions to an average of six and one-half functions out of nine functions listed. Completely wrong responses represented 11% of responses. Partially-correct or partially-complete responses received half credit and represented 32% of responses. Fully acceptable responses represented 57% of the total. These percentages suggest that this nonanalogical Activity 6 was difficult.

**Analogical path: Part 2.** In analogical Activity 6, fifth-hour groups were challenged to match listed cell functions to one of nine symbolic representations. Some symbols used included: circles, lines, arrows, chains, formulas, and words. The circle represented a "cell." The symbolic representations were designed to be as simple as possible, yet convey a particular cell function. They also wrote a definition for each process.

The Pelicans, Harriers, Ferrets, Snakes, and three Lions matched all nine symbolic pictures to the proper cell function. The Red Foxes succeeded with six. Two Lions only matched three correctly. The analogical groups expended much effort in matching these symbols and functions. They wrote brief descriptions of the processes. They worked about two hours on analogical Activity 6.
Activity 6: Panoramic Photos Taken from Student Vantage Points

Student evaluations. Optional student evaluations provided multiple perspectives of Activity 6. In fifth hour, 19 students evaluated analogical Activity 6. In sixth-hour, 30 students responded and in seventh hour, 16 students responded with their views. In total, 46 students evaluated nonanalogical Activity 6.

Selection of adjectives to describe activity. Table 37 lists the percentages of evaluators who chose a listed adjective to describe their Activity 6. Percentages are listed from most similar to least similar to highlight the similarities and differences in student perspectives toward analogical Activity 6 and nonanalogical Activity 6.

A majority of students described their Activity 6 as either "comfortable" or "easy," "simple" or "clear," while a similar minority of evaluators called their activity "complex." Similar minorities thought their Activity 6 was "interesting," "fun," and "typical."

Fifth-hour evaluators tended to see their analogical activity as "creative" and "okay". Sixth- and seventh-hour evaluators focused more on their nonanalogical activity being "well-structured." It should be mentioned that 19% of these same evaluators selected "boring" and 20% selected "tedious." None of the fifth-hour evaluators chose "boring" or "tedious."

Based on these responses, both activities were reasonable, accessible learning activities. The analogical Activity 6 tapped student creativity more than the nonanalogical Activity 6. Fifth-hour students were satisfied with their Activity 6, while some sixth- and seventh-hour students were displeased.

Identification of activity processes. Table 38 lists processes identified by student-evaluators as part of their Activity 6. Cross comparison of processes identified for analogical and nonanalogical Activity 6 is recommended.
Table 37

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 6

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interesting</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Simple</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>Fun</td>
<td>32</td>
<td>30</td>
</tr>
<tr>
<td>Typical</td>
<td>47</td>
<td>43</td>
</tr>
<tr>
<td>Comfortable</td>
<td>47</td>
<td>54</td>
</tr>
<tr>
<td>Complex</td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td>Easy</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
<td>Clear</td>
<td>42</td>
<td>27</td>
</tr>
<tr>
<td>Well-structured</td>
<td>21</td>
<td>36</td>
</tr>
<tr>
<td>Creative</td>
<td>53</td>
<td>26</td>
</tr>
<tr>
<td>Okay</td>
<td>79</td>
<td>47</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

\( ^a \) Only adjectives circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

\( ^b \) \( n = 19 \) evaluators out of 29 fifth-hour students.

\( ^c \) \( n = 46 \) evaluators out of 31 sixth-hour and 31 seventh-hour students.
A majority of evaluators selected processes associated with cooperative learning: "thinking," "discussing," and "communicating." Fifth-hour evaluators chose the following processes more frequently than Hour 6 and 7 evaluators: "categorizing," "evaluating," "choosing," "analogizing," and "hypothesizing." Sixth- and seventh-hour evaluators chose the following processes more frequently than fifth-hour evaluators: "remembering," "learning," and "researching." These process selections suggest that nonanalogical Activity 6 was a traditional learning activity conducted in a group format; while analogical Activity V was a less traditional activity which engaged students in higher level thinking processes within a group.

**Student rating of activity in 10 categories.** Student evaluators rated their Activity 6 in 10 categories. Class ratings means are listed in Table 38. Students on both the analogical and nonanalogical paths gave the same ratings: 4.5 to number of students and method of selection; 4.0 to directions, teacher input, and age level; and 3.5 to motivation and challenge. Hour 6 and 7 students were more satisfied with time involved, but Hour 5 students were more satisfied with their knowledge gain and enjoyment. The differential in their ratings was 0.5 points.

**Additional comments.** Some evaluators wrote comments about their Activity 6. Two comments favored the analogical Activity 6 and one comment favored the nonanalogical Activity 6. The nonanalogical Activity 6 elicited six unfavorable comments.

Two girls in fifth-hour expressed satisfaction: "learned a lot" (Tina), and "This was pretty good" (Sarita). Linda in seventh hour enjoyed her activity and her group members. Hour 6 and 7 evaluators complained. Cordelia objected to having to remember physical science concepts. Some described Activity 6 as "not really necessary" (Daveed); "boring" (Adam and Anton); "typical" (Jonas); needed "more time" (Anton and Jonas); and "confusing" (Sharon).
Table 38

Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 6

<table>
<thead>
<tr>
<th>Process</th>
<th>Analogical(^b)</th>
<th>Nonanalogical(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking</td>
<td>100</td>
<td>91</td>
</tr>
<tr>
<td>Discussing</td>
<td>89</td>
<td>78</td>
</tr>
<tr>
<td>Communicating</td>
<td>74</td>
<td>76</td>
</tr>
<tr>
<td>Categorizing</td>
<td>58</td>
<td>26</td>
</tr>
<tr>
<td>Evaluating</td>
<td>58</td>
<td>21</td>
</tr>
<tr>
<td>Choosing</td>
<td>53</td>
<td>40</td>
</tr>
<tr>
<td>Analogizing</td>
<td>42</td>
<td>20</td>
</tr>
<tr>
<td>Remembering</td>
<td>42</td>
<td>70</td>
</tr>
<tr>
<td>Hypothesizing</td>
<td>37</td>
<td>25</td>
</tr>
<tr>
<td>Learning</td>
<td>37</td>
<td>48</td>
</tr>
<tr>
<td>Problem solving</td>
<td>32</td>
<td>27</td>
</tr>
<tr>
<td>Researching</td>
<td>6</td>
<td>41</td>
</tr>
</tbody>
</table>

**Note.** Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

\(^a\) Only processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

\(^b\) \(n = 19\) evaluators out of 29 fifth-hour students.

\(^c\) \(n = 46\) evaluators out of 31 sixth-hour and 31 seventh-hour students.
<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical(^a)</th>
<th>Nonanalogical(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Time involved</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Age level</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Motivation</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>4.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Note.** The rating scale is 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means have been rounded to the half-decimal.

\(^a_n\) = 19 evaluators out of 29 fifth-hour students

\(^b_n\) = 46 evaluators out of 31 sixth-hour and 31 seventh-hour students.
Collage of student viewpoints. Evaluations of Activity 6 by students suggest that the analogical Activity 6 had an edge over the nonanalogical Activity 6 in terms of student involvement and satisfaction. Both activities promoted integration of student learning. Activity 6 for fifth hour relied more on higher level thinking processes, while Activity 6 for sixth and seventh hour relied more on researching answers.

Reflections on the Panoramic Views of Activity 6

Activity 6, analogical and nonanalogical, asked students to recall their concept of states of matter and encouraged synthesis of their knowledge of the functions of cell. Both analogical Activity 6 and nonanalogical Activity 6 provided a challenging learning activity for students. The nonanalogical Activity 6 was more traditional and required students to remember, research, and apply knowledge. Analogical Activity 6 required students to remember, research, and apply knowledge. In addition, it challenged students to analyze, evaluate, analogize, and decide. Using pictorial or symbolic analogs as representations of scientific concepts generated student discussions, increased student interest in learning, and promoted student involvement in their own knowledge construction.

Activity 6: Analogical Groups

Activity 6: The Pelicans

Group movie: Pelicans decipher pictures. The Pelicans easily matched the picture analogs to the correct state of matter. The difference in spacing of people in the pictures reminded these students of the difference in spacing between particles of a solid, liquid, and gas. They connected the military unit to a solid because particles are "tightly fit together." They matched the people at a reunion party with particles "not as close together" in a liquid. They linked soccer players to gas particles "all over the place."
This team did not completely, nor systematically support their other mappings. They associated running soccer players with rapid movement of gas particles; but did not address this issue for a liquid or solid. They thought that a solid would not allow air through, but that air would get through a liquid better, then dropped this issue for gases. Thinking their task was easy, they engaged weakly in this analysis.

The Pelicans found the cell function analogical pictures more difficult to decipher. Through reading definitions of cell functions, scrutinizing the symbolic analogs, deciding and then revising decisions, the Pelicans successfully matched each cell function with its corresponding symbolic analog. They improved their knowledge of cell functions.

Pelicans received the following SMILE scores for Activity 6: 2.25 for Ed; 2.00 for Randy; and 1.75 for Keisha and Michelle. Table 40 lists Pelican SMILE levels and subscores.

Table 40

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2.25</td>
<td>3</td>
</tr>
<tr>
<td>Randy</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Keisha</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td>Michelle</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
</tbody>
</table>

The Pelicans worked as a cooperative group to make the connections between the picture analogs and the targeted concepts in science. They responded favorably to Activity 6. What role did Ed and Keisha play in Pelican deciphering of the scientific meaning hidden in the pictures?
**Close-up focus on Ed.** Ed was influential in his group's analysis of states of matter. The pictures clearly caused him to think of the spacing and movement of particles in a solid, liquid, and gas. He explained that the military unit represented "togetherness, unity" and "restriction" of a solid. The class reunion represented "less restriction in its movement"; and a soccer game showed "hardly any restriction to the movement." With a prompt, Ed said, "I'd say restriction would deal with movement, and to move, you need energy." In response to a series of questions, Ed connected increasing amounts of energy to change from solid to liquid to gaseous states. Ed knew more about states of matter than he incorporated into the Pelican's analysis during Activity 6 (Interview, May 10, 1997).

Ed believed that the "symbolic ones for the cells, that took a little more thinking." He was attracted to the abstract symbols for cell function. When Ed looked at more realistic picture analogs designed by his fifth-hour peers to represent cell functions, he easily associated the proper cell function with the student-drawn analogs. He still preferred the abstract symbols that conveyed the necessary information to him. Ed claimed that Activity 6 helped him learn and remember cell functions better. Ed said, "When I first got it, I could name three or so," but as he did Activity 6, he could name nine functions of the cell (Interview, May 10, 1997).

Ed earned a SMILE score of 2.25. He rated a 1 in selection for his acceptance of assigned analogies. He earned a 3 for mapping of similarities with the help of his peers. He received a 2 in inference for his ability to infer meaning from the symbols in dialogue with his teacher. He shared a 3 in evaluation with his peers.

**Close-up focus on Keisha.** Following Ed's lead, Keisha helped her group to decipher the pictures. She was careful to record group responses. The pictures appealed to Keisha and they helped her learn and remember more science. Keisha explained, "The pictures help you understand. . . . how you can look at something that we look at maybe everyday and base it on scientific things" (Interview, May 27, 1997).
She suggested that the more realistic picture analogs drawn by other fifth-hour students would have been easier for her to relate to the functions of the cell. She thought it was harder for her to find meaning in the symbolic analogs for cell functions.

Keisha rated a 1.75 SMILE score. She received a 1 for selection in that she accepted assigned analogies. She earned a 2 for mapping because she helped her group, but really needed more teacher guidance. Her dependence on a teacher for inference gave her a 1 in inference. Keisha rated a 3 in evaluation for her participation in her group's judgement of the learning value of the analogies.

**Movie review: Pelicans decipher pictures.** Pelicans searched picture analogs for meaningful connections to scientific concepts. They matched realistic picture analogs to states of matter. They identified the most accessible similarities, but did not reach for more abstract connections. They learned as they met the challenge of deciphering the abstract symbol analogs in terms of cell functions. Ed led his group's meaning making. Picture analogs, realistic or abstract, appealed to him. With the support of her peers, Keisha learned a lot. Realistic pictures provided more accessible analogical meaning for Keisha.

**Activity 6: The Harriers**

**Group movie: Harriers decipher pictures in the sky.** The Harriers matched pictures of: a military unit standing at attention to a solid; a class reunion party to a liquid; and a soccer game to a gas. They associated soldiers and particles of a solid with "very close packing," "not very much energy," "resistance," and "unmoving." For the last two terms, they may have switched from thinking of particles of a solid to thinking of something solid. They discussed the melting process of changing a solid to a liquid through addition of "high temperatures" (6: H, 1-2).

They linked people at a class reunion party with a liquid because particles in a liquid have more energy, flow around, are not as closely packed, and offer less resistance.
They wondered if a liquid could be represented by soldiers standing at ease and moving around. These young men seemed to enjoy playing with mental images. They associated soccer players and particles of a gas with fast movement, lots of energy, and lots of spacing apart.

This team was consistent in comparing states of matter on the basis of particle spacing and particle energy. Were they systematic in their comparison of particle movement? Did the soldiers standing at attention mislead them to think of particles of a solid as not moving at all, or did their term "unmoving" refer to a solid object rather than to particles of a solid? Similar problems arise with their use of "resistance." They needed to more clearly state their conceptual understandings.

With some difficulty, the Harriers matched all of the symbolic representations with an appropriate cell function. Bill wisely looked up the definitions of the cell processes to assist his group. This encouraged members to revisit concepts studied during the first semester. Together, the boys made sense of the abstract symbol analogs for cellular processes. In late May, artists Bill and Jonah argued for more realistic pictures as analogs. These Harriers engaged in independent analogical thought to develop realistic picture analogs to represent cell functions. Of the five Harriers, only Ton preferred the original abstract representations.

The Harriers earned the following SMILE scores for their expressed analogical ability during Activity 6: 3:00 for Bill and Jonah; 2.50 for Ton and David; and 1.75 for Barry. Table 41 lists Harrier SMILE scores for Activity 6.

The Harriers eagerly debated the possible scientific meanings of the picture analogs. These young men worked as a focused and relaxed team, except for a small interval during which Ton antagonized David. Jonah was especially eager to explain his ideas on the states of matter. The boys felt confident talking about the states of matter, but were less secure talking about cell functions. These students learned more about cell functions through deciphering scientific meaning concealed within the
symbolic picture analogs. What roles did Jonah and David play in Harrier meaning making?

Table 4.1

<table>
<thead>
<tr>
<th>Harriers</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Bill</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>Barry</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.75</td>
<td>3</td>
</tr>
<tr>
<td>Jonah</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>3.00</td>
<td>3</td>
</tr>
<tr>
<td>David</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2.50</td>
<td>3</td>
</tr>
</tbody>
</table>

Close-up focus on Jonah. Jonah easily and eagerly matched the states of matter to the realistic picture analogs, yet he did it in his own unique way. "I dream of what a solid is. Then I actually imagine me being in the same diagram, so it ends up this one is a solid" (6: H, 1). He used the soldiers apparent nonmovement to say that a solid is unmoving as opposed to a liquid which may flow. He did not explain that the particles of a solid move very slowly, as surely the soldiers move while trying to be absolutely still. He did speak at length about the heat theory and associated some energy with the military unit. He spoke at length about solid, liquid, and gaseous states of matter.

Jonah was challenged to match the symbols for cell functions. With peer help, he identified cell functions with the appropriate symbolic analog. During his May 10, 1997 interview, he created realistic images to replace the abstract images of cell functions. He thought a "cell" circle was okay. He suggested improvements to the response to stimuli symbol of a wiggly lined circle with stimuli words listed around it. He replaced stimuli words light and fire with a light bulb and flames of a fire. For pressure, he
suggested a ball bouncing and hitting the circle causing a dent in it. Jonah drew a filled waste can exiting the "cell" circle to represent excretion. For secretion, which sends useful substances from one cell to other cells, he suggested using a post office with mail slots that allow balls to go out or into the cell. He thought the balls should carry some address. Jonah was delighted to use his imagination and his artistry to convey his scientific understanding. His suggestions showed a highly developed ability to think analogically through actual pictures.

Jonah earned a 3.0 SMILE score. He received 4 points for selection because he used teacher-generated, peer-generated, and his own analogies. Jonah went a step beyond in inference to earn 2 points. He shared responsibility for evaluating the analogies to earn a 3 in evaluation.

Close-up focus on David. In discussing states of matter, David fluctuated between literal and metaphorical thinking. When Bill and Jonah discussed how the soldiers in the military unit might be put at ease and allowed to move around so that metaphorically "they melt into a liquid," David argued literally that "People don't melt" (6: H, 2). He did associate the low energy of soldiers at attention to low energy of particles in a solid. He noted that particles in a liquid "have a lot of energy and they move around a lot more" (6: H, 2). But when he considered the soccer game as representative of a gas, he became confused by literal thinking. He said, "It can't be a gas because they [soccer players] are breathing the gas" (6: H, 2). Jonah's explanation helped David to understand the soccer game in an analogical sense.

Later, David said that the soccer game did not work well for him because he did not know much about soccer. He suggested using basketball instead. David clarified the energy associated with each state. For example, he said particles of a solid "have kinetic energy, but as a unit. It's not like a piece is going to break off there by itself. They move together" (Interview, May 27, 1997). David further explained that if the
particles of a solid had even more energy, they would move faster and maybe even split apart, as in a liquid.

At the start of Activity 6, David remembered only three cell functions. He claimed the symbolic pictures helped him learn. For example, at the end of the activity he associated excretion with getting rid of "bad stuff" and secretion with "good stuff" going to "parts of the body." David felt the pictures helped him better than just learning a definition. He thought that you may "forget it later on, but if you just think about the little circle and something bad come out of it, excretion. It's a lot easier to remember." When I reminded him that every cell did that, he joked, "That's a lot of waste" (Interview, May 27, 1997). He then related this idea to the Harriers' class presentation of the excretory system.

David preferred more literal pictures suggested by Bill to represent cell functions. For example, he liked Bill's wrecking ball hitting a brick wall as a representation of digestion. David laughed at Bill's picture of a hand throwing away trash, and preferred this image for excretion. David critiqued Bill's use of a food pyramid for animal nutrition as ineffective unless it was shown going into a "cell." For plant nutrition, David gave his own idea of a plant enveloping the food pyramid to suggest a plant making its own food. A picture of a chef making food did not remind David of a plant making food (Interview, May 27, 1997).

David described Activity 6 as "comfortable," "okay," "clear," "creative," and "fun." He rated motivation and challenge as "okay" and rated enjoyment and knowledge gain as "good." David's circling of "fighting" suggests that he was sensitive to Ton's ribbing him.

David earned a 2.50 SMILE score. He received a 3 for selection because he worked with teacher-and student-generated analogs. He earned a 3 for mapping similarities. He rated a 1 for inference because of his teacher dependence in this area. He rated a 3 for his shared role in evaluation of the analogies.
**Movie review: Harriers decipher pictures in the sky.** It was no surprise that the Harriers with three artistic members found Activity 6 "Does a Picture Equal 1,000 Words?" very appealing. They used pictorial analogs to inspire and organize their explanations of states of matter. They learned more about cell functions through their attempts to understand the symbolic pictures in terms of cellular processes. Pictures were a highly motivating element for both Jonah and David. Jonah's talent as an artist combined with his tendency to think in pictures resulted in good analogical thinking. David's intense interest in the meaning hidden in the pictures led to his full involvement and his realization of full learning benefits from his peer group work. The Harriers not only made sense of the assigned picture analogs, but also later added their own to the metaphorical sky.

**Activity 6: The Ferrets**

**Group movie: Ferrets decipher pictures.** Ferrets easily matched the familiar analog pictures with the correct states of matter. The soldiers standing at attention as a military unit reminded them that particles of a solid are tightly packed together and individually move only a little. The solid moves together as a single unit. The class reunion party reminded the Ferrets that the particles of a liquid have more freedom of movement, but still stay within boundaries as the alumnists stayed within the party space. The soccer game reminded the Ferrets that particles of a gas have free movement without limits. The Ferrets' did not venture far from the immediate concepts evoked by the pictures. They did not relate particle spacing and particle movement to particle energy, which is an important but more abstract concept.

Even though the second part of Activity 6 was difficult, the Ferrets accurately matched cell functions with their symbols. They wrote very brief descriptions of cell functions. The boys dominated this part of Activity 6.

The Ferrets rated these SMILE levels: 2.50 for Jim; 2.00 for Eve, Mark, and Max; and 1.25 for Paula. Table 42 lists the SMILE scores for the Harriers.
Table 4.2

Researcher SMILE Scores for Ferrets in Activity 6

<table>
<thead>
<tr>
<th>Ferrets</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eve</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Jim</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Mark</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Max</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2.00</td>
<td>3</td>
</tr>
<tr>
<td>Paula</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
<td>2</td>
</tr>
</tbody>
</table>

Ferrets worked as quickly as they could to finish Activity 6. All members were familiar with the states of matter, but the girls did not know as much as the boys about cell functions. The male team members did not slow down to help the girls even when asked. All the Ferrets liked Activity 6 and thought they learned from doing it.

How did Eve fare during Activity 6?

**Close-up focus on Eve.** Eve was a competent team member during Ferret analysis of states of matter. Eve liked the realistic picture analogs. She liked the use of people to represent the particles and the people in different activities to represent different states of matter. Eve explained, "You're used to seeing the little circles that are compact, and these are little people. It kinda of brings it out to everyone, instead of the science person" (Interview, May 10, 1997). With a few lead questions, Eve was able to use the pictures to describe the states of matter even in abstract terms of energy.

Eve struggled to understand the more abstract symbolic depictions of cell functions. She associated the circle with a cell. Her group's fast pace made it difficult for Eve to keep up. She explained, "Maybe if I took my time and just looked, maybe I
could understand it better. I just didn’t know anything” (Interview, May 10, 1997).

With a little guidance and a slower pace during her interview, Eve understood the diagrams and gained confidence in her ability to learn science.

When Eve looked at more realistic analogical pictures designed by students to represent cell functions, she felt their meanings were more accessible to her. For example, Eve was able to associate digestion with Bill's rendition of a brick wall being broken down by a wrecking ball and each brick was labeled as a small molecule (e.g., sugar, amino acid). With this realistic picture, Eve was able to also understand the more abstract representation. Eve said, "See if I saw that [abstract picture] I wouldn't have thought of digestion. Maybe is it these are supposed to be all connecting and this breaks down?" With guidance, Eve began to make sense even of the abstract symbols. She explained, "I've never seen anything like this before because science has never been this elaborate" (Interview, May 10, 1997).

Eve described Activity 6 as "comfortable," "interesting," "clear," "creative," and "unusual." She rated motivation, challenge, and knowledge gain as "excellent, and gave a "good" rating to enjoyment. Eve liked Activity 6.

Eve received 2.00 for her SMILE score. She earned a 2 for selection because she used the teacher-selected analogs, but used her peer-generated analogs as well. She received a 2 for mapping because she needed teacher guidance for mapping. She rated a 1 for inference since she was teacher-dependent. She shared with her peers the task of judging the value of the analogies and so earned a 3 for evaluation.

Movie review: The Ferrets decipher pictures. The Ferrets worked quickly to match the picture analogs with the target scientific concepts. Their associations were correct, but their written support for their analogical connections was brief. Male members had better scientific knowledge bases than the girls. Eve did not always follow the mental analogical leaps made by the boys. Eve tried to meet the challenge of integration of cell functions studied throughout the year.

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Activity 6: The Red Foxes

Group movie: Red Foxes decipher signs in a forest. The Red Foxes made analogical connections between the picture analogs and the states of matter in terms of spacing, movement, and energy. They connected the picture of the military unit to a solid based on the close proximity of soldiers standing at attention as low energy particles in a solid are tightly packed to form a rigid structure. The people strolling around at a class reunion reminded them of the less close packing of particles in a liquid. The people moved freely within the party space, as atoms or molecules of a liquid are further apart and have energy to move easily. The soccer players reminded the Foxes that the particles of a gas are spaced far apart and possess a lot of energy. The picture analogs shaped the Foxes’ conceptual recall of states of matter.

The Foxes successfully matched six symbolic representations to the proper cell function. They mismatched the symbols for secretion, digestion, and nutrition. Part of their difficulty derived from their sketchy definitions of nutrition in terms of nutrition and secretion in terms of secreting. Better definitions for the other cellular processes allowed members to make correct matches. The abstract nature of the picture analogs may have added another confusing element.

Without adequate working definition for all cell processes, the Foxes became confused by the symbols and three poorly defined cell processes. The misidentification of the abstract symbol for digestion as nutrition may be explained by the listing of important nutrients as a result of the digestive process. It is less easy to explain Fox labeling of nutrition symbolic image as secretion and the secretion symbolic image as digestion. It seems likely that the group simply had no idea what secretion really involved. So while a definition is not sufficient for scientific understanding, it surely is an essential element.
Red Foxes rated the following SMILE scores for Activity 6: 2.25 for Kevin, 1.75 for Kirk, Ching, and Rika, and 1.25 for Mai. Table 43 lists Fox SMILE subscores.

Table 43

Red Fox SMILE Scores for Activity 6

<table>
<thead>
<tr>
<th>Red Foxes</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mai</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.25</td>
<td>2</td>
</tr>
<tr>
<td>Kirk</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Ching</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1.75</td>
<td>2</td>
</tr>
<tr>
<td>Kevin</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2.25</td>
<td>2</td>
</tr>
<tr>
<td>Rika</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1.75</td>
<td>2</td>
</tr>
</tbody>
</table>

These teens worked cooperatively and confidently through analysis of realistic picture analogs as representing states of matter. They were familiar with both images of people engaged in three different activities and with the topic of states of matter. Each member used their own words to synthesize ideas from group dialogue. Members lost confidence as they struggled to match each symbol to a specific cell function.

What roles did Kevin and Mai assume in their cooperative group's Activity 6?

**Close-up focus on Kevin.** Kevin really liked the picture analogs for the states of matter. He easily mapped points of similarities in terms of spacing, movement, and energy. He said, "I think they are good pictures because they almost exactly fit the definition of the states of matter" (Interview, May 10, 1997). Kevin's statement could only be true in a metaphorical sense, but Kevin thought that way.

Kevin thought symbolic images related to cell functions "were good enough for us to figure it out. Some of them were confusing." He identified as confusing the symbols for these processes: secretion, digestion, biosynthesis, and response to stimuli. He thought realistic pictures analogs were more useful "because you could see
it better what you were talking about." When asked to propose his own picture analogs, Kevin suggested that a stomach with stuff in it might represent digestion, and "a puzzle with fats and proteins written on pieces" might represent biosynthesis, the assembly of small molecules to build larger molecules of life (Interview, May 10, 1997).

Kevin's self-image needed boosting at times. He said, Whenever you start with what I was thinking, it's not going to be very good" With encouragement, Kevin critiqued a set of potential picture analogs for reproduction. He even laughed at my symbol for "reproduction," a circle with a line dividing it into two equal parts. Kevin explained, "Well it makes sense, but it's kind of hard to tell what it is cause it's a circle with a line through it" (Interview, May 10, 1997).

For Kevin, the first part of Activity 6 was easy, but he found the cell function part difficult and confusing. He preferred more realistically depicted analogs to more abstract representations. Nevertheless, he believed that the symbolic pictures helped him to remember the cell functions.

Kevin earned a 2.25 SMILE score. He rated a 3 in selection for his collaboration with his teacher and peers in choosing analogs. He earned a 3 in mapping for his identification of similarities between the analogs and targets with the help of his group. He received a 1 for inference for his dependence on the teacher in this area. He shared a 2 for evaluation with his peers because they needed teacher assistance to judge the learning value of several of the cell function analogs.

Close-up focus on Mai. Mai participated in analysis of the analogs for the states of matter. She was happy that she understood the use of the pictures to represent solids, liquids, and gases. She was terribly confused by the task of matching the symbolic pictures to functions of the cell. She herself did not understand all cell function terms, and her group's definitions were deficient. She was confused by the abstract nature of the picture analogs for cell functions. In her May 29, 1997
interview, Mai explained that she liked the easy part about the states of matter, but she did not like the hard part about cell functions.

Mai earned a 1.25 SMILE score. She accepted the analogs provided to rate a 1 for selection. She earned a 1 for mapping and inference because of her teacher dependence in these areas. She shared a 2 evaluation rating with her team members because the Foxes needed some teacher guidance for judging the learning potential of some analogs.

Movie review: Red Foxes decipher signs in a forest. The Foxes achieved a measure of success with Activity 6 "Does a Picture Equal 1,000 Words?" They followed the visual signs in the picture analogs to their explanation of the states of matter. They were confused by a few of the signs pointing to cell functions. This team probably needed more realistic signs and very clear definitions for cell functions. They matched six of nine cell processes to the correct symbolic images. Kevin and Mai were attracted to the realistic picture analogs for states of matter, but found the abstract analogs for cell functions confusing. It took effort, but Kevin did solidify his understanding of cellular function. Mai did not benefit much because she was too confused by abstract symbols and did not recall much about cellular processes. She felt successful in following the states of matter analysis by her group.

Activity 6: The Snakes and the Lions

The Snakes. The Snakes correctly matched the picture analogs of the military unit, reunion party, and soccer game with solids, liquids, and gases. They explained their decision on the basis of how the particles in each state are spaced out in a continuum from very close together in a solid to very far apart in a gas. Their support for these matches was minimal. The Snakes seemed sensitive to the minimalist abstractions of cell functions and correctly matched the picture analogs to cell functions. They did not write detailed definitions.
The Lions. The Lions connected the people in the pictures (military unit, reunion party, and soccer game) to the states of matter (solid, gas, and liquid) in strange ways. Their explanations did not reveal a firm understanding of the states of matter. The soldiers were linked to solids on the basis that the military is strict so that the soldiers stick together and particles in a solid stick together. The soccer game was linked to a liquid because the particles of a liquid mimic the actions of soccer players who "roam in different directions and they mix together" yet "the people are farther apart so they cover more ground that way" (6: L, 1). The class reunion was linked to a "gas because people come from far away to make one [class reunion] and the others [in the class] are far apart just like the particles of a gas" (6: L, 1). Only through the Lions' expansion of the class reunion party to include all members of the class does their match make any sense.

Due to conflict within the Lion group, Sarita and Sandra split away from the other three Lions to work on the second part of Activity 6. Using some incorrect definitions, Sarita and Sandra correctly matched only three symbolic analogs to cell functions. The other girls used good definitions to correctly match cell processes with their analogs.

Activity 6: Summary

For nonanalogical Activity 6, "How Well Do You Remember?", sixth- and seventh-hour students wrote descriptions of state of matter and cell functions. For analogical Activity 6, Does a Picture Equal 1,000 Words?", fifth-hour learning groups deciphered scientific meaning contained within pictorial analogs. Students matched a picture to a state of matter and mapped relations between the people in each picture and particles in that state of matter. Students followed a similar process in matching abstract symbolic representations of cell functions. Did analogical Activity 6 promote student learning and analogical development? What was the quality of interactions among the
students within their cooperative learning groups and between the students and their teacher? How did student experiences in fifth-hour compare to those of sixth- and seventh-hour students with their Activity 6?

Activity 6: Learning Science

The nonanalogical Activity 6 and the analogical Activity 6 helped students review their knowledge of properties of particles in each state of matter. Many groups in all three classes discussed particle spacing, particle movement, and particle energy associated with each state of matter. Some groups in all three classes discussed only some of these issues. Misconceptions were expressed by a few students in all classes. This focus on states of matter as relevant to biology encouraged students to integrate their studies in science.

Sixth- and seventh hour students recalled or looked up definitions of cell functions. Some groups productively discussed cellular functions in relation to body systems. Some groups named examples of each state of matter and each cell function.

Fifth-hour students' attempts to match symbolic images with correct cell functions promoted better learning. Students were more involved and more focused on their subject. Like Hour 6 and 7 students, they either looked up definitions or drew one from memory, but they also had to match their definitions to a symbol. This forced them to evaluate and sometimes revise their ideas.

Activity 6: Development of Analogical Thought

Only analogical Activity 6 had potential for developing students' analogical abilities. It gave students practice with using visual analogs to think of connections to scientific targets. Pictures of a military unit, a class reunion party, and a soccer game served as
analogs for solids, liquids, and gases respectively. The visual aids provided tangible clues for comparing people in the pictures and particles in each state of matter.

Salient features in the picture analogs helped all fifth-hour groups to discuss particle spacing and four groups to discuss the rate of particle movement. Only Harriers and Foxes related particle movement to kinetic energy of particles in each state. To make analogical connections to energy, these students related the implied movement of people in the pictures to the abstract concept of energy.

Students' attempts to match a cell function to a symbolic image of cells functions promoted analogical thinking. Students translated meaning back and forth between verbal definitions and visual symbols for cell functions. The task was difficult, yet most fifth-hour students made correct matches. In cases of error, the students did not have a correct definition to guide their analogical thinking. Activity 6 required students to focus their attention on the meaning of the definitions and the symbolic representations. This involvement promoted better learning than memorization.

The visual symbols for cell functions were simple abstract diagrams with a few words. Deeper analogical thought was required to match abstract symbols to cell functions. Most of the students succeeded in using the more abstract forms to learn about cell functions, even if they preferred more realistic picture analogs. Some students found the symbolic diagrams more appealing than the realistic pictures. These students tended to be verbally strong and very bright.

A bonus from Activity 6 was gained during student interviews in May. Several students proposed and drew more realistic picture analogs for cell functions. This dramatically displayed their depth of analogical thought. It also suggested a way to tap student creativity while developing analogical thought.
Activity 6: Quality of Group Interactions

Hours 6 and 7 students did their nonanalogical Activity 6 with little enthusiasm. They accepted their traditional activity as educational review. They comfortably discussed with each other the states of matter. For the more challenging subject of cell functions, team members helped one another with definitions.

Analogical Activity 6 used pictures to promote analogical thought, and this format appealed to many fifth-hour students, especially visual learners. Most students felt confident matching the three picture analogs to states of matter. They were eager to discuss a familiar scientific subject. All members could contribute something. Most group members were less confident of their ability to distinguish between cell functions. Nevertheless, the symbols intrigued them. Fifth-hour students persevered past their doubt, toward confidence as they helped each other figure out the puzzling symbols.

Activity 6: Teacher-Student Interactions

As teacher, I tried to keep sixth- and seventh-hour students focused on the states of matter review. Overconfident students engaged in more off-talk and off-task behavior during this first part. Some Hour 6 and 7 groups needed help with states of matter, because they were not as fluent in physical science as some other groups. Description of cell functions was a challenge for these students. I frequently helped confused students distinguish between functions.

Fifth-hour groups needed little reminding to stay on task. They were interested in their Activity 6, which they approached as a puzzle to solve. I offered hints. These students did not want to be given answers. Four groups were successful on their own because they used good cell function definitions to guide their choices. I regret that I
did not recognize the problems which the Foxes and Lions had with several cell functions. Perhaps for these two groups, a desire to act autonomously inhibited them from requesting help even in their confusion.

**Activity 6: Analysis Implications**

Most students found their Activity 6 easy with regard to states of matter. Fifth-hour students were more interested in this topic because they liked matching a picture to each state. Both analogical and nonanalogical Activity 6 served as reviews of student knowledge of states of matter. The picture analogs of analogical Activity 6 made this review of familiar science concepts more interesting.

Analogical and nonanalogical Activity 6 were both challenging as regards cell functions. While students had learned about cell functions individually, they had never considered them all together. Students tended to be more cognizant of these functions in terms of body systems, rather than at a cellular level. Activity 6 challenged students to clarify their understanding of cellular functions and the importance of these cellular processes to the function of body systems.

The analogical Activity 6 seemed qualitatively better in terms of student learning, motivation, and involvement. Students not only defined a cell function, but also applied this information to the task of matching this function with its symbol. The mystery element held fifth-hour students' attention as they tried to match symbols to their definitions. This visual meaning was more powerful than just words. These students had studied cell functions earlier, yet they did not remember all of them. By the end of Activity 6, they could give a general description of cell functions and distinguish between them. Hour 5 students retained visual images in their mind to help them remember in the future.
Activity 6: Reflections on Specific Students

To some extent, the picture analogs appealed to all the students selected for special focus. These students varied in their preferences for the abstract or realistic picture analogs.

Pelicans: Ed and Keisha

Ed did not share all he knew about the states of matter during his group's analysis of the picture analogs. Ed improved his understanding of cell functions. Both the realistic and symbolic picture analogs inspired Ed analogical thinking. They made sense to him. He liked thinking hard about cell functions. He earned a 2.25 SMILE score.

Keisha felt comfortable and competent working with the picture analogs of the states of matter. She liked the realistic pictures and the familiar scientific subject. Keisha was less enthusiastic about the symbolic pictures for cell functions. She learned about cell functions, but thought that she would have learned more if the pictures had been realistic rather than abstract symbols. Keisha earned a 1.75 SMILE score.

Harriers: Jonah and David

Jonah was content working with the artistic elements of Activity 6. He was inspired to give a long explanation of the states of matter in terms of the picture analogs. He worked hard to match cell functions to appropriate abstract images. Later, he even drew realistic images that could be used as picture analogs for cell functions. Jonah earned a 3.00 SMILE score.

David liked the pictorial analogs of Activity 6. He actively contributed to Harrier analysis of states of matter. He had difficulty matching each cell function to its appropriate symbolic analog, but he learned from his efforts. He preferred more
realistic picture analogs, nevertheless, he believed that the symbols helped him to remember cell functions. David earned a 2.50 SMILE score.

**Ferret: Eve**

Eve liked the realistic picture analogs for the states of matter. She eagerly participated in the group's work on states of matter because she felt safe talking about a scientific subject with which she was familiar. She lacked readily available definitions for many cell functions and her team members moved too fast for her to follow their reasoning. The abstract nature of cell function symbols added to her difficulty. She learned some cell functions, but really only mastered them later when given teacher guidance and a slower pace. Her later success with the cell functions made her feel more confident about her ability to understand science. Eve earned a 2.00 SMILE score.

**Red Foxes: Kevin and Mai**

Kevin used the analogical pictures to talk about his knowledge of states of matter and to develop his understanding of cell functions. He persevered with his group's past confusion to make sense of many of the symbolic analogs for cell functions. While he thought realistic or abstract pictures were helpful, he preferred the more realistic pictures. He was in his element thinking metaphorically. Kevin earned a 2.25 SMILE score.

Mai liked using the realistic pictures to talk about solids, liquids, and gases. She felt competent using them to discuss her understanding of states of matter. She was totally confused dealing with the abstract symbolic analogs for cell functions. Her group used some incorrect definitions for cell functions, and she did not have better ones in mind. She earned a 1.25 SMILE score.
Activity 7

Activity 7: Analogical versus Nonanalogical

Activity 7: Black and White Photo Shots

Introduction. The subject of Activity 7 was classification of invertebrates, animals with no backbone. Biology students in all three classes studied eight invertebrate phyla including: Porifera, Cnidaria, Platyhelminthes, Nematoda, Annelida, Mollusca, Arthropoda, Echinodermata. For each phylum, they studied the meaning of the phylum name, animal characteristics, representative animals, and the animals' ecological roles. Students took notes from lectures, read from their biology text, did homework, and received a handout that summarized information about each phylum and provided pictures of organisms in each phylum. Activity 7 provided students with an opportunity to reinforce and integrate their understanding of invertebrate phyla. Students engaged in Activity 7 on May 16, 1997.

Activity 7 descriptions. The nonanalogical Activity 7, "Invertebrate Phyla Survey," involved students in observation of representative animals in each phylum. Sixth- and seventh-hour students referred to their written notes and typed handout on invertebrates to name the phylum and list three characteristics of each phylum. They colored and labeled pictures on their handout. Since the specimens were organized in sets throughout the lab, students moved station to station. It was not possible for students to work together in their larger groups, nor tape their dialogue. Students reported activity time as about four hours, but this included time spent taking phyla notes.

Fifth-hour students reported spending two hours on their Activity 7. Because fifth-hour students lost class time to school activities, I only had one day to discuss the notes on the invertebrate handout. During one class, notes were discussed; and in the next class, they did analogical Activity 7. "Does a Hands-On Experience Equal 1,000 Words?" (see Appendix Z) involved students in observation of specimens, use of
the invertebrate handout, and movement from station to station in the lab. The limited space at each station did not permit large groups to work together and audiotaping was not possible. The unique element of analogical Activity 7 was a hands-on experience to help students remember some of the characteristics of the phyla. Fifth-hour students used these experiences to list a set of characteristics associated with animals in each phylum (see Appendix AA for hypothetical responses).

Phylum Porifera includes sponges. For this group, an artificial sponge was shaped into a vase and placed into water. Students squeezed absorbed water out a hole on top, which simulated the movement of water through a sponge and highlighted the pores or holes in sponges.

Phylum Cnidaria includes jellyfish, coral, sea anemones, etc. Students attached sparkler streamers to a paper cup and placed a few tacks through the streamers. The cup represented the hollow insides of these animals. The streamers with tacks represented tentacles with stinging cells called cnidocytes, which have stinging barbs.

Phylum Platyhelminthes includes flatworms such as planarians, flukes, and tapeworms. Students rolled clay into a long tube, then pounded the clay flat to remind students of the flat worm form. Students poked one hole into the clay to represent the one opening which serves as mouth and anus for these worms.

Phylum Nematoda includes roundworms. Students observed a thread which hinted at both the shape of these worms and the meaning of the phylum name. They rolled clay into a long round form and poked a hole all the way through lengthwise. This suggested the round, long form of roundworms and the presence of a mouth, long digestive tract, and anus.

Phylum Annelida includes segmented worms such as earthworms and leeches. Students rolled clay into a long rounded form and cut a series of circular grooves along the length to suggest a long, round, segmented form of these worms.
Phylum Mollusca includes such animals as clams, snails, and squid. Students wrapped a piece of foam with a cellophane covering and placed this combination inside a shell. The foam suggested the soft body of molluscs. The cellophane represented the special tissue called a mantle, which produces the molluscan shell in those species with shells.

Phylum Arthropoda includes insects, spiders, crabs, shrimp etc. Students connected two or three corks together and added pipe cleaner attachments to their cork creature. The two corks represented the two body sections of spiders and four pairs of pipe cleaners formed legs. The three corks represented the three body sections of insects and three pairs of pipe cleaners formed legs. Students bent the pipe cleaners into many segments suggesting the segmentation of arthropod appendages and phylum name meaning "jointed legs. The hardness of the cork suggested the hard exoskeleton, hard outer covering.

Phylum Echinodermata includes starfish, sand dollars, brittle stars, and so forth. Students cut out a star and stuck toothpicks into the star. The star suggested the five-part symmetry of these animals and the toothpicks suggested "spiny skin" which is the meaning of Echinodermata. Students placed straws in water and drew water up into the straws. This suggested tube feet connected to a water circulation system.

Activity 7: Panoramic Photos from Researcher Vantage Points

Nonanalogical path. Hour 6 and 7 students enjoyed observing specimens from each phylum. They used their observations and their invertebrate handout to list characteristics of each phylum. They liked coloring pictures of representative animals. They were comfortable and happy with their nonanalogical Activity 7.

Analogical path. Hour 5 students enjoyed observing specimens from each phylum and doing the assigned "experiences." They used these experiences, their observations, and their invertebrate handout to list the characteristics. They liked that they had to figure out which phylum each station represented. They worked
individually or in small groups. While simple, the hands-on experiences gave students aid in distinguishing phyla characteristics and a valuable memory tool.

**Activity 7: Panoramic Photos Taken from Student Vantage Points**

**Student evaluations.** Optional student evaluations provide multiple student views of their Activity 7. The following number of students completed forms: 21 our of 29 students in Hour 5, 18 out of 31 students in Hour 6, and 28 out of 31 in Hour 7.

**Selection of adjectives to describe activity.** Students selected adjectives to describe their Activity 7. Table 44 lists the percentages of evaluators who chose a listed adjective to describe their Activity 7. Cross comparison and movement down the table will serve to highlight the similarities and differences in student perspectives.

A majority of students evaluators of either analogical Activity 7 or nonanalogical Activity 7 described their activity as "comfortable," or "easy," with Hour 5 students favoring "comfortable," and Hour 6 and 7 students favoring "easy." A majority, or close to a majority, described their Activity 7 as "okay," or "interesting." Students in all classes chose adjectives "clear," "simple," or "understandable."

Many Hour 5 students tended to see their analogical Activity 7 as "creative," "open-ended," and "unusual." Many Hour 6 and 7 students tended to see their nonanalogical Activity 7 as "well-structured," "tedious," and "fun."

Both activities were viewed as comprehensible, accessible, interesting learning activities. Nonanalogical Activity 7 was more traditionally structured and was experienced as enjoyable by some, but arduous for others. Analogical Activity 7 was a less traditional class activity that tapped student creativity.

**Identification of activity processes.** Table 45 lists Activity 7 processes identified by student evaluators. Cross comparison of processes for the analogical and nonanalogical Activity 7 is suggested.
Table 4.4

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 7

<table>
<thead>
<tr>
<th>Adjectivea</th>
<th>Analogicalb</th>
<th>Nonanalogicalc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
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<td>33</td>
</tr>
<tr>
<td>Interesting</td>
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<tr>
<td>Easy</td>
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<tr>
<td>Understandable</td>
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<td>43</td>
</tr>
<tr>
<td>Tedious</td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>Creative</td>
<td>48</td>
<td>28</td>
</tr>
<tr>
<td>Fun</td>
<td>19</td>
<td>39</td>
</tr>
<tr>
<td>Comfortable</td>
<td>67</td>
<td>48</td>
</tr>
<tr>
<td>Open-ended</td>
<td>38</td>
<td>13</td>
</tr>
<tr>
<td>Unusual</td>
<td>48</td>
<td>20</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

a Only adjectives circled by at least 25 % of either Hour 5 or Hour 6 and 7 evaluators are listed.

bn = 21 evaluators out of 29 fifth-hour students.

cn = 46 evaluators out of 31 sixth-hour and 31 seventh-hour students.
A majority of student evaluators of analogical Activity 7 and a majority of student evaluators of nonanalogical Activity 7 identified the following processes: "thinking," "learning," "discussing," and "observing." Hour 5 students selected "thinking," more frequently, while, Hour 6 and 7 students selected "learning" more often. Analogical Activity 7 evaluators more frequently picked "analogizing." Nonanalogical Activity 7 evaluators more frequently picked "categorizing," "researching," and "drawing."

**Student rating of activity in 10 categories.** Students rated their activity in 10 categories. Class mean ratings are listed in Table 46. Evaluators for analogical Activity 7 and for nonanalogical Activity 7 gave the same ratings of 4.5 to group selection and teacher input, 4.0 to motivation, and 3.5 to enjoyment. Fifth-hour ratings of 4.5 for number of students, time involved, and age level were 0.5 higher than ratings from Hour 6 and 7; but Hours 6 and 7 evaluator ratings of 4.5 for directions, and 4.0 for challenge were 0.5 higher, and rating of 4.5 for knowledge was 1 point higher than the analogical activity evaluators. These scores are all "good" to "excellent." The higher knowledge gain for the nonanalogical group is probably due to their consideration of note-taking as part of their Activity 7.

**Additional comments.** Some evaluators wrote extra comments. These evaluators included: four students from fifth hour, and 23 students from sixth- or seventh hours. Many students gave overall reactions, but some students specifically focused on the invertebrate subject and the handout with pictures and notes.

The four Hour 5 comments favored analogical Activity 7: "Great" (Jim); "Cool dude daddio" (Mai); "simple activities, but we learned a lot from them and I remembered it." (Kevin); "Each of your lab events are very good, but they are basically alike" (Sarita).

Most seventh-hour students liked their nonanalogical Activity 7. Six students gave general comments of praise including: "good," "fun," "loved it," "interesting," "cool," and "different." Two sixth-hour students expressed similar views. Sheena in Hour 7...
### Table 45

Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 7

<table>
<thead>
<tr>
<th>Process</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking</td>
<td>91</td>
<td>61</td>
</tr>
<tr>
<td>Learning</td>
<td>62</td>
<td>84</td>
</tr>
<tr>
<td>Discussing</td>
<td>62</td>
<td>70</td>
</tr>
<tr>
<td>Observing</td>
<td>62</td>
<td>52</td>
</tr>
<tr>
<td>Remembering</td>
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<td>50</td>
</tr>
<tr>
<td>Evaluating</td>
<td>31</td>
<td>33</td>
</tr>
<tr>
<td>Choosing</td>
<td>31</td>
<td>22</td>
</tr>
<tr>
<td>Analogizing</td>
<td>31</td>
<td>11</td>
</tr>
<tr>
<td>Categorizing</td>
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<td>57</td>
</tr>
<tr>
<td>Researching</td>
<td>24</td>
<td>43</td>
</tr>
<tr>
<td>Drawing</td>
<td>5</td>
<td>33</td>
</tr>
</tbody>
</table>

**Note.** Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

*aOnly processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.

*b\(n = 21\) evaluators out of 29 fifth-hour students.

*c\(n = 46\) evaluators out of 31 sixth-hour and 31 seventh-hour students.
Table 46

Comparison of Mean Category Ratings by Students for Their Activity 7

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogicala</th>
<th>Nonanalogicalb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Time involved</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Age level</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Motivation</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Challenge</td>
<td>3.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>3.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Note.** The rating scale is 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means have been rounded to the half-decimal.

a\(n = 21\) evaluators out of 29 fifth-hour students

b\(n = 46\) evaluators out of 31 sixth-hour and 31 seventh-hour students.
said, "Your assignments are very helpful on the test that you give." Anton thought the information was helpful, but wanted a challenge to "do a specific task."

Five students in Hour 7 praised the pictures of the invertebrate animals. Monika said, "With pictures available to us, I was able to comprehend better. Wanda said, "With aid of the pictures, I finally passed a test." Three other students stressed how the pictures helped with recall, understanding, and learning. Millie in sixth-hour felt, "It was easier to remember the invertebrates because of the pictures. . . . You did great in relating each note with a picture."

Estelle and Laurel in seventh hour and Kirsten in sixth hour liked studying invertebrates. Laurel wanted to spend more time on these animals, as did her classmate Victor. Daveed wrote, "I loved your sea anemone impression."

Students in all classes gave very favorable responses to their Activity 7. Hour 6 and 7 students were particularly enthusiastic over their activity, the invertebrate subject matter, and the pictures and notes which helped them on their test.

Collage of student viewpoints. Students liked whichever Activity 7 they did. The sixth- and seventh-hour students especially liked picture diagrams of real animals. These same pictures were available to fifth-hour students, but they paid more attention to their hands-on experiences. Fifth-hour students may have taken the pictures for granted since this activity followed one in which they had used pictures as analogs.

Both activities promoted learning, yet Hour 6 and 7 students placed more emphasis on learning with their Activity 7. Hour 5 students placed more emphasis on thinking and analogizing with their Activity 7. Students in all classes claimed good motivation. Fifth-hour's analogical activity was viewed as slightly less difficult than the nonanalogical activity. This is interesting since the same scientific concepts were involved. The hands-on activities may have made fifth-hour's activity less daunting.
Reflections on the Panoramic View of Activity 7

Both analogical Activity 7 and nonanalogical Activity helped student participants to learn and reinforce their knowledge of invertebrate phyla. Students responded enthusiastically. They liked the subject matter. Hour 6 and 7 students particularly liked the pictures that accompanied their notes. Hour 5 students particularly liked the hands-on experiences.

The nonanalogical Activity 7 was a traditional learning activity. Students observed organisms and then reviewed characteristics of the phylum associated with these organisms. They wrote down a list of characteristics. This activity helped students review for their test. The analogical Activity 7 used all the traditional strategies, but added a set of hands-on experiences to promote learning of information about invertebrate phyla. Fifth-hour students liked these simple activities which helped them learn and remember phylum characteristics.

Activity 7: Analogical Groups

Since students did not work in their full cooperative groups and did not tape their discourse, focus on groups must be omitted. Nevertheless, it is possible to glean additional information from the students selected for special focus within the analogical groups. Guidesheet responses, student evaluations, and student interviews provide some evidence upon which to base a closer look at the students followed throughout the year. SMILE scores were not assessed for Activity 7 because of the lack of audiotapes to reveal details of the students’ analogical thinking.

Activity 7: The Pelicans

Close-up focus on Ed. Ed’s guidesheet responses cite many of the possible connections between the hand-on experiences and invertebrate phyla. For example, Ed wrote, “the foams soft just like mollusks, it means soft body.” Ed also wrote, “The thread represents the phylum because nematoda means ‘thread.’” He missed some possible analogical connections. For example, he connected the stringy sparklers with
tacks with the stinging tentacles of cnidarians, but did not connect the cup with the hollow insides of these organisms. He acceptably named some characteristics unrelated to the hands-on acts. For example, Ed named the three tissue layers of flatworms.

In his May 2 interview, Ed said, "The hands-on helps a whole lot, plus with study." Ed earned a 93 on his May 19 animal phyla test. His interview revealed his enthusiastic response to observation of the specimens in jars with animals. Ed described the experiences for jellyfish, flatworms, roundworms, and segmented worms and explained the analogical meaning of these experiences. His memory of the experiences relating to Porifera, Mollusca, Arthropoda, and Echinodermata were less clear. He thought that doing the hands-on experiences, and doing them again right before the test would improve their usefulness. When asked if consciously trying to learn while doing the hands-on actions would improve learning, he agreed, "Yeah, cause that would even use another method of learning."

**Close-up focus on Keisha.** Keisha worked with her Pelican friends and gained from her collaboration. Keisha believed that hands-on activities fit her learning style "very well because like I mean the sponge for example. . . . and the Phylum Porifera, I guess I will always remember that" Keisha appreciated the "handouts with pictures and stuff, that also helped us with remembering things" (Interview, May 27, 1997). Keisha earned a 97 on her animal phyla test. Analogical Activity 7 helped Keisha learn.

**Activity 7: The Harriers**

**Close-up focus on Jonah.** Jonah did not provide any written evidence of his participation in Activity 7. During his May 27, 1997 interview, he said that the hands-on experiences were helpful to him, but when he explained more, he did not sound so certain. Jonah said, "Yeah un hun, somewhat, although I didn't have any clue as to what to do if I was gonna." Typically Jonah needed more one-on-one guidance with lab, but he worked alone during Activity 7. He never really focused. His performance
fits his earlier description of his tendency to concentrate on doing without thinking about why he is doing something. Jonah scored 63 on his animal phyla test.

**Close-up focus on David.** David systematically mapped features of the hands-on experiences to features of the corresponding phylum. For Phylum Cnidaria, he mapped the hollow cup to hollow insides, sparkler strands to tentacles, and tacks to stingers. For Phylum Echinodermata, he mapped a star to a starfish, toothpicks to spiny skin, straws to suction cups, and water to the ocean. David's echinoderm mappings were reasonable and accessible. David worked with his friend Barry, but neither one pushed the other to translate their mappings into more scientific terms. For example, the straw "suction cups" could suggest tube feet of starfish. The star could stand for a whole starfish, but it also suggests pentaradial symmetry, five rays out of a circle. David's responses showed his involvement in Activity 7, but also his tendency to settle for the most readily accessible analogical connections.

In his May 27 interview, David explained that he was confused at first about Activity 7, but once he got into the lab and worked with the stuff, he understood. David said, "You had a very good idea. It was easy once you actually tried to do it and it helped me more so than the book". He easily recalled the foam sponge for Porifera and its meaning. "It had little holes, little pores. It absorbs water, just which Poriferans soak in." He gave a very good explanation of the hands-on experience for Cnidaria. He admitted that he did feel the tacks to simulate a jellyfish stinging. He easily recalled all hands-on experiences related to the rest of the phyla. Unfortunately, he did not always make the connections in scientific terms. Even with this deficiency, he felt that Activity 7 helped him on the test. "If I wouldn't have remembered some of this stuff, I probably would have failed". David earned a 60 on his animal phyla test. David even enjoyed learning during our interview, as when I helped him translate his "suction cups" into tube feet and his molluscan "protective membrane" into a mantle.
Having skipped Platyhelminthes, he was happy to learn that squished clay was intended to suggest flatworms.

**Activity 7: The Ferrets**

**Close-up focus on Eve.** Eve described Activity 7 as "hard," "interesting," "confusing," "tedious," and "unusual." She gave "good" to motivation and knowledge gain, but "poor" for enjoyment. Eve felt Activity 7 was a difficult challenge, but a worthy learning activity. Eve and Paula worked together, but neither girl brought a strong knowledge of invertebrates to Activity 7. Eve recognized some relevant similarities between elements of the hands-on experiences and traits of organisms in the phyla, but she only listed phyla characteristic. She would have improved her ability to use her hands-on experiences as memory prompts if she had explicitly mapped the analog features of the hands-on acts. Eve earned a 50 on her animal phyla test. Even with Activity 7 and a typed invertebrate handout, Eve had too much to learn. Her poor science background placed her at a disadvantage among her more prepared peers.

**Activity 7: The Red Foxes**

**Close-up focus on Kevin.** Kevin described Activity 7 as "comfortable," "interesting," "clear," "creative," "understandable," open-ended," "well-structured," "fun," and "unusual." He gave "excellent" to motivation and knowledge gain, a "good" to motivation, and a "poor" to challenge. While Kevin thought Activity 7 was simple, he wrote an extra comment to say that it was useful for learning and remembering. Kevin earned 96 on his animal phyla test. He had no difficulty with making analogical connections from the experiences to the characteristics of phyla. Activity 7 tapped his natural affinity for metaphorical thinking and his intense interest in animals.

**Close-up focus on Mai.** Mai described Activity 7 as "comfortable," "okay," "understandable," "well-structured," and "typical." She gave "excellent" to motivation and challenge, "good" to knowledge gain, and an "okay" for enjoyment. Mai earned a 93 on her animal phyla test.
With the help of her friends, Rika and Ching, Mai made good analogical connections between some features of the hands-on experiences and invertebrate characteristics. For Phylum Annelida, she mapped the cuts in the clay to the rings or segments of the worms, and mapped the worm cut in half as indicative of bilateral (two-sided) symmetry. Most of her responses were accurate, but she did err. For example, she named the three parts of an insect body as head, thorax, and cephalothorax. The last term should have been abdomen. Overall, Mai learned from analogical Activity 7.

Activity 7: Summary

During analogical Activity 7, fifth-hour students reviewed a handout on invertebrates, then worked individually or with their peers to learn and reinforce their knowledge of invertebrate phyla. They carried out simple activities designed to remind them of specific characteristics of organisms in a phylum. Analogical thinking was required to transform features of each activity into characteristics of a specific phylum. They recorded their responses on their guidesheet “Does a Picture Equal 1,000 Words?” Was analogical Activity 7 effective in promoting learning and developing analogical thought? What was the quality of student interactions and student-teacher interactions during analogical Activity 7? How did analogical Activity 7 student experiences in fifth-hour compare to the nonanalogical Activity 7 student experiences in sixth and seventh hours.

Activity 7: Learning Science

Sixth- and seventh-hour students observed representative organisms and recorded three important characteristics of each phylum. This lab activity helped students reinforce their knowledge of major invertebrate phyla. If they did not recall this information, they referred to their notes or invertebrate handout.

Fifth-hour students also observed specimens and recorded phylum characteristics, but their task was transformed by the addition of simple activities at each station that were intended to help students list phylum traits. Many traits listed by Hour 5
students were analogically related to elements of the hands-on experience. Each lab station provided an opportunity for learning.

Fifth-hour students’ average grade on the animal phyla test was 83 compared to an average 81 scored by sixth- and seventh-hour students. This similarity in average grade is somewhat surprising since Hour 6 and 7 students spent twice as much class time on invertebrates as Hour 5 students. Analogical Activity 7 was an effective learning exercise for fifth-hour students.

**Activity 7: Development of Analogical Thought**

Nonanalogical Activity 7 did not provide an opportunity for development of analogical thinking by students in sixth- and seventh-hour. Analogical Activity 7 did provide fifth-hour students with an opportunity to develop their analogical thinking. Each hands-on experience was a potential aid for remembering characteristics of organisms in a certain phylum. This benefit accrued to students who mentally transferred an element of their experience to some trait of organisms in the targeted phylum. For example, students compared absorption of water into a synthetic sponge and squishing it out the top to the movement of water through the many pores of a sponge and out a big hole.

Some students only listed phylum characteristics, while others explicitly linked a feature of their hands-on experience to features of that phylum. For example, some students just listed tentacles and stinging barbs for Phylum Cnidaria; other students explained that the stringy sparklers and tacks reminded them of the stinging tentacles of organisms in Cnidaria. Students who explicitly mapped their connections followed most closely the spirit of Activity 7 and improved the odds that their hands-on experiences would improve their ability to recall phylum characteristics later.

Analogical connections made by students varied. Stronger students tended to relate a hands-on element to more difficult scientific concepts. For example, they associated a star with pentaradial symmetry of echinoderms, and associated dipping a
star in water with a water vascular system. Weaker students often made more accessible associations. For example, they cut out a star shape to remember that a starfish is an echinoderm, and dipped a star in water to remember the ocean habitat of a starfish.

**Activity 7: Quality of Group Interactions**

Students in all three classes enjoyed working in lab. Some students worked alone, but most collaborated with their peers. Students moved freely between stations and willingly shared items and ideas with their peers. Most students were interested in invertebrates. Hour 5 students enjoyed more intense interactions as they tried to discover scientific meaning in simple activities, like dipping a star into water.

**Activity 7: Teacher-Student Interactions.**

Students in all three biology classes appreciated the handout with invertebrate pictures and notes. They listened well to explanations of each phylum. Within the lab, they exercised independence. They felt comfortable asking questions. As teacher, I monitored student behavior to insure safety. Most students were focused on their task, so I rarely had to admonish anyone to return to work. I spent most of my time circulating around the lab to assist students in their identification of phyla characteristics. For fifth-hour students, I often added verbal explanations to the written instructions for their hands-on actions.

**Activity 7: Analysis Implications**

Students in all three biology classes liked their Activity 7 and liked learning about invertebrates. Students from the nonanalogueous groups appreciated the pictures on the handout, the clarity of the invertebrate handout, and observation of the preserved specimens. They were aware of the learning benefits of their Activity 7.

Students from the analogueous groups in fifth hour liked observing specimens and hands-on learning experiences. They appreciated the analogueous thinking involved in their Activity 7. Many students used a now familiar format of explicitly mapping
elements (analogs) from the hands-on activities to characteristics of invertebrate phyla (targets). These mental or written connections helped students recall phyla characteristics during testing.

Both analogical and nonanalogical Activity 7 were worthwhile learning activities. The analogical Activity 7 seemed “qualitatively better.” Fifth-hour students were more actively engaged via their hands-on experiences. Hour 5 students engaged in higher level thinking needed for analogizing. They learned through a method that provided them with an accessible memory tool for recalling information. They were actively involved in meaning making. Recall that fifth-hour students matched the performance of sixth- and seventh-hour students on the invertebrate phyla test with only half the amount of class time preparation.

**Activity 8**

**Activity 8: Analogical Versus Nonanalogical**

**Activity 8: Black and White Photo Shots**

**Introduction.** All three biology classes studied the systems of the human body through lectures, notes, homework, watching relevant films, and worksheets. The human body systems are: integumentary, digestive, endocrine, circulatory, excretory, skeletal, muscular, nervous, respiratory, reproductive, and lymphatic. These systems work together to keep the body functioning. Activity 8 provided students with an opportunity to reinforce their understanding of body systems through a series of cooperative group presentations on assigned body systems. They made presentations to their own class on May 30, 1997.

**Activity descriptions.** Nonanalogical Activity 8, "Can You Say It through Pictures?", required each learning group to research an assigned body system, construct a realistic poster of that system, and give an oral presentation on that system to their class. Class presentations were audiotaped. Similarly, the analogical Activity 8 required research on a body system, poster construction, and taped class
presentation by each cooperative group. The unique feature of analogical Activity 8 was the type of poster. Students constructed a poster collage that metaphorically, rather than literally, represented a body system. They followed the guidesheet “Can You Say It Through Pictures?” (see Appendix BB for copy and Appendix CC for hypothetical responses).

**Activity 8: Panoramic Photos Taken from Researcher Vantage Points**

**Nonanalogical path.** Hours 6 and 7 students read directly from their reports. These reports tended to be so full of details and scientific terms that the rest of the class had difficulty following the presentations. Often, one member of a group would know his part, but would not integrate it into the whole group presentation. Some students did not even understand their own part of the group report. Students did little to transform the information they obtained from books. Presentations elicited little enthusiasm or any response at all from the class.

The realistic diagrams of the body systems were accurate. Students often magnified a diagram from a biology book to draw their poster. Important parts carried labels. The students sometimes stumbled over pronunciation of hard vocabulary words such as medulla oblongata, and capillaries. Students rarely pointed to their poster as they gave their oral reports.

A few groups figured out ways to make their presentations more interesting. The Albatrosses put creativity into their reports on skeletal and muscular systems. They baked cupcakes imprinted with a bone or muscle term. As a student defined a term, this student received that muffin. The Loons constructed a three-dimensional poster of the circulatory system. To color code blood vessels, they threaded colored yarn within plastic tubing. The Grizzly Bears simply told fascinating facts about the integumentary system, which in man involves skin and hair.

**Analogical path.** Fifth-hour students researched their systems. They had to draw or cut out magazine pictures, which they could use to analogically convey
information about structure and function of the organs in their assigned system. For example, a picture of a pump might represent a heart in the circulatory system. Fifth-hour students pointed to pictures on their posters and explained how the picture figuratively stood for information related to their system. Compared to the nonanalogical reports, the analogical reports tended to be shorter, less detailed, more focused on important concepts. Hour 5 students transformed their researched information. Nonpresenting students tried to guess which system each poster represented. They were interested in each group's explanation for their collage. They asked what pictures meant if group members did not explain their significance. Analogical Activity 8 kept the whole class involved.

Activity 8: Panoramic Photos Taken from Student Vantage Points

Student evaluations. Students who completed optional evaluation forms provide multiple views of each Activity 8. The following number of students acted as evaluators: 26 out of 30 students in fifth hour, 20 out of 31 students in sixth hour, and 14 out of 31 students in seventh hour.

Selection of adjectives to describe activity. Table 47 lists the percentages of student evaluators who circled a listed adjective. Table 47 is organized to highlight the similarities and differences in Hour 5 and Hour 6 and 7 student evaluators' perceptions of their Activity 8.

A majority of evaluators of analogical Activity 8 and a majority of evaluators of nonanalogical Activity 8 chose "fun," "interesting," "clear," and "comfortable." Minority choices of "easy," "okay," simple," and "understandable" lend further support to the majority view of both activities as accessible, motivating activities. Fifth-hour evaluators placed more emphasis on their Activity 8 being "well-structured," while sixth- and seventh-hour evaluators placed more emphasis on their Activity 8 being "creative."
Table 4.7

Comparison of Percentages of Student Evaluators Who Chose Specific Adjectives to Describe Their Activity 8

<table>
<thead>
<tr>
<th>Adjective</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fun</td>
<td>73</td>
<td>71</td>
</tr>
<tr>
<td>Interesting</td>
<td>58</td>
<td>62</td>
</tr>
<tr>
<td>Clear</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td>Easy</td>
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<td>38</td>
</tr>
<tr>
<td>Typical</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>Comfortable</td>
<td>54</td>
<td>64</td>
</tr>
<tr>
<td>Simple</td>
<td>31</td>
<td>21</td>
</tr>
<tr>
<td>Well-structured</td>
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<td>35</td>
</tr>
<tr>
<td>Okay</td>
<td>31</td>
<td>53</td>
</tr>
<tr>
<td>Creative</td>
<td>31</td>
<td>59</td>
</tr>
<tr>
<td>Understandable</td>
<td>15</td>
<td>47</td>
</tr>
</tbody>
</table>

Note. Percentages are listed vertically from most similar to most different by comparison.

a Only adjectives circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.
b n = 26 evaluators out of 30 fifth-hour students.
c n = 34 evaluators out of 31 sixth-hour and 30 seventh-hour students.
Identification of activity processes. Table 48 lists processes evaluated by students as part of their Activity 8. Percentages are listed in order from highest to lowest based on fifth-hour evaluator responses. Cross comparison of processes identified for the analogical Activity 8 and for the nonanalogical Activity 8 is recommended.

A majority of evaluators of either Activity 8 identified these processes: "thinking," "discussing," "communicating," "learning," "researching," "drawing," "creating" and "choosing." These processes were part of both analogical and nonanalogical Activity 8. A majority of fifth-hour students chose "analogizing," a process unique to their Activity 8.

Student rating of activity in 10 categories. Student-evaluators rated their activity in 10 categories. Class rating means are listed in Table 49. Evaluators gave the same ratings of 4.5 to number of students and method of group selection, 4.0 to time involved, age level, motivation, and knowledge gain. Hour 5 evaluators gave a 0.5 point higher score of 4.5 to directions and teacher input; a 0.5 point higher score of 4.0 to challenge; and 1.0 point higher score of 4.5 to enjoyment. The analogical Activity 8 may have been qualitatively better in these areas.

Additional comments. Some evaluators wrote extra comments. In fifth-hour, four evaluators wrote comments. Out of sixth- and seventh-hour evaluators, 12 students wrote comments. Most comments concerned overall favorable reactions, but a few students made specific comments relative to group learning. From fifth hour, Max and Sarita called their Activity 7 "fun," and Mai said it was the "best activity!! done this year." Students in sixth- and seventh hours liked the "fun," "learning," and "creativity" of their nonanalogical Activity 8. Millie "enjoyed this activity because, "You didn't limit our creativity to just a poster. I enjoyed cooking cupcakes." Lisa had fun making posters and seeing everyone else's. Abel in sixth hour saw value in peer teaching.
## Table 48

**Comparison of Percentages of Student Evaluators Who Identified Specific Processes in Their Activity 8**

<table>
<thead>
<tr>
<th>Process</th>
<th>Analogical</th>
<th>Nonanalogical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thinking</td>
<td>88</td>
<td>74</td>
</tr>
<tr>
<td>Discussing</td>
<td>81</td>
<td>82</td>
</tr>
<tr>
<td>Communicating</td>
<td>77</td>
<td>85</td>
</tr>
<tr>
<td>Learning</td>
<td>65</td>
<td>53</td>
</tr>
<tr>
<td>Researching</td>
<td>65</td>
<td>100</td>
</tr>
<tr>
<td>Drawing</td>
<td>65</td>
<td>53</td>
</tr>
<tr>
<td>Creating</td>
<td>61</td>
<td>53</td>
</tr>
<tr>
<td>Choosing</td>
<td>54</td>
<td>59</td>
</tr>
<tr>
<td>Analogizing</td>
<td>54</td>
<td>15</td>
</tr>
<tr>
<td>Categorizing</td>
<td>46</td>
<td>62</td>
</tr>
<tr>
<td>Evaluating</td>
<td>42</td>
<td>26</td>
</tr>
<tr>
<td>Observing</td>
<td>35</td>
<td>44</td>
</tr>
<tr>
<td>Hypothesizing</td>
<td>27</td>
<td>6</td>
</tr>
</tbody>
</table>

**Note.** Percentages of processes selected by students are listed vertically from highest to lowest percentage of selectors from fifth-hour.

*Only processes circled by at least 25% of either Hour 5 or Hour 6 and 7 evaluators are listed.*

\( n = 26 \) evaluators out of 30 fifth-hour students.

\( n = 34 \) evaluators out of 31 sixth-hour and 30 seventh-hour students.
### Table 49

**Comparison of Mean Category Ratings by Students for Their Activity 8**

<table>
<thead>
<tr>
<th>Category</th>
<th>Analogical&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Nonanalogical&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of students</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Method of group selection</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Time involved</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Directions</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Teacher input</td>
<td>4.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Age level</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Motivation</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Enjoyment</td>
<td>4.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Challenge</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Knowledge gain</td>
<td>4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

**Note.** The rating scale is 1 = bad, 2 = poor, 3 = okay, 4 = good, 5 = excellent. Calculated means have been rounded to the half-decimal.

<sup>a</sup><sub>n = 24 evaluators out of 30 fifth-hour students</sub>

<sup>b</sup><sub>n = 31 evaluators out of 31 sixth-hour and 31 seventh-hour students.</sub>
Helen in fifth hour and Sonny and Sharon in seventh hour complained of members not helping enough. Victor in Hour 7 wanted "more depth" and Cade in Hour 6 wanted "more class periods to work on it."

**Collage of student viewpoints.** Students in all three biology classes responded favorably to their Activity 8, "Can You Say It Through Pictures?" Both analogical and nonanalogical activities involved elements of fun and creativity. They both emphasized thinking, communication, creativity in poster design, learning, and researching. Students were motivated to learn. Fifth-hour's analogical collage project had an edge over the nonanalogical poster project. Hour 5 students engaged in analogical thinking, faced an enticing challenge, and experienced more enjoyment.

**Reflections on the Panoramic Views of Activity 8**

Student views and this researcher's view suggest that both analogical and nonanalogical Activity 8 provided accessible, motivating learning experiences, which reinforced students' understandings of human body systems. Both activities involved students in many processes important to science. Students learned from group presentations of each body system.

Nevertheless, analogical Activity 8 seemed "qualitatively better" than nonanalogical Activity 8. The traditional format of nonanalogical Activity 8 required skilled presenters to keep the class focused. Boring presenters lost their audience. The format of analogical Activity 8 attracted the attention of students listening to each group's presentation. The analog pictures held a mystery meaning, which students wanted revealed. Fifth-hour students developed their analogical thought. They transformed their knowledge of a human body system into a metaphorical image and shared their analogical insights with their friends.
Activity 8: Analogical Groups

Activity 8: The Pelicans

Group movie: Pelicans build new meaning. The Pelicans produced a collage of 11 pictures to portray digestive system organs and their functions. Some pictures related to their own concrete experiences with digestion, but others related to scientific concepts learned in class. The Pelicans used literal, as well as symbolic pictures, to depict the digestive system. The literal pictures included: a boy eating, a tongue and teeth, intestines, and a diagram of a person swallowing liquid. They related analog pictures to science concepts. For example, they used matches and fire to represent energy needed for digestion. The fuel in a battery connected to a light bulb suggested food in the mouth reaching a stomach which turns on as food enters. They used a log burning to show fat breaking down with the help of the liver.

Pelican use of literal pictures suggests that they did not completely understand the assignment, or did not easily distinguish between literal pictures and analogical pictures. Their pictures represented a continuum from literal to analogical. Where on this continuum does a diagram of timed movement of food through a digestive tract fall? All their pictures were helpful in conveying a sense of the digestive system in action.

Some Pelican images were easy to figure out. For example, scissors represented teeth. Other pictures demanded explanation and clarification. For example, they explained that a tire represented a stomach churning. The Pelicans’ mapping of a log burning to the liver’s role in fat breakdown was unclear. At least they recognized the liver played a role in fat metabolism. But the liver is a "mystery organ" for many people. The Pelicans had difficulty using analogical pictures to depict scientific concepts for which they lacked concrete experiences.

The Pelicans earned the following SMILE scores for Activity 8: 3.25 for Ed and Randy, 2.50 for Keisha and Michelle. Table 50 lists Pelican SMILE levels and subscores.
Table 50  
Researcher SMILE Scores for Pelicans in Activity 8

<table>
<thead>
<tr>
<th>Pelicans</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.25</td>
<td>3</td>
</tr>
<tr>
<td>Randy</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.25</td>
<td>3</td>
</tr>
<tr>
<td>Keisha</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Michelle</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.50</td>
<td>3</td>
</tr>
</tbody>
</table>

Pelicans worked well together on their collage. Ed and Randy took the lead in oral presentation, but Keisha and Michelle participated too. Keisha spoke less than the boys, but this allowed her to be an observant monitor of the whole presentation. Overall, these teens viewed their activity as enjoyable, attainable, and educational.

**Close-up focus on Ed.** Ed shared with Randy lead of their group's presentation. He explained a complex picture of a machine taking water out of a river and dumping it into the ocean as standing for removal of water by the large intestines. He related a tire to a turning sensation in a stomach "if you get a fritz or something" (8: P, 1). This embarrassed Keisha. Ed explained that people needed a tongue for tasting things so that "you can know if you want to digest it or not" (8: P, 2). The class laughed when Ed made a sound suggesting what happens as waste leaves the body.

In his May 27, 1997 interview, Ed explained another picture analog of how "we drop the tablet into the water and it fizzles up. That's almost like when the food goes into the stomach and the enzymes cause a reaction." He explained, "The pictures . . . are not directly digestive system; it has something to do with it, like matches up. It correlates." Ed said he preferred this comparison approach to using literal pictures.

Ed received a 3.25 SMILE score. He earned 4 points for analog selection with his peers. He earned 3 in mapping for his abilities to work with his group to map
similarities. He rated a 3 in inference for his tendency to enhance and provide further explanations. He received a 3 for evaluation for his sharing responsibility with his peers in judging the learning value of their analogies.

**Close-up focus on Keisha.** Keisha was an enthusiastic participant in Activity 8. She mapped scissors to teeth cutting up food. She alerted her group to questions from the class. She tried to restrain Ed from adding silly humor about the digestive system. In her quiet way, she monitored the Pelicans' presentation. In her May 27, 1997 interview, she added another analog, "You know how a water pipe goes one way, just like stuff in the digestive system goes one way."

Keisha described Activity 8 as "too easy," "interesting," "simple," "creative," "understandable," and "fun." She gave "excellent" to motivation, enjoyment, challenge, and knowledge gain. Keisha viewed Activity 8 favorably.

Keisha earned a 2.50 SMILE score. She selected analogs with her group so she earned a 4 for selection. She contributed a few mappings so she gained a 2 for mapping since she was still somewhat dependent. Her dependence in the area of inference earned her a 1. She shared with her peers a 3 for evaluation of the meaning of their analogs.

**Movie review: Pelicans build new meaning.** The Pelicans built an imaginative metaphorical collage and eagerly shared its meaning. The Pelicans independently chose pictures to convey analogical meaning about the digestive system. They also used literal pictures to enhance their portrayal of digestive organs functioning. They gave their best explanations for scientific concepts for which they had realistic experiences, but struggled to explain less accessible digestive concepts. Ed contributed his imagination and analogical ability to Pelican effort to build new meaning from a collage of pictures. Keisha delighted in the task as well, and showed ability to analogize about scientific concepts with which she had some experience.
Activity 8: The Harriers

Group movie: Harriers graphically depict complex meaning. A toxic waste symbol on a truck clued Mark into the Harrier's poster as representing the excretory system. Peers were surprised that a heart, depicted as a factory, was represented on an excretory system poster. Bill explained that blood with waste leaves the heart via the aorta "tube" color coded purple for blood with waste and returns to the heart via the vena cava color coded red for clean blood. Initially, Bill confused the names of these blood vessels and I clarified this point.

Ton explained that two rectangular box filters signified kidneys. Each box was divided into a purple half and a red half to distinguish between unpurified blood entering a kidney and purified blood leaving. Bill explained that a black tube leaving each kidney was a ureter that emptied into the urinary bladder. The bladder was a toxic waste dump truck that carried waste away. When I asked what road the truck took, I ended up answering my own question. The urethra is the path of urine out of the body. Jack used the Harriers' poster to redescribe the excretory system.

The Harriers made a good poster to represent the basics of the urinary part of the excretory system. They mapped a dump truck to the urinary bladder; two filters to kidneys; two black tubes to ureters; purple and red tubes to blood vessels that bring blood to and from the kidneys; and a factory to a heart. Their design conveyed a lot of information in a simple way. Bill seemed to be the only Harrier with enough confidence to explain the system using scientific terms. Even he got confused about the names for the blood vessels.

Fifth-hour students seemed to understand the excretory system better after the Harriers presentation, even though the poster design had a few problems. Using a factory for a heart may suggest that something is made in the heart, which is not true. They could have called the building a pumping station instead. The aorta and vena cava were represented twice which could mislead students. Using purple to represent
blood with waste and red to represent purified blood could conflict with a traditional use of red for oxygenated blood and blue for deoxygenated blood.

Harriers received the following SMILE scores for Activity 8: 2.75 for Bill; 2.50 for Ton; 2.00 for Barry and David; 0.00 for Jonah. Table 51 lists SMILE levels and subscores for the Harriers in Activity 8.

Bill gave the Harrier presentation with a little assist from Ton. David and Barry were quiet and Jonah was absent. Harrier evaluations suggest that at least David, Ton, and Bill interacted well during the making of their poster and liked Activity 8. Nothing is known of Jonah's role. Since Jonah was not present and David did not speak during the presentation, it is not possible to do close-ups on them for Activity 8.

Table 51

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ton</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.50</td>
<td>3</td>
</tr>
<tr>
<td>Bill</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>2.75</td>
<td>3</td>
</tr>
<tr>
<td>Barry</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2.00</td>
<td>2</td>
</tr>
<tr>
<td>Jonah</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>David</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2.00</td>
<td>2</td>
</tr>
</tbody>
</table>

Movie review: Harriers graphically depict complex meaning. The Harriers used a simple graphic design to portray and explain the excretory system. They used symbolic and realistic picture analogs to identify functions of excretory organs and their relationship to the circulatory system. Bill and Ton presented their group's metaphorical depiction of the excretory system. Jonah was absent and David was content to let Bill and Ton present.
Activity 8: The Ferrets

Group movie: Ferrets depict a simple meaning. The Ferrets designed a simple poster to represent the respiratory system. Mark explained that movement of air in and out of a balloon represented breathing. Max mapped a vacuum cleaner to filtering air for the lungs and a garbage can to carbon dioxide, which Mark identified as waste. Max said a flower represented a source of oxygen for lungs. Eve explained the sun was there for the flowers, which provided oxygen for people. Eve continued:

Okay the balloon with the little rays on it is the lungs. And you inhale and whenever you inhale air comes in and it gives off oxygen to the body and then when you exhale all of this is coming outside (8: F, 2).

Jim ended with a "Tata." But Jim surely provided many ideas for their poster.

The Ferrets did not fully develop their metaphorical image of the respiratory system. They used a few picture analogs to convey a few commonly known ideas about the respiratory system. Only Eve gave any lengthy explanation for their picture analogs. They did not convey even some of their basic ideas well. They should have used the green part of the plant, not a flower to show plants as a source of oxygen. Only the green parts of the plants photosynthesize making food and releasing oxygen needed for respiration. The Ferrets did not properly evaluate their symbolism or their too quick explanations. They were complacent because they thought they knew respiration really well.

Jim, Mark, Max, and Eve received the same SMILE score of 2.25. They showed independence in their ability to select analogs to represent concepts related to the respiratory system. They showed more dependence on a teacher to encourage them to clarify their mappings, make inferences, and judge the full value of their self-selected analogs. Table 52 lists Ferret SMILE scores and subscores for Activity 8.

Jim, Mark, Max, and Eve shared a clear understanding of their rather basic metaphorical poster. The Ferrets presented in a lazy manner, as though they assumed
Table 52

Researcher SMILE Scores for Ferrets in Activity 8

<table>
<thead>
<tr>
<th>Ferrets</th>
<th>Selection</th>
<th>Mapping</th>
<th>Inference</th>
<th>Level</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eve</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>2</td>
</tr>
<tr>
<td>Jim</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>2</td>
</tr>
<tr>
<td>Mark</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>2</td>
</tr>
<tr>
<td>Max</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2.25</td>
<td>2</td>
</tr>
<tr>
<td>Paula</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0</td>
</tr>
</tbody>
</table>

their peers could just look at their poster and figure it out. Mark and Max rushed their brief explanation. When I asked for a slower presentation, Eve put the whole story together. Jim provided a cynical comment about absent Paula's "one-hour viruses."

On their evaluations, Eve and Mark both circled "fighting," which suggests that Ferrets continued to have interpersonal conflicts. Male Ferrets seemed overconfident. Nevertheless, they rated their motivation, enjoyment, challenge, and knowledge gain from "good" to "excellent." But only Eve seemed to give forth her full effort.

**Close-up focus on Eve.** While Eve initially just agreed with Max and Mark, she was eager to add her own voice. When Eve became the speaker, she gave a better explanation for the analogical significance of the balloon. She followed the boys' lead in hastily connecting the sun with flowers and flowers with oxygen to the body. She probably did this because she was insecure about her knowledge of photosynthesis.

The simple design of the Ferret poster may have suited Eve's very basic grasp of science.
Eve described Activity 8 as "comfortable," "interesting," "simple," "fun," and "well-structured." She identified "analogizing" as part of this activity. She gave "excellents" to motivation, enjoyment, challenge, and knowledge gain. Eve was pleased.

Eve received a 2.25 SMILE score. Eve rated a 4 in selection for her group role in selecting analogs. Eve received a 2 for mapping of similarities because she still needed teacher guidance to clarify the group's mappings. Eve remained dependent in inference earning 1 point. Eve earned a 2 for evaluation because she needed teacher guidance to fully understand the learning potential of the group-selected analogs.

**Movie review: Ferrets depict a simple meaning.** The Ferrets analogically portrayed the respiratory system in a simplistic way. They made a few good analogical connections, but were surely capable of assembling a richer metaphorical collage for the respiratory system. Members gave short explanations of their analogical thoughts. By being so unconcerned, the Ferrets even presented some science concepts incorrectly. Only Eve seemed to have worked up to her potential. She was proud of her contributions.

**Activity 8: The Red Foxes**

**Group movie: Red Foxes separately depict meaning.** The Red Foxes researched endocrine glands that secrete substances directly into the bloodstream. Each Fox chose pictures which he or she could relate to endocrine glands. Rika used pictures of girls fighting and girls flying to associate "fight or flight" hormones with adrenal glands. Ching used a scale to symbolize calcium balancing by the parathyroids. Kirk compared a car's regulation of fuel to a thyroid's regulation of energy. Kirk used a computer microchip to signify the pituitary's role as master gland. Mai used sugar to suggest blood sugar control by a pancreas. Mai's highlighting of the hypothalamus on a brain diagram indicated this gland's location. Mai explained that the hypothalamus controls the pituitary. Kevin used a picture of parrot parents caring for baby birds to suggest the roles of ovaries and testes in reproduction.
Rika, Ching, and Kirk signified endocrine glands' functions through analogy. Pictures of girls fighting or flying, a scale, a car, and a microchip symbolized glandular function of the adrenals, parathyroids, thyroid, and pituitary respectively. Kevin and Mai did not use analogies. Kevin's parrot family example indirectly suggested the activity of ovaries and testes in reproduction. Mai used sugar as a literal connection to pancreatic control of blood sugar. Mai's brain diagram indicated location of the hypothalamus.

The Foxes received the following Smile scores for Activity 8: 3.0 for Kirk, Ching, and Rika; and 1.0 for Kevin and Mai. Table 53 lists these team members' SMILE levels and subscores.

The Foxes independently researched parts of the endocrine system and presented this information in mini-reports within their class presentation. Group Interactions were minimal. What role did Kevin and Mai in their group's Activity 8?

Table 53

<table>
<thead>
<tr>
<th>Researcher</th>
<th>SMILE Scores for Red Foxes in Activity 8</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Selection</td>
</tr>
<tr>
<td>Mai</td>
<td>1</td>
</tr>
<tr>
<td>Kirk</td>
<td>5</td>
</tr>
<tr>
<td>Ching</td>
<td>5</td>
</tr>
<tr>
<td>Kevin</td>
<td>1</td>
</tr>
<tr>
<td>Rika</td>
<td>5</td>
</tr>
</tbody>
</table>

Close-up focus on Kevin. Kevin briefly explained the roles of ovaries and testes in reproduction. He used a picture of parrot parents with their babies to represent reproductive glands. This visual aid probably helped students think of ovaries and testes as parts of an endocrine system. Yet, Kevin's pictures did not tap
analogical thinking. The parrot family exemplified a result of reproduction. Kevin's intense interest in animals may have influenced his choice of pictures.

Kevin described Activity 8 as "comfortable," "okay," "clear," "creative," and "unusual." He recognized "analogizing" as a process in Activity 8. He gave "okays" to motivation, enjoyment, challenge, and knowledge gain.

Kevin earned a 1.00 SMILE score because he failed to use analogical thought. He showed dependence in selection, mapping, inference, and evaluation, so he received a 1 for all categories. While Kevin thought he understood the assignment, he did not distinguish between pictures that connect to a subject through analogy or through another method.

Close-up focus on Mai. Mai proudly presented her assigned endocrine glands. She gave good information about the location of the hypothalamus and its function in control of the pituitary gland. Her poster picture showed the location of the hypothalamus within the brain. Through her picture of sugar, she accurately suggested a relationship between sugar and the pancreas. She misled when she said, "The pancreas secretes sugar and insulin in our body" (8: R, 1). Insulin secreted by the pancreas helps regulate sugar levels in the blood. Mai's difficulty with English made scientific language all the more difficult for her. She did not interpret her pictures analogically, but used one to indicate location and another to identify an actual substance. Nevertheless, quiet Mai scored a victory in speaking before her class.

Mai called Activity 8 "comfortable," "okay," "simple," well-structured," and "fun." She recognized "analogizing" as a process within Activity 8, even if she did not use analogies in her own report. She gave "goods" to motivation and challenge and "excellents" to enjoyment and knowledge gain. She wrote, "Best activity!! done this year." Mai's low SMILE score of 1.00 reflected her failure to use analogical thought in her presentation. She earned 1s in all categories due to her dependent state in analogizing.
**Movie review: Red Foxes separately depict meaning.** Each Fox helped their peers learn about the endocrine glands and their functions. The visual aids on the Fox poster conveyed useful information. Each Fox member traveled his or her own path to depict meaning. Ching, Rika, and Kirk used pictures to analogically convey information about endocrine gland function. Contrary to instructions, Kevin and Mai used pictures that related to their assigned glands in nonanalogical ways. They endured personal discomfort in speaking before their whole class.

**Activity 8: The Snakes and Lions**

**The Snakes.** Members of the Snake learning group assembled a very original and detailed collage to represent the circulatory system. They used cut out magazine pictures to form the shape of a person. Some of their metaphorical images included: a runner carrying a number represented blood carrying oxygen to all parts of the body; band-aids represented the role of blood clotting in wound healing; medicine bottles suggested the role of white blood cells in fighting illness; a battery signified a heart that keeps a person running; and a pump signified a heart pumping blood around a body. These Snakes showed creativity and good knowledge of the circulatory system.

**The Lions.** Members of the Lion learning group assembled a true collage of pictures to signify the nervous system. Their rich and detailed collage conveyed the complexity of a functioning nervous system. Some of their metaphorical images included: books to suggest that the brain stores knowledge; a lightening bolt to convey the electrical nature of a nerve signal; an ant colony to suggest the nervous system working all together; and an apple dropping to show the neuron signals travel only in one direction. These girls assembled rich imagery to depict the nervous system.

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Activity 8: Summary

For Activity 8, sixth- and seventh-hour learning groups made posters of human body systems, which depicted the organs and gave their functions. Each fifth-hour learning group created a poster collage of pictures to signify a certain human body systems. Instructions for "Can You Say It Through Pictures?" stressed selection of pictures which students could analogically relate to their assigned system. Was analogical Activity 8 effective in promoting learning and developing analogical thought. How did students interact within their groups and with their teacher? How did student experiences with analogical Activity 8 compare to student experiences with nonanalogical Activity 8?

Activity 8: Learning Science

Members of sixth- and seventh hour groups spent time researching their assigned body system. Their posters tended to be magnified versions of a textbook diagram. They learned about their assigned system, but did little to transform this scientific information for presentation to peers. Sixth- and seventh-hour students liked researching, creating a visual aid, and orally presenting their system. These same students did not seem as interested in listening to others present long detailed reports.

The requirement to select pictures to relate to a certain aspect of a human body system encouraged fifth-hour students to focus on particular scientific concepts, especially functions of a body system. Students researched their system, but analogical Activity 8 also required students to transform scientific information into pictures and then orally interpret these pictures for the class. This format discouraged students from giving a report verbatim from a text, thereby avoiding an often too detailed and boring presentation. Analogical Activity 8 helped student participants review body systems just before final exams.

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Activity 8: Development of Analogical Thought

The nonanalogical Activity 8 was not structured to develop analogical thinking of sixth- and seventh-hour students. The analogical Activity 8 required fifth-hour students to first choose their own analogies, evaluate learning potential, and explain their analogies. The use of pictures to signify their analogy facilitated the selection process. Students considered many pictures as potential analogs for target concepts related to a human body system. Even rejection of a picture involved students in analogical thought because they decided that there was not a mappable similarity. Most students in fifth-hour successfully chose analog pictures and presented their analogical interpretations in class. Listening students gained from the other students' succinct explanations.

A few fifth-hour students took nonanalogical routes to relate pictures to a body system. Some pictures were literal representations of organs in the system. Some pictures provided examples of the result of a system's function. These choices of nonanalogical pictures suggest the challenge students face in choosing their own analogs. These nonanalogical pictures still were visual prompts for remembrance of specific scientific concepts.

Activity 8: Quality of Group Interactions

Cooperative groups in all three biology classes chose different organizational approaches. Some groups decided to let members work independently then combine the results of their efforts. Other groups decided to work together through all parts of Activity 8. In all classes, a few groups suffered from inequity in members' contribution.

There was a difference in the quality of audience participation in the three biology classes. Students in fifth-hour were more receptive and attentive than students in sixth- and seventh-hour. Hour 5 group presentations focused on a limited set of scientific concepts in correlation with the collage pictures. Curious classmates listened to learn the hidden analogical meaning of the pictures in terms of the human body.
Only the most talented and creative communicators in Hours 6 and 7 held their friends' attention throughout lengthier and more traditional presentations.

**Activity 8: Teacher-Student Interactions**

Most student research and collage assembly was undertaken during free moments in class or at home. During group members' reports, I praised their efforts, facilitated their presentations, interceded when students misled, and posed questions when student explanations were inadequate. I pressed fifth-hour students to give clear, complete explanations of their mappings from their chosen pictures to scientific concepts. The students in all three biology classes liked the creative freedom and independence of their Activity 8.

**Activity 8: Analysis Implications**

Students in all three biology classes were challenged to think, communicate, create, remember, and learn through Activity 8, "Can You Say It Through Pictures?" Most students viewed their Activity 8 as an achievable, motivating, learning activity with an element of fun. Most students liked creating a poster to accompany their class presentations on a body system. Many liked sharing their information with their peers. Unfortunately, the sixth- and seventh-hour presenters did not always enjoy a receptive audience. Hour 6 or 7 students were more likely to pay attention if the presenter was a talented communicator or the presenter included some extra element of creativity in his or her presentation.

Analogical Activity 8 was qualitatively better because it involved fifth-hour students in higher level thinking. Students focused on a set of specific scientific concepts, transformed this scientific information into analogies, and then interpreted these analogies for their peers. Even as an audience, fifth-hour peers maintained a higher level of involvement than sixth- and seventh-hour peers. Fifth-hour students were enticed to pay attention by the mystery element inherent in a metaphorical collage.
Activity 8: Reflections on Specific Students

Pelicans: Ed and Keisha

Ed easily adopted collage as a vehicle for meaning making. He explained the meaning of a few analogical pictures and one of the literal pictures. He moved easily between a metaphorical world and realistic experiences with the digestive system. He earned a 3.25 SMILE score.

Keisha enjoyed making a collage to represent the digestive system. She chose a simple picture analog to explain, but she understood the others on her group’s poster. Keisha tried to restrain Ed from making clownish comments regarding digestion because she wanted to make a good impression. Keisha earned a 2.50 SMILE score.

Harriers: Jonah and David

Jonah was not present for his group’s presentation. David was present, but did not say anything. David’s evaluation indicated that he liked Activity 8. Little more is known about these two Harriers during Activity 8.

Ferret: Eve

Eve was proud of the Ferrets’ poster of the digestive system. When finally given a chance, she willingly explained in detail the analogical basis for using a balloon to represent the lungs of the respiratory system. She revealed her tenuous grasp of photosynthesis in another comment. Eve earned a 2.25 SMILE score.

Red Foxes: Kevin and Mai

Neither Kevin nor Mai selected pictures that conveyed meaning analogically, which explains their low SMILE scores of 1.00. Kevin simply used a family of parrots to suggest reproduction, a function of his assigned endocrine glands, ovaries and testes. Mai used pictures that literally related to her assigned topics. Just presenting alien topics like the hypothalamus and pituitary glands placed heavy demands on Mai. Mai could not deal with the additional task of selecting an analogical way to present her scientific information.
Student Performances in Other Biology Class Activities

**NABT Pre- and Posttest**

Most (80) Honor Biology students took the 1986 standardized NABT Biology Achievement Test on 9-10-96. Twelve students were moved into sixth or seventh hour too late to take this pretest for assessment of their entrance knowledge. Most (85) Honors Biology I students retook this test again on 5-26-98. A total of 19 students did not take either the pre-or posttest. Statistical calculation of class means and standard deviations for the pretest and posttest resulted in descriptive statistics listed in Table 54.

Table 54

**Comparison of Honors Biology I Classes’ NABT Biology Achievement Scores**

<table>
<thead>
<tr>
<th>Class</th>
<th>Statistics</th>
<th>Fifth(^a)</th>
<th>Sixth and seventh(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Pretest</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>11.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation</td>
<td>9.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Posttest</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>29.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Standard deviation</td>
<td>11.17</td>
</tr>
</tbody>
</table>

\(^a\)\(n = 30\) students out of 30 for pretest; \(^b\)\(n = 49\) students out of 61 for pretest

These statistics suggest that fifth-hour students started the year a little lower in achievement than sixth- and seventh-hour students and ended the year a little lower in achievement. This view is captured also by mean G.P.A scores. The mean G.P.A for fifth-hour students at mid-year was 3.52, while the mean G.P.A scores for the
combined students in sixth and seventh hour was 3.65. The greater standard deviation on the posttest for the fifth-hour students leads to an intriguing conjecture. Could it indicate that for a few individuals the analogical approach was very effective, and for a few individuals this approach was markedly ineffective? It is also possible that the broader standard deviation is not related to the analogical activities at all.

A one-way analysis of variance based on the difference in scores of students who took both pre- and posttests resulted in an F value of 0.79. The critical value of F for alpha = .05, is 3.99. The computed value for F does not exceed this critical value. The null hypothesis should not be rejected. This statistical test does not allow a rejection of the hypothesis that students in fifth-hour and students in sixth and seventh hour made the same gains in scores on the NABT achievement test.

While this does not provide evidence to support the analogical activities in terms of achievement gains on a standardized biology test, it seems to suggest that participation in the analogical activities did no harm to fifth-hour students’ performance on a standardized achievement test. Novak (1997) argues that transformation of students "metacognitive processing" and development of "organized knowledge structures" takes time (p. 7). It is not likely that such a gradual transformation would be reflected in a standardized test that was not designed to measure cognitive change through student participation in a set of analogical activities. Mintzes and Wandersee (1997) emphasize the critical importance of researcher choice of measures of assessment. This researcher used a traditional assessment tool, a standardized achievement test, but did not intend for the results to provide a "thumbs-up" or "thumbs-down" to the analogical activities as a learning strategy. This
instrument simply provided a means for collecting student data in the form of pre- and
posttest scores to add to the data available for analysis.

**Essays on Biology Unit Tests**

**Introduction**

This researcher analyzed student essays on biology unit tests for any evidence of
analogical thought. If essays by sixth and seventh-hour students showed comparable
use of analogical thought, then this would suggest that the analogical activities had
not affected the way fifth-hour students answered essay questions on biology tests.
Each test lasted about an hour, so the essays were a small part of the whole test.
Students varied in the amount of time they had to write essays after taking the
objective part of the tests.

**Essays**

The following essay questions were part of biology unit tests:

1. You are on board a spaceship that is exploring another galaxy. You find something
   unusual on one of the planets. How would you determine if this thing is living?
   (9-27-96)

2. Drawing on your knowledge of the nutrients required for life, describe an ideal
   healthy meal and explain why it is healthy for you. (10-22-96)

3. Contrast the structure of a typical animal cell and a typical plant cell. (11-6-96)

4. What does it mean when one calls respiration the “fire of life?” (12-4-96)

5. What does it mean to say that photosynthesis is the bridge between inorganic and
   organic worlds? (12-4-96)

6. Draw and label the plasma membrane and explain the function of the parts of which
   it is composed. (12-12-96)
7. You are trying to explain to a younger child the way in which a virus makes a person become sick. Write down how you would explain the concept of a virus and viral infection and the development of immunity, and ways to avoid infections. (4-9-97)

8. Describe either the nervous system or the endocrine system in terms of structure and function. (6-3-97)

Content Analysis

This researcher read each essay to identify elements of analogical thought. Some of the essays (# 4, 5, and 7) were more likely to reveal analogical thought than others. This researcher counted by class the number of students who included analogical elements in their essays. The percentage of students who expressed analogical thought in their essays was calculated for fifth-hour and for sixth- and seventh-hours. Only students who wrote essays were included in percentage calculation. Table 55 lists percentages of students by class who expressed analogical thought for each essay. Class percentages are very similar regardless of the type of activities students engaged in. This does not provide evidence that participation in the analogical activities affected fifth-hour students' expression on biology test essay.

The low percentages of expression of analogical thought for essays #1, 2, 3, 6, and 8 might be expected based on the nature of these essays. The high percentages for essay #4 may be explained by the fact that the analogy in this essay was explained in class. Most students successfully recalled the explanation from class. The percentages for essay #5 and 7 may best reflect the percentage of students by classes who tend to use analogical explanations when primed to do so. Essay #8 was part of these students' final exam. These percentages may reflect the number of students who choose to use analogical explanations even when not primed to do so.
Table 55

Class Percentage of Student Expression of Analogical Thought in Essays on Biology Tests

<table>
<thead>
<tr>
<th>Date of essay</th>
<th>Fifth</th>
<th>Sixth and seventh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 9-27-96</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2. 10-22-96</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3. 11-6-96</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4. 12-4-96</td>
<td>89</td>
<td>89</td>
</tr>
<tr>
<td>5. 12-4-96</td>
<td>50</td>
<td>58</td>
</tr>
<tr>
<td>6. 12-12-96</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>7. 4-9-97</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>8. 6-3-97</td>
<td>22</td>
<td>12</td>
</tr>
</tbody>
</table>

Student Comments, Responses, and Behaviors

This researcher recorded fieldnotes. Some notes provided student descriptions included in discussion of Activity 1. Fieldnotes enriched description of students in action with their analogical activities. Other notes formed a record of some student comments, responses, and behaviors outside of the analogical or nonanalogical activities. This section focuses on discussion of fieldnotes regarding: student responses to teacher use of explanatory analogies, student generation of analogies, students on personal level, interruptions and disruptions of biology class, and student concerns about role as evaluators.

As usual in teaching biology, I used explanatory analogies. Before fifth-hour students could even begin their animal symbol activity, I provided examples of
metaphors (e.g., Life is a beach.). Jonah chimed in with, “Life is a box of chocolates.” Missy offered, “Life is a bowl of cherries.” These students showed their familiarity with common metaphors. Students in all classes liked the analogy of a “stadium with entrance and exit gates” as an explanation for protein channels in a cell membrane that limit substances entering or leaving a cell. They liked using the image of a “person cloaking himself in a disguise to sneak into a room” to understand a virus wrapping itself in the cell membrane of the host cell to gain entrance. In general, students liked teacher-provided analogical explanations and learned from them.

Some analogies were not immediately understood and students asked for explanations. A seventh-hour student wanted help with a test term “powerhouse of the cell”, a reference to energy-releasing mitochondria. Sixth- and seventh-hour students asked questions during lecture about “Respiration is the fire of life.” During a test, sixth- and seventh-hour students requested help with “Photosynthesis is the bridge between the organic and inorganic worlds.” Hour 6 and 7 students were more likely to ask for help with analogical terms, possibly because they did not have the benefit of analogical activities.

Sometimes students spontaneously offered their own analogies. When I referred to the endoplasmic reticulum of a cell as a “transport system,” Mark called it a “highway system.” When I explained a long red wavelength of light as a “red elephant that took long slow strides,” and the shorter violet wavelengths of light as a “violet bee with high activity,” Randy suggested instead a “red bicycle” and a “violet car.” When I explained DNA in terms of a language, Mark wanted to know if there was “slang” in DNA’s language. Students who generated their own oral analogies were usually in fifth-hour. Even so, this was an infrequent occurrence.
Fieldnotes captured students as they revealed more about themselves. Quiet Mai had the courage to model her native costume on stage during a multicultural program. Jonah eagerly shared his experience of autism with his classmates, and his friends were interested and empathetic. Eve told how difficult life was as a left-hander in a right-hander world. Jack, another left-hander, suggested that there was an intelligence link with left-handedness. There were many left-handers in my fifth-hour. Recall that writing was an arduous task for autistic Jonah, so he avoided doing many written homework assignments. Jonah started taping his homework for some classes as a result of discovering his affinity for recording his voice during his biology group activities.

Fieldnotes included a record of interruptions and disruptions throughout the year. Some interruptions included career day, multicultural program, class meetings, club meetings, and registration. Unanticipated disruptions occurred. The school lost several teachers based on lower enrollment than expected. This resulted in massive class changes well after school began. A benzene and toluene spill on the river caused two lock-ins at school till the fumes passed. These notes demonstrate the lack of control any education researcher has in doing a study at an actual school.

Fieldnotes showed that student participants took their role in this study seriously. When I asked students to complete evaluation forms, many expressed concern that they could hurt my chances for getting a degree. This gave me another opportunity to assure them that for research all comments were valuable. Even negative results contribute to building scientific knowledge. With this explanation, they seemed to understand the importance of being honest discriminating evaluators.
**Student Exit Interviews**

**Introduction**

Much of the content of special-focus students' interviews are contained within discussion of the analogical activities. This statement applies best to initial and second interviews. Exit interviews (see Appendix EE for copy of questions) will be discussed in this section. During the last week in May, 1997, I interviewed special focus students Ed, Keisha, Jonah, David, Eve, Kevin, and Mai and also Jim. My questions about the analogical activities concerned the following: chief goal, comparison to traditional activities, correlation with students' learning styles, student acquisition of learning strategies, cooperative groups, criticisms, praises, and metaphors for teacher's and students' roles during the analogical activities. In addition, these students gave their interpretations of the simile "A cell is like a city."

**Chief Goal of Analogical Activities**

Keisha, Jim, and David associated analogical activities with improvement in learning, remembering, and understanding; while Jonah, Mai, and Ed emphasized learning. Eve said the goal was "to make science easier and more drawn out to where you can understand what it means." Kevin explained, "to find out different ways for us to learn information." These students identified the chief goal of the analogical activities as improving education.

**Comparison of Analogical Activities to Traditional Activities**

Students described traditional activities in these terms: "may work by yourself and find things out" (Keisha); "teacher explain stuff from book . . . boring activities . . . usual notebook" (Jonah); "teacher lecturing on the board" (Kevin); "more like busy work" (Jim); "some hands-on but not as much" (Ed); "planned out to where anything
that happens you know this is what you have to do" (Eve); and "reading the book" (David). These students understood traditional school activities as teacher-empowered, text-based, solitary work that required students to read, listen, and write.

Students generally preferred the analogical over traditional activities. They identified in their comments thinking as an asset of the analogical activities: "stimulated the brain" (Jim); "challenge us all to think" (Eve); "we had to figure out the information for ourselves" (Kevin); and "students actually think. If a student doesn't understand, it kind of forced us to understand anyway" (Jim). Interviewees praised the emphasis on doing: "more fun.... working in groups" (Keisha); "do something to learn more" (Jonah); "to get involved, actually get more input (Mai); "learn more by seeing and doing" (David); and "do the lab, and talk about it, and the guide would help" (Ed).

For Ed, the analogical activities felt like labs. Jonah liked that, "You learn as you need." These students viewed the analogical activities as student-empowered, experience-based, group work, which required students to think, visualize, discuss, and understand.

Some students did not like all analogical activities. For scientifically literate Jim, some were extraneous. For Mai, some were harder than traditional ones. Mai correctly observed that traditional learning activities were essential for student participation in the analogical activities. Mai explained, "We had to pay attention in class, listen to know how to understand this stuff."

**Correlation of Analogical Activities with Student Learning Styles**

The analogical activities fit each student's learning style to some degree. Jonah and Keisha thought the match was good. Jonah said, "If I get into doing more stuff like this, I can actually learn more and better." Ed gained learning options. "You try to put
in a little versatility, make yourself a little broad to learn different ways." David believed they, "helped me more so than the book." Kevin felt, "They fit okay." Mai thought, "Most of the time I understood it, but sometimes... it got kind of confusing." Eve said, "Well they helped me in certain ways, like... I like things that are drawn," but, "I had to work on them a lot to understand what they were saying." As a "pictorial learner," Jim claimed, "half of them fit my learning style perfectly, the others were more left-brain oriented." All activities did not suit all students, but all students felt some activities fit their learning styles.

**Acquisition of Learning Strategies**

Student gained a new learning strategy from their analogical activities. Keisha said, "The thing that I really did pick up is I can use things that I know to compare to things I need to learn." Ed too picked up this strategy. Mai explained, "It was like you have to like... put yourself in that position." Jonah said, "They sort of like memory that just pops up when you need it at the time." Kevin said that he always had used the strategies of "using pictures to remember stuff and analogies." Not having heard the activities called "analogical," most interviewees used their own words to describe this "analogical" learning strategy.

Some students became more aware of the possibility of using pictures, hands-on experiences, or stories to help them learn. Ed liked that "you could see the pictures in your mind making it easier to understand." David, Keisha, and Eve liked the pictures and hands-on experiences. Eve also liked the stories. Through the story activity, Jim "learned how to think through a problem better." Analogical group activities increased student appreciation of the multiplicity of ways to learn.
Cooperative Learning Groups

Some students noted that group collaboration helped. For example, Bill's structured-approach helped David learn about cell functions. Keisha explained that group members knew different things and so they helped each other learn. Mai explained, "We had to figure out things on our own, whenever you were helping other groups." Kevin said, "We can do the groups and learn it better and we remember it more."

Keisha and Jonah noticed that they got to know other students better through their group work. Keisha said, "You had to know the person better, even though you were still trying to learn things about science." Despite Jonah's initial reluctance to work with his group and his sometimes difficult experiences within his group, Jonah believed, "I have been brought closer to those people." While on this subject, Jonah asserted, "I think I might have changed. . . . I think it might have been for the better."

Some students mentioned difficulties. Jonah explained that working all year with the same people was hard because you really knew them, and got into "aggravating stuff about them coming out." Mai complained that her "group argued back and forth, it got confusing because we didn't know what to do." Facing up to these difficulties may have helped these students develop their interpersonal skills. For some groups, teacher mediation was essential. David and Mai mentioned that their groups wasted time joking or talking off the subject. David suggested a set time limit would ameliorate this problem. Mai suggested that "students not pick their own groups cause they'll pick their friends." Kevin thought groups of four would be better.
Metaphors for Teacher and Student Roles During the Analogical Activities

Student choices of metaphors for the roles of teacher and student during the analogical activities were diverse. For Ed, the teacher was "paramedic" because "every time we needed help or something, we could like call on you." Ed was a "light beacon" who led his group. For Keisha, the teacher was "scientist" who tried out things for the first time with her students. Keisha was a "specimen" who tried to do the "first time things." Keisha thought the scientist treated her "specimens" well. Keisha added, "Ha, yeah, it was fun."

For Jonah, the teacher was the "professional" who was "teaching me how to do stuff." Jonah saw himself as a "self-automated robot" who "would observe" and who "would do" according to instructions. Jonah's autism probably shaped his personal metaphor choice.

For Eve, the teacher was a "moderator" who tells us what we need to do, and just watched and made sure we did what we needed to do." Eve was a "litigator" because, "We were always arguing about no this is right, and then we argued to prove our point." For Jim, the teacher was an "observer" who's "watching from afar and steps in every time we get off track, but for the most part...let's us do our own thing." Jim was a "foreman on a construction site" who was "given the basic layout for the job, but it's up to him to use his own discretion to figure out how to do the job."

For Kevin, the teacher was a "band director" who "told us what to do, but we had to know how to do it in order to do it." Kevin was a "band student" learning to play his instruments well. He was a doer, not just a listener. Kevin really did play in the school band. For Mai, the teacher was a "leader" who "went around helping everybody and
explained it. Mai was a "follower" because she "had to listen to what your [teacher] instructions were." Insecure Mai took comfort in knowing that adult help was near.

These students chose highly personal metaphors for their own role in the analogical activities. It seemed that the analogical activities possessed a flexibility, which permitted each student to assume a role with which she or he could be comfortable. In a similar way, the students described a variety of teacher metaphors, which suggests that a teacher must assume multiple roles in response to needs of individuals participating in these analogical activities.

**Students' Analogies for Organelles of the Cell "City"**

Students ended their interviews by analyzing the metaphor that "A cell is a city." They did not use this metaphor during their study of the cell. This task of metaphor analysis gave students a risk-free challenge to reveal their analogical ability and their recall of cell concepts which they studied during first semester. If a cell was a city, what would be analogs for the organelles, the parts of a cell?

Students linked control to the nucleus via: "head of government" (Jonah), "governor" (Kevin), "capital" (Mai and Keisha), "city hall" (Eve and Jim), and "control cell for the city" (Ed). "Capital" and "governor" convey control, but suggest a different level of organization—the state. "Control cell for the city" literally states the function, and is confusing in use of both the word "cell" and "city." For the nucleus, all students identified its control function, but four students did not choose the best analog.

Some students chose analogs for the cell membrane to suggest its function in setting boundaries of the cell including: "city limits" (Jonah), "city walls" (Ed), or "city" (Mai). "City" is too broad and "city wall" may confuse students because another
organelle in some cells is a cell wall. Other students used analogs to convey a cell membrane's function in controlling movement into or out of a cell: "police" (Kevin), "policemen" (Jim), and "fits around prison" (Eve). Eve tried to combine both functions within her analog, but a prison is only one part of a city, so this makes her analog lack systematicity. Keisha's choice of "houses in the neighborhood" was confusing.

Students conveyed a water storage function of water vacuoles via: "reservoir" (Eve and Jim), "water body" (Mai), and "little plants, not Exxon, that store" (Keisha). Keisha was thinking of the tanks for Exxon oil storage, but with water in them. Mai was too broad with "water body."

Some students conveyed storage and waste processing in waste vacuoles with these analogs: "garbage men" (Kevin), "sewage stuff" (Mai), "recycle plants and dumps" (Eve), "waste management" (Ed), and BF (Jim).

Students connected energy production to mitochondria via these analogs: "nuclear power plant" (Jonah), "electric company" (Kevin), "sun" (Mai and Keisha), "power plant" (Eve and Jim), and "energy cell" (Ed). Only Ed and Jim remembered the association of mitochondria with energy. Others needed to be reminded. Ed's "energy cell" combines the literal function with the term cell, but Ed may have had in mind a battery "energy cell."

For cytoplasm, some students focused on the location of cytoplasm all over the cell as in: "surrounding atmosphere" (Ed) and "all ground in city territory" (Jonah). Most focused on the movement of substances by the cytoplasm. Their analogs were: "roads" (Kevin and Jim), "river" or "main body of water" (Mai), and "streets" (Eve). Only Mai's analog suggests the liquid nature of cytoplasm, but she also was the only one who had to be reminded of the nature of cytoplasm.
Students had difficulty with ribosomes, cell bodies that participate in making proteins. Two student analogs worked: "factory assembly workers" (Ed) and "industrial manufacturing" (Jim). Jim and Ed knew what ribosomes did. Even after reminders, others did not suggest meaningful analogs.

Students had difficulty with endoplasmic reticulum, which modifies and transports proteins through membrane channels. Even with help, three students (Kevin, Jonah, and Mai) did not propose a useful analog. Three students conveyed a transport function with these analogs: "conveyor belt" (Ed), "roads" (Jim), and "canal" (Keisha). Ed and Jim remembered this function, but Keisha needed reminding.

All interviewees succeeded in naming meaningful analogs for some of the organelles, but they differed in their overall success. Jim excelled in both scientific knowledge and in his ability to choose an appropriate analog. Ed possessed scientific knowledge and analogical ability, but vacillated between literal and analogical mappings. Jonah showed good analogical ability, but his scientific knowledge occasionally failed him. Kevin, Mai, Eve, and Keisha all received reminders of some organelle functions. Reminded of these scientific concepts, Eve displayed her talent for thinking analogically. Kevin showed analogical ability as well, but some of his analogs stretched analogical thinking too far. Mai and Keisha received the most prompts and still struggled to propose good analogs for several organelles. Mai's analogs were often too general. Evaluating their analogs was a problem for both Keisha and Mai. This exercise suggests that these students ended the year at different levels of analogical development and biology-domain knowledge. But, they did not start Biology I with the same scientific knowledge, nor the same level of analogical ability.
How effective were the analogical activities for these individual students and others in terms of analogical development, biological learning, group interactions and teacher-student interactions. Discussion of results included relevant conclusions for each section. It is time to frame these conclusions in response to the major question and subquestions posed by this study.
CONCLUSIONS

Introduction

Theories of analogy, teaching through analogies, and constructivism provided frameworks for this study. Research into use of analogies in teaching biology is limited. The goal of this study was to contribute to that body of educational research that focuses on pragmatic uses of analogies in teaching biology. This study focused on high school biology students' participation in a year-long sequence of research-based analogical activities. Emphasis was placed on analysis of student development of analogical meaning making within cooperative learning groups.

In an analogy, a familiar concept (analog) is used to understand an unfamiliar concept (target). Analogical thinking requires four interrelated processes: (a) selecting a useful analog; (b) mapping connections between the analog and target; (c) using the analogy to make inferences about the target; and (d) evaluating the efficacy of the analogy (Holyoak & Thagard, 1995). This study of student development of analogical thinking considered students' abilities to engage in these processes and their level of independent thinking within the context of biological learning. The primary research question that guided this study was: How do high school biology students develop analogical thought as they proceed through a year-long sequence of research-based analogical activities?

Throughout the lengthy Results and Discussion chapter, this question has been addressed within the context of individual student participants, individual cooperative learning groups, and specific analogical activities. Yet statement of general conclusions remains a daunting task due to the very personal, specific, and unique qualities of every participant's thoughts. Given this caveat to recognize and appreciate the singularity of
each student’s analogical thinking, this exploratory study yielded some general conclusions about how participation in analogical activities affected development of biology students’ analogical thought.

**Analogical Activities’ Development of Analogical Thought**

*Sequenced Practice of Analogical Thinking Processes*

The sequencing of the analogical activities allowed students to build on skills practiced in previous activities. For development of an ability to select useful analogs, students followed this sequence: (a) acceptance or rejection of teacher analogs for a target; student selection of an analog for a somewhat familiar target; (b) acceptance or rejection of teacher analogs in the form of a statement, experience, story, pictures, or hands-on mini-activities; and (c) student selection of a set of analogs to convey a system of information related to one target. For development of the ability to map connections between an analog and target, students followed this sequence: (a) mapping one similarity; (b) mapping a set of similarities; (c) mapping a set of similarities and dissimilarities; and (d) mapping a system of similarities. For development of ability to make inferences from an analogy and evaluate the efficacy of an analogy, students sequentially evaluated the analogical meaning they uncovered within: (a) similes, (b) a metaphor, (c) a verbal analogy, (d) a lab experience, (e) stories, (f) realistic and abstract pictures, (g) hands-on mini-activities, and (h) a collage. Repetitive practice of similar processes in the context of different types of activities with different complexities promoted students’ abilities to engage in analogical thinking.

*Value of Peer Communication on Analogical Thinking*

Peer communication within learning groups was vital to development of students’ analogical thinking. Within their groups, students expressed their ideas orally. For some
students this was a very risky venture, yet peer membership placed pressure on these students to contribute. Peers responded to the spoken word of others with praise, doubt, encouragement, acceptance, co-option, and challenge. Group conversation and active listening were powerful catalysts for learning through analogies. Students with more developed analogical skills modeled the process for students with less developed analogical skills. Together students found analogical meaning. It is doubtful that many of these young high school biology students could have accomplished the same tasks alone.

**Analogical Activity Elements that Motivate Student Engagement**

Certain elements of the analogical activities promoted student involvement. Some of these elements were: familiarity of the analogs, visual cues from analogs, audiotaping, value placed on student ideas, and opportunities for thinking and doing. Experiences of success in discussing familiar analogs taken from their everyday world encouraged students to attempt discussion of a less familiar world of science. In their novice way they discovered that "explication by analogy relieves concept density and ties new terms with familiar knowledge" (Cardinale, 1992, p. 178).

Visual cues from analogs had strong appeal for students. Trowbridge and Wandersee (1997) confirm this appeal of the "visual cognitive milieu" (p. 128). Activities involving pictures or concrete experiences provided actual visual cues. Activities which relied on verbal analogs (e.g., stories, similes) still had potential to serve as virtual visual cues.

Students liked the emphasis placed on their thinking and their doing. Students felt empowered by the value placed on their thoughts. Audiotaping of group discourse further motivated students to express their thoughts. Students liked the analogical activities that required them to be physically active, as well as mentally active.
Change with Awareness of Impediments to Analogical Thinking

Participation in the analogical activities throughout the year promoted student awareness of impediments to analogical thinking. As students became aware, they often took steps towards solutions. Some impediments included: not explicitly stating ideas; not defining a scientific target concept at the beginning; not distinguishing literal and analogical connections made between the analog and target; avoiding the hard work of analysis; and brainstorming ideas without retrospection.

When students did not explicitly state their ideas, they had more difficulty doing an activity. It was especially important for students to explicitly state their mappings from an analog to a target. Student expression showed a gradual transition to more explicit statements, but there remained a tendency to rely on implication.

Another impediment was failure to establish at least a working definition for the scientific target. This was especially critical for students who had the weakest foundation in the targeted area. As students experienced the effect of this definition deficit on their ability to proceed, many learned the value of looking up concept definitions and related information. Indeed there seemed to be a correlation between the conceptual understanding students brought to an activity and the level (attribute, relation, or system) of their attempted analogical connections. Nevertheless, as long as students had some basic foundational understanding, students could make progress in learning biology through participation in these analogical activities.

Some students initially did not distinguish between literal and analogical connections. Through listening to other students' mappings and through their own mapping attempts, students gained a better understanding of the nature of analogical connections. This
was hard for students who preferred literal statements. The literal versus analogical distinction remained a problem for some students.

Some students generated many similarity and dissimilarity connections between an analog and target, but their brainstormed ideas needed peer evaluation. These students had difficulty with stepping back and weighing their statements. They had amazing insights, but also some unfounded or at least non-useful ideas. Peers' comments slowed these spontaneous students down so that they might learn to critique their own ideas.

While some students delighted in analytical work, some were not inclined to such thinking. These students tended to accept the first similarities they identified between an analog and target. Often such mappings were of surface features. They did not spend much time analyzing the value of what they said. Through participation in the analogical activities, these students encountered peer members who modeled deeper analysis of analogies. Peers challenged too simplistic ideas. Students tried a little harder to be analytical because they wanted to show their group members that they could think of impressive ideas too.

*Science for All Americans* (American Association for the Advancement of Science, 1989) urges development of students' imaginations and enhanced thinking strategies through science education. As fifth-hour students participated in their analogical activities, they tapped their imaginations and improved their thinking strategies.

**SMILE Assessment of Student Analogical Development**

**SMILE Value and Interpretation**

SMILE assessment of a student's analogical development deserves discussion. This rubric and scale was developed by Hackney and Wandersee as an evaluation tool for this study of students engaged in analogical activities. The student's SMILE level (0
to 5) roughly represents a student's level of independence in analogizing. The SMILE instrument provides a structured way to approach analysis of a student's analogical ability.

This assessment depends on expressed analogical thought. The word 'expressed' is very important because a student does not always express all his or her analogical thoughts. This researcher tried to indicate those instances when the SMILE score may have been affected by such variables as illness, departure from class, personal dilemmas and so forth. SMILE scores assigned under these circumstances should be considered less indicative of that student's actual analogical ability.

Since analogical thinking is context dependent, it is important to emphasize that this study focused on students' analogical ability within the domain of biology. It was anticipated that each high school biology student would be capable of analogical thought somewhere along a continuum from total teacher dependence, to a combined dependence on teacher and class, to dependence on teacher and peers, to dependence on peers, to individual independence. It was also anticipated that this dependency would vary with the particular activity, as well as with the different processes (selection, mapping, inference, and evaluation) in analogizing.

SMILE scores facilitate comparison of students' expressed analogical thinking during a particular analogical activity. These may include intra-group member comparisons or inter-group member comparisons. For a teacher, such comparisons would help identify students with strength in analogical thinking who might act as peer group leaders. It would also identify students most in need of assistance in developing their analogical abilities. Such comparisons would suggest the level of difficulty of the activity for the
particular students involved. If scores are too low, students may need more class practice doing the activity under guidance by the teacher.

A student's sequential SMILE scores on this sequence of analogical activities should not be simplistically interpreted as a direct numerical indicator of a student's progress in analogical development. This interpretation might be somewhat justified if students participated throughout the year in the same analogical activity with different science targets of similar difficulty. But for this study, each different analogical activity emphasized different steps of analogizing and each analogical activity varied in difficulty. For this reason, a similar SMILE score on a more difficult analogical activity might indicate progress.

**Special Focus Students' SMILE Levels**

Table 56 lists the special focus students' SMILE levels on each analogical activity, except for Activity 7. A quick perusal of these SMILE scores reveals these students' variation in expressed analogical development and each student's variation in expression of analogical thinking during different analogical activities. More careful examination may provide some indication of how well the SMILE scores reflect this study's deep description of these special focus students in terms of their analogical development.

Table 56 also includes calculated means for the SMILE scores for each student. The score of 0 indicates nonparticipation, and was not used in calculation of means. Recall that 1 indicates total dependence on the teacher when analogizing; 2 indicates dependence on the teacher and class when analogizing; and 3 indicates teacher and peer group dependency when analogizing. The SMILE level number indicates the type of support a student would need to achieve maximum understanding from the analogy.
In this sense, the SMILE level is a very conservative score. In fact, these students often worked successfully beyond their mean SMILE level. They worked in their "zone of proximal development" so they were challenged to grow.

Table 56

Researcher SMILE Scores for Special Focus Students in Analogical Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Students</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VIII</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ed</td>
<td>2.50</td>
<td>3.00</td>
<td>3.00</td>
<td>1.50</td>
<td>2.50</td>
<td>2.25</td>
<td>3.25</td>
<td></td>
<td>2.60</td>
</tr>
<tr>
<td>Keisha</td>
<td>1.75</td>
<td>2.75</td>
<td>2.00</td>
<td>1.00</td>
<td>1.75</td>
<td>1.75</td>
<td>2.50</td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td>Jonah</td>
<td>2.50</td>
<td>3.25</td>
<td>1.75</td>
<td>3.25</td>
<td>2.25</td>
<td>3.00</td>
<td>0.00</td>
<td>2.50</td>
<td>2.10</td>
</tr>
<tr>
<td>David</td>
<td>1.75</td>
<td>1.00</td>
<td>2.75</td>
<td>2.25</td>
<td>2.50</td>
<td>2.50</td>
<td>2.00</td>
<td></td>
<td>2.10</td>
</tr>
<tr>
<td>Eve</td>
<td>1.25</td>
<td>1.75</td>
<td>1.25</td>
<td>1.75</td>
<td>2.50</td>
<td>2.00</td>
<td>2.25</td>
<td></td>
<td>1.90</td>
</tr>
<tr>
<td>Kevin</td>
<td>1.50</td>
<td>2.25</td>
<td>1.50</td>
<td>2.50</td>
<td>0.00</td>
<td>2.25</td>
<td>1.00</td>
<td></td>
<td>1.80</td>
</tr>
<tr>
<td>Mai</td>
<td>1.00</td>
<td>2.25</td>
<td>1.00</td>
<td>1.25</td>
<td>1.00</td>
<td>1.25</td>
<td>1.00</td>
<td></td>
<td>1.30</td>
</tr>
</tbody>
</table>

Ed

Ed brought strengths to the analogical activities. He was knowledgeable, curious, open-minded, confident, and playful in his thinking. He showed a natural affinity for metaphorical and analytical thinking. He needed the most help in judging the value of his mappings, because while many were useful, others were not. His received SMILE scores that were relatively high, with the exception of Activity IV for which some relevant evidence was missing. His mean score (2.60) suggests that he was able to maintain some independence in analogical thinking with support of his teacher and his Pelican learning group regardless of the degree of difficulty of the activity. He refined his analogical skills as he participated in the sequence of analogical activities.
Keisha

Keisha approached the analogical activities with an eagerness to learn, and she had much to learn. She was most helped by the use of familiar things to help her understand more difficult science things. When the science topic itself was more familiar as in Activity 2 and 8, Keisha was able to contribute more of her own analogical thought. Overall, Keisha depended on her Pelican peers and teacher for assistance in her learning. Her mean score (1.90) suggests that she remained dependent on the teacher and class for full understanding.

Jonah

Jonah showed a strong ability to analogize and to analyze. His low score on Activity 3 seemed related to his poor affective state during that activity. Jonah’s artistic sensitivity to mental visualizations helped him succeed in these analogical activities. The Harriers gave Jonah praise and encouragement to contribute his ideas. Jonah especially needed his peers to critique his connections between an analog and a target because Jonah could be a little too creative in his mappings. Jonah’s mean score (2.50) suggests that he showed independence in analogical thinking with a little help from his teacher and his Harrier learning group.

David

David was willing to participate, but initially lacked the requisite foundation. He also tended to identify first the most easily retrieved connections between an analog and target. These often were shared surface features. Nevertheless, David’s scores even showed improvement in his analogical development over time. He responded positively to the pictures, hands-on activities, and reliance on concrete experiences and objects from everyday life. He learned a lot from his more analytical peers, who
encouraged David to develop his own analytical abilities. While David's mean score (2.10) showed his need for additional teacher and class input, the overall pattern of his scores showed he was moving toward greater independence in analogical thinking with support of his Harrier learning group.

**Eve**

Eve was determined to try even though the analogical activities were very challenging for her. Eve's persistence paid off as her scores even rose over time. In the beginning, she did not distinguish between literal and analogical connections, but over time she learned to distinguish between these very different connections. She also brought a very weak scientific knowledge base to her first tasks, but she gradually learned the importance of having at least a working definition for the target concept. She also learned to trust her ability to make worthwhile contributions. She was drawn to the visual elements, hands-on activities, and stories. While Eve's mean score (1.90) showed her need for additional teacher and class input, the overall pattern of her scores showed she was moving toward greater independence in analogical thinking with support of her Ferret learning group.

**Kevin**

Kevin did not always distinguish between making literal versus an analogical connection. His scores suggest that he did learn more analogical skills from participating in the analogical activities. His progress was somewhat hampered by his aversion for talking a lot. He did not express completely his ideas about the relationship of the analog to the target. He revealed his potential to analogize and analyze in several activities, but his performance was inconsistent. Kevin's mean score (1.80) shows his need for teacher and class support, yet in some of the analogical
activities he showed much ability to function independently within his Red Fox learning group.

**Mai**

Mai showed a definite preference for the literal. Throughout these analogical activities, she spoke very little. This stance may have been related to her Asian heritage, which may have predisposed her to take a listening role. She also had difficulty with English as her second language. It is not surprising then that she had trouble speaking in English about a very foreign domain of science through the medium of analogy. Mai did not seem to develop her analogical abilities very much through participation in the analogical activities. Mai's mean SMILE level (1.30) conveys her teacher dependent status in analogizing.

**Summary**

The SMILE rubric for assessment of student analogical development provided a useful tool for summarizing rich descriptive data in a general way. SMILE level calculations tend to be very conservative since they must be based on actual evidence provided by a student. A mean SMILE score is also conservative in that students have shown ability to function above this level in some activities. The SMILE scores for the students selected for special focus provided evidence of analogical development for six of the seven students. A student's SMILE score may well fluctuate, even on similar activities, depending on what is to be produced, because having or learning relevant biological content knowledge is central to successful analogical performance.

**Research Subquestions**

In addition to the major research question, this study focused on responses to four subquestions. Responses to these questions enhance this response to the major
questions. These subquestions focused on: student dependency on the teacher, changes in student learning, possible relationships between development of analogical thinking and learning biology content, and quality of biology classroom interactions.

**Students' Dependency on the Teacher**

How does students' dependency on the teacher change as they participate in the sequence of analogical activities? The results of this study show that students gradually decreased their teacher dependency to assume more personal responsibility. Students developed their own ability to select a useful analog, map the connections between the analog and target, use the analogy to make inferences about the target, and evaluate the efficacy of the analogy. Degree of independence attained by each student varied since students began with different levels of autonomy and experienced the activities as unique individuals.

This development of greater independence was a gradual process. Most students began the sequence of analogical activities with little understanding of how to independently tap the power of analogy to learn biology. To begin Activity 1, all groups relied on a guided teacher model for mapping one characteristic from analog to target of each simile. In addition to instructional guidance, they needed teacher encouragement to boost confidence in their ability to do the task. Each new analogical activity required careful teacher instructions and guidance, but the students did not begin each new activity with the same perplexity they brought to the first activity. For example in Activity 1, they practiced mapping a similarity from an analog to a target. They brought this incipient understanding of mapping to Activity 2. This time they mapped a set of similarities, but their prior experiences with Activity 1 made this more complex task a
little less foreign. Each new activity offered a new challenge, but also the comfort of some familiar elements from previous activities.

As students gained confidence in their own abilities, they changed how they related to the teacher. In the beginning, they wanted the teacher to tell them what to do, how to do it, and whether they were doing it right. As they progressed through the sequence of analogical activities, students engaged in more balanced conversations with the teacher. They wanted to share their ideas and appreciated teacher input, but they cherished their own meaning making. They liked thinking for themselves.

While students chose their own learning group members and adopted their own organizational styles, they did not immediately become functional groups. These students needed teacher help with pragmatic aspects of tape recording, seating arrangement of group members, and time management. To different degrees, each group needed teacher intervention when members came in conflict, chose ineffective approaches, or engaged in dysfunctional behavior. Gradually students assumed more responsibility for solving their own group-related problems. They discovered that peers could influence peers to reach a more mature level of engagement. They discovered that they could reach better understanding through cooperative efforts.

**Changes in Students' Learning**

How does students' biology learning change as they participate in the sequence of analogical activities? Learning by student-participants in the analogical activities required students to engage in analysis, synthesis, and evaluation. While some familiarity with the scientific target concepts was essential, such knowledge was not sufficient for students to successfully engage in the sequence of analogical activities. Students' biology learning changed to emphasize higher level thinking. Students
engaged in decision making to select an analog. They used correlational reasoning to map similarities and dissimilarities between an analog and target. They made inferences as part of their analysis. Students synthesized ideas gleaned from an analogy to judge its learning value.

Student engagement in higher level thinking did not detract from the value of knowledge, recall, and application. Students quickly learned that to succeed with the analogical activities, they needed to revisit or learn for the first time scientific concepts pertinent to their activity. They needed specific working definitions for both analogs and scientific targets. Their conceptual understanding of these scientific concepts developed as they tried to make analogical connections. Rather than just memorization of definitions, the analogical activities pressured students to seek full comprehension of the definition's meaning.

Development of Analogical Thought and Learning Biology Content

Are there any parallels between the students' development of analogical thought and their learning of biology content? The results of this study show that student learning of biology content was promoted when students made analogical connections between familiar concepts and unfamiliar science concepts. Feeling knowledgeable about the familiar analog, students gained confidence to persevere in trying to understand the target concept. Their mental trips back and forth between analog and target caused students to concentrate on scientific concepts. Student efforts at constructing meaning were rewarded with personal ownership of biological knowledge.

Development of analogical thought promoted learning of biology in a more integrated context. Mintzes and Wandersee (1997) describe this process:

Those who learn meaningfully begin to form these kinds of cross-connections between related concepts and eventually develop well-
integrated, highly cohesive knowledge structures that enable them to engage in the type of inferential and analogical reasoning required for success in the natural sciences (p. 41).

The novice biologists in fifth hour attempted to make these ties between concepts as they interpreted analogical meaning. The open-ended nature of the analogical activities gave students freedom to explore biological concepts in a way rarely experienced by high school biology students. This promoted their broad and deep understanding. In this sense, student development of analogical thinking correlated with better learning of biology content.

This study had the benefit of a descriptive comparison group of students who engaged in substitute nonanalogical activities. These students too learned biology content through participation in their more traditional activities. Several of their nonanalogical activities were particularly effective learning activities. Traditional learning activities provided the necessary foundational knowledge for students to engage in their analogical activities. Mintzes and Wandersee (1997) affirm that: "Meaningful learning may result from either a process of discovery or through interaction with well-designed instructional materials of a more traditional, didactic nature" (p. 41). The results of this study do not dispute the benefits of some traditional activities, but the results do support analogical activities as another way to learn biology content. In some ways analogical activities were qualitatively better than most of the traditional activities.

**Quality of Biology Classroom Interactions**

How does the quality of biology classroom interactions of these students compare to equivalent biology classes? The nonanalogical groups' members cooperated in finding the right answers either through sharing their knowledge or through looking in the book.
They liked their social interactions and the shared responsibility that lightened their burden. Many of these traditional assignments could have been accomplished working alone, but most analogical activities would have been beyond most biology students' capability if done alone.

Students who engaged in the analogical activities were intrigued by the puzzle or mystery element of many of their analogical activities. This motivated them to greater involvement in their task as compared to students engaged in traditional nonanalogical activities. They liked the challenge of thinking together to uncover meaning hidden within the analogies. They liked the partially open-ended nature of the analogical activities since there were many different but acceptable responses. They seemed to enjoy doing most of their analogical activities more than students engaged in nonanalogical activities.

Analogical groups' members placed a premium on cooperation because collaboration was essential to accomplish their tasks. Their biology text was a useful reference, but the answers they sought could not be found solely in a book. Students had to derive scientific meaning from an analogical world. They communicated ideas, debated points, discussed possibilities, and reached decisions. At first students felt the stress of assuming so much responsibility for their own knowledge construction. Some groups released this tension in conflict. But as the year progressed, most groups' members established a productive camaraderie. This study showed analogical activities enriched biology classroom interactions in terms of student motivation, enjoyment, cooperation, group dynamics, and meaning making.
Knowledge and Value Claims

This research study of high school biology students' participation in a year-long sequence of research-based analogical activities supported the following knowledge claims: Through participation in a year-long sequence of research-based analogical activities:

1. Students developed some ability to select a useful analog, map the connections between the analog and target, use the analogy to make inferences about the target, and evaluate the efficacy of the analogy. Students moved toward independent analogical thinking, but the degree of independence attained varied with the student.

2. Students improved their understanding of biology in terms of depth and breadth of knowledge and in personal ownership of such knowledge.

3. Student development of analogical thinking correlated with better learning of biology content in terms of integration of concepts through use of higher level thinking skills. Students learned biology content at knowledge level as well as students using traditional learning strategies.

4. Biology classroom interactions were enriched in terms of student motivation, enjoyment, cooperation, group dynamics, and meaning making.

The value claim is that: biology students' participation in a sequence of analogical activities leads to greater student independence in analogical thinking, improved learning of biology, and enrichment of biology classroom interactions.

Implications of this Study

This study suggests that inclusion of a sequence of analogical activities could enrich a high school biology curriculum for students. These analogical activities move education in directions advocated by science educators and scientists (AAAS, 1989)--
toward more active student involvement, toward reliance on higher level thinking, toward increase in student responsibility for their own meaning making, and toward a creativity inherent in analogical thinking.

This research study was conducted with a diverse group of honor students at an academic magnet high school. Further research is needed to determine the effectiveness of this teaching approach with students of different academic abilities. Would modifications of this teaching strategy using group analogical activities be necessary if used with different student populations?

This flexible teaching strategy allows for modifications to better suit the student participants. For example, depending on the ability of the students, more or less time may need to be spent using the teacher guide strategy before letting the students work in cooperative groups. The generic analogical activities may be adapted to target different scientific concepts. Repetition of the same generic activity with different targets may further contribute to analogical development. Most students in this study responded to realistic picture analogs, so the abstract analogs might be coupled or replaced by more realistic ones. Research will be needed to determine effects of modifications of this teaching strategy for different student populations.

This study highlighted the vital role played by the teacher during the analogical activities. A teacher, who uses this strategy of analogical group activities, should be familiar with use of analogies for scientific explanation and knowledgeable of the target scientific domain. The teacher should be prepared to model each activity. The open-ended nature of these activities requires that a teacher be able to recognize and appreciate the original thinking of their students, yet also provide critical feedback, especially when students' interpretations of the analogies lead them toward
misconceptions. Finally, the teacher should reinforce important concepts in a post-activity summary.

These analogical activities helped develop young high school biology students' analogical thinking, but students did not achieve full independence in analogical thought. Certainly age is a relevant variable here. Participants in this study were often working to the edge of their capacity, or perhaps the edge of their experience and knowledge. Further study is needed of student development of analogical thinking within the context of biology as teens mature and expand their knowledge base during the upper high school years.

The SMILE instrument developed by Hackney and Wandersee shows potential as a tool for evaluation of students’ expressed analogical development. It structures assessment in terms of a student’s contribution to selection of an analog, mapping connections between an analog and a target, making inferences from the analogy, and evaluating the efficacy of the analogy. Information generated by use of SMILE may be used by a teacher to refine her teaching with analogies based on her SMILE assessments of her students’ analogical development. This information seems relevant given the importance of inference and reasoning by analogy to achievement in all the natural sciences including biology (Mintzes and Wandersee, 1997).

While the influence of gender was not a major focus of this study, gender appeared to be an important variable that affected student behaviors and performances during the analogical group activities. For example, classification of hardware for Activity 4 used a domain (hardware) with which most of the boys were more knowledgeable than most of the girls. This choice of hardware as the analog domain had the unintended effect of decreasing some girls’ confidence in their ability to contribute to the task.
This suggests that further study of the receptivity of girls and boys to different analog domains should be undertaken. What effects would use of gender-neutral domains have on performances and behaviors? What effects would a balanced use of gender-associated domains have on performances and behaviors? What effects would emphasis on female- or male-associated domains have on performances and behaviors? This issue of domain familiarity based on gender is an important one, since even the popular biology writers draw their analogs most heavily from domains (e.g., military) that society associates with the masculine gender (Hackney & Wandersee, 1998).

Gender was one of many variables which shaped group interactions. Four of the six cooperative groups were mixed-gender groups. Student status in three of these groups seemed to be partially determined by gender, that is, both boys and girls looked to the boys for leadership. Also some girls felt that they had to work hard to prove their ability to male members. The mixed-gender group which achieved the best equality was the only group in which females (3) outnumbered males (2). Members of the all-girl group, when they were unable to get along, sometimes split into two smaller working units. The all-boy group had intense encounters, which sometimes became arguments. This study points to the need for greater exploration of effects of the gender composition of the learning groups on student performances and behaviors.

The gender effects on development of analogical thought within the context of biology are worthy of consideration. It would be interesting to look back at the data of this study from the perspective of a comparison of the development of analogical thought by girls and by boys as they participated in these analogical activities. And
beyond this study, the influence of gender on analogical development within the
domain of science is a promising area for future research.

An unexpected outcome of this study was realization of the value of using tape
recorders in a biology classroom. Audiotaping provides a motivating element for
students. By replaying their tapes, students can listen and reflect on their own words.
Tape recording provides the teacher with a way to hear group dialogue in its entirety.
The students say so much more than they write down. By hearing students in the
process of meaning making, teachers may identify students' alternative conceptions
and their scientific understandings. The tapes provide teachers with a way to get to
know their students better, since the students are surprisingly candid on their
audiotapes.

Finally, the results of this study support the relevance of metaphor to science
education. Students should be helped and encouraged to use metaphorical thought as
a metacognitive tool for learning. Sticht (1993) illuminates the relevance of metaphor
to learning:

The metacognitive knowledge of how to manipulate ideas explicitly in
metaphor so as to transform either one's own or another's knowledge
into new knowledge makes metaphor a major tool for extending our
capacities for analytical thought, at the same time changing us as tool
users. (p. 631)
REFERENCES


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**APPENDIX A: A GOWIN'S VEE DIAGRAM OF RESEARCH**

**WORLD VIEWS**

- Lakoff & Johnson (1980). Metaphor is the basis of all language.
- Von Glasersfeld (1990). Knowledge is constructed from our experience.
- Vygotsky (1934). Knowledge construction is social.

**THEORIES**


**RESEARCH QUESTION**

How do high school biology students develop analogical thought as they proceed through a year-long sequence of research-based analogical activities?

**SUBQUESTIONS**

- How does students' dependence on the teacher change as they participate in the sequence of analogical activities?
- How does students' biology learning change as they participate in the sequence of analogical activities?
- Are there any parallels between the students' development of analogical thought and their learning of biology content?
- How does the quality of biology classroom interactions of these students compare to an equivalent class?

**VALUE CLAIMS**

Biology student participation in a sequence of analogical activities leads to greater independence in analogical thinking, improved learning of biology, a gain of a metacognitive tool, and enrichment of biology classroom interactions.

**KNOWLEDGE CLAIMS**

Through participation in a year-long sequence of analogical activities:

- Students develop their ability to select a useful analog, map connections between the analog and target, use the analogy to make inferences about the target, and evaluate the efficacy of the analogy.
- Students improve their understanding of biology in terms of depth and breadth of knowledge and in personal ownership of such knowledge.
- Biology classroom interactions are enriched in terms of student motivation, cooperation, and group dynamics.

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**PRINCIPLES**
*Analogy, metaphor, and simile require analogical thought which uses the familiar (analog) to throw light on the unfamiliar (target).
*The target is the unfamiliar entity and the analog is the more familiar entity that is used to help explain the target.
*Shared and unshared characteristics of the analog and target must be identified to ensure productive transfer; yet perception of similarity is somewhat subjective and context dependent.
*Useful analogies may be made whether the analog and target are drawn from the same domain or different domains.
*Analogizing requires 4 processes: selecting the analog; mapping connections; making inferences; and evaluating the analogy.

**TRANSFORMATIONS**
*Transcripts of student written responses on analogy guidesheets
*Selected samples of student products from the analogical activities
*Transcripts of relevant oral student responses to classroom questions.
*Transcripts of relevant student questions
*Transcripts of selected student answers to essay item of biology unit tests.
*Transcripts of taped group interactions (fifth hour) and selected excerpts taped group interactions (sixth & seventh hours)
*Statistical summary of results of Student Perceptions Survey responses
*Statistical comparison of students' scores on standardized biology achievement pre- and posttests
*Transcripts of student interviews
*Teacher SMILE ratings of fifth-hour students' analogical development
*Content analysis of students' analogical artifacts and all transcribed material

**CONCEPTS**
*analogy
*metaphor
*simile
*analog
*target
*within-domain
*between-domain
*shared and unshared characteristics
*selection
*mapping
*inference
*evaluation
*biology
*dependency
*analogical thought
*classroom interactions
*learning
*constructivism

**OBJECTS/EVENTS**
*Students write responses to analogy guidesheets or substitute worksheets
*Students construct projects for the analogical or nonanalogical activities
*Students respond orally to classroom questions.
*Students direct questions to the teacher.
*Students respond to an essay question on each unit biology test.
*Students work in groups on most of the analogical or nonanalogical activities.
*Students complete an optional Student Perceptions Survey for each analogical or nonanalogical activity.
*Students take standardized biology achievement pre- and posttests.
*Selected students give initial, middle, and exit interviews
*Researcher records observations and reflections based on questions.

**RECORDS**
*Students' written responses on analogy guidesheets or substitute worksheets
*Students' products from the analogical or nonanalogical activities
*Students' relevant oral responses to classroom questions
*Students' essay answers on unit biology tests.
*Audiotapes of interactions during group analogical or nonanalogical activities
*Student Perceptions Survey responses
*Students' pre- and posttest scores on standardized test.
*Selected students' responses to interviews
*Assessment of students' analogical development
*Researcher fieldnotes

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APPENDIX B: FLOW CHART DIAGRAM OF RESEARCH

1991-1996

- Literature search

World views
Theories of analogical thought
Analogy applications in science education

Development of research-based analogical activities that target biology

spring semester 1996

Pilot study of six specific analogical activities with high school biology students
Analysis of data from pilot studies

Generic analogical activities
Specific analogical activities
Hypothetical responses to some specific analogical activities

summer and fall 1996

Preparation, presentation, and approval of prospectus proposal

Research study

weeks 1-6 of 1996-97 research study

- Standardized biology achievement pretest (fifth, sixth, and seventh hours)
- Build student-student and teacher-student relationships (fifth, sixth, and seventh hours)
- Researcher observations (fifth, sixth, and seventh hours)
weeks 7-36 of 1996-97 research study

Student participation in analogical activities that target biology (fifth hour)
or
Student participation in nonanalogical activities that target biology (fifth, sixth, and seventh hours)

• Student group interactions taped (fifth, sixth, and seventh hours)
• Student written responses on analogical guidesheets (fifth hour) or nonanalogical worksheets (sixth and seventh hours)
• Student products of analogical (fifth hour) or nonanalogical activities (sixth and seventh hours)
• Student Perceptions Surveys (fifth, sixth, and seventh hours)
• Researcher observations (fifth, sixth, and seventh hours)
• Researcher rating of analogical development-SMILE (fifth hour)
• Researcher analysis ongoing

Selected student performances in other biology class activities (fifth, sixth, and seventh hours)

• Written essays for free-response question on unit biology tests (fifth, sixth, and seventh hours)
• Student oral questions to teacher; Student oral responses to teacher questions; Student spontaneous comments (fifth, sixth, and seventh hours)
• Researcher interviews with selected students (fifth hour)
• Researcher observations (fifth, sixth, and seventh hours)
• Researcher analysis ongoing
weeks 35-36 of 1996-97 research study

- Students post-analogical activities (fifth hour) or post nonanalogical activities (sixth and seventh hours)

- Standardized biology achievement posttest (fifth, sixth, and seventh hours)

- Selected fifth-hour students exit interviews with researcher

- Biology achievement pre- and posttests statistical comparison of student performances of fifth to sixth and seventh hours

- Selected fifth-hour students' exit interview tapes

- Final analysis and evaluation of 1996-97 research study in dissertation

Baseline

- Student artifacts (fifth, sixth, and seventh hours)

- Selected students interview tapes (fifth hour)

- Researcher fieldnotes (fifth, sixth, and seventh hours)

- Student artifacts (fifth, sixth, and seventh hours)

- Student Perceptions Survey responses (fifth, sixth, and seventh hours)

- Researcher fieldnotes (fifth, sixth, and seventh hours)

- Researcher SMILE ratings of students (fifth hour)
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*Note.* Information provided by Milner, L., administrator at EMHS (October 29, 1996).
## APPENDIX D: PROFILE OF STUDENTS IN HONORS BIOLOGY I CLASSES
### 1996-97

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# Appendix F: Profile of All Students in Engineering Honors Biology I

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### APPENDIX I: PROFILE OF MAGNET HONORS BIOLOGY I STUDENTS BY CLASS

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| **Sixth** |       |        |      |               |
| Afro-American | 9     | 10     | 2    | 1             |
|           |       | Total  | 2    | 1             |
| Euro-American | 9     | 10     | 4    |               |
|           |       | Total  | 4    |               |
| Asian-American | 9     | 10     | 1    | 1             |
|           |       | Total  | 1    | 1             |
| **Total students** | | | 3 | | 7 |

| **Seventh** |       |        |      |               |
| Afro-American | 9     | 10     | 14   | 3             |
|           |       | Total  | 14   | 3             |
| Euro-American | 9     | 10     | 5    | 2             |
|           |       | Total  | 5    | 2             |
| Asian-American | 9     | 10     | 1    | 1             |
|           |       | Total  | 1    | 1             |
| **Total students** | | | 17 | | 26 |

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APPENDIX J: LETTER TO PARENTS TO PROVIDE INFORMATION ON RESEARCH STUDY

Letter From: Mrs. Teacher  
Honors Biology I Teacher  
1996-97

To: Parents or Guardians of Honors Biology I students at Excellence Magnet High School

The honors biology classes for both engineering honors and magnet honors have been going well. We managed to get past the difficult student class changes made in the middle of the six weeks. We have successfully accomplished labs dealing with safety in the lab, the microscope, acids and bases, buffers, and biochemical identification. The subjects covered so far include the characteristics of life, inorganic chemistry, and biochemistry. I very much enjoy working with your teens.

With the school year well begun, I now feel that it is possible for me to begin my science education research with your young people. I have been preparing for this research for five years, as I have been working towards a doctorate in science education, specifically in the area of improving biology education. Students in all three classes will be part of my research. The planned enrichment activities are simply part of my biology curriculum. The activities will relate to a scientific topic. Many activities will involve students working in groups. Such cooperative group work has been proven to be a very successful strategy for student learning. Quite a few of these activities have been tried out with at least one of the groups of students who participated in my pilot studies.

EMHS students are valued participants in educational research in Green City. They have the reputation for full participation and then honest evaluation. Both positive and negative comments from your child will be appreciated. Students will have an option to complete a survey regarding their personal perceptions of the activity. Such student feedback is extremely valuable to a teacher-researcher. At the close of the
school year, a few students will be asked to participate in an optional interview conducted and taped by an outside researcher. The activities themselves are not optional because they are part of class work. Students will receive credit for full participation in these activities. Their group activities may be taped to help me understand how the students figured things out. Above all, your student's efforts to learn will be respected.

Your signature on this page will indicate that you are aware that your child ______________________________ (name) will participate in educational research within Mrs. Teacher's Honors Biology I class during the 1996-1997 school year.

______________________________________________________________
Signature of Parent or Guardian

______________________________________________________________
Date

If you have any concerns regarding this project, please contact me at school or at my telephone number 000-0000. Thank you very much for your support in this endeavor.

______________________________________________________________

Mrs. Teacher Honors Biology I Teacher at EMHS
APPENDIX K: IS IT LIKE IT OR NOT? [ANALOGICAL ACTIVITY 1]

Title: Is It Like It or Not?

Subject: ____________________________________________________________

Student Group: ___________________ # of Students ____________________

Names: __________________________________________________________________

Purpose: Based on an understanding of science and the use of simile, a student group will evaluate simile statements as to their effectiveness in helping to explain a scientific concept. Acceptance or rejection of each simile must be supported.

Materials: worksheet- Is It Like It or Not?
- pencils or pens
- list of simile statements
- reference material (optional)

Guide to Action:

1. First, talk about what you know about the subject, and jot down some of your ideas. Ask your teacher if you may use reference help.

2. Now, you may read the simile statements. Similes are figures of speech which compare two things which are different, and the word "like" is used. The two things may be compared because they can be thought of as the same in some way.

3. Decide whether to accept (!) or reject (x) the simile. Your decision should be based on whether you can identify a shared characteristic that is important to understanding the scientific concept.

4. You must support your acceptance with a sentence stating the connection between the concept and that to which it is compared; or, you must explain your rejection. For example:

The heart is like a pump. (!) A heart moves blood like a pump moves a fluid.
The heart is like a stone. (X) The heart is constantly moving as part of the living body, but a nonliving stone does not move itself.
Is It Like It or Not?  

Subject: __________________________

1. _______ is like _______. ( ) ______________________________
2. _______ is like _______. ( ) ______________________________
3. _______ is like _______. ( ) ______________________________
4. _______ is like _______. ( ) ______________________________
5. _______ is like _______. ( ) ______________________________
6. _______ is like _______. ( ) ______________________________
7. _______ is like _______. ( ) ______________________________
8. _______ is like _______. ( ) ______________________________
9. _______ is like _______. ( ) ______________________________
10. _______ is like _______. ( ) ______________________________
11. _______ is like _______. ( ) ______________________________
12. _______ is like _______. ( ) ______________________________
13. _______ is like _______. ( ) ______________________________
14. _______ is like _______. ( ) ______________________________
APPENDIX L: BIOCHEMISTRY SIMILE STATEMENTS [ANALOGICAL ACTIVITY 1]

SIMILE STATEMENTS: LIPIDS, CARBOHYDRATES, PROTEINS

Hint: The basis of comparison may involve structure or function.

1. Lipid is like coal.
2. Lipid is like bubble packaging.
3. Lipid is like a pantry.
4. Lipid is like a backpack.
5. Lipid is like dumbbells.
6. Lipid is like a seat cushion.
7. Lipid is like a coat.
8. Lipid is like a safety deposit box.
9. Lipid is like a piece of a puzzle.
10. Lipid is like the protective coating around electrical wires.
11. Lipid is like $2 bills.
12. Lipid is like corrugated packaging

1. Carbohydrate is like gasoline in automobiles.
2. Carbohydrate is like a house building material.
3. Carbohydrate is like a train of identical boxcars.
4. Carbohydrate is like a wall.
5. Carbohydrate is like coal.
6. Carbohydrate is like $1 bills.
7. Carbohydrate is like a chain.
8. Carbohydrate is like armor.
9. Carbohydrate is like money in a money machine.
10. Carbohydrate is like the director of a play.
11. Carbohydrate is like a key that turns a machine on or off.
12. Carbohydrate is like a seat cushion.

1. Protein is like building blocks.
2. Protein is like a pop-it-necklace.
3. Protein is like a freight train with different types of boxcars.
4. Protein is like a piece of a puzzle.
5. Protein is like a varied bead necklace that is twisted around itself and then packed into a uniquely shaped box.
6. Protein is like a river.
7. Protein is like a sentence in a special language.
8. Protein is like a fuel.
9. Protein is like an orchestra conductor.
10. Protein is like a machine.
11. Protein is like a train of identical boxcars.
12. Protein is like a key that turns a machine on or off.
APPENDIX M: IS IT LIKE IT OR NOT? [HYPOTHETICAL RESPONSES TO ANALOGICAL ACTIVITY 1]

Subject: Biochemistry -- Protein

1. **Protein** is like **building blocks** (I) because proteins are used to build parts of the body like muscles.

2. **Protein** is like a **pop-it-necklace** (I) because proteins are made by linking amino acids together like the necklace is formed by linking pop-it-beads.

3. **Protein** is like **a freight train with different types of boxcars** (I) because there are 20 different kinds of amino acids that may be used to build a protein by linking them together in different numbers of amino acids and different orders.

4. **Protein** is like a **piece of a puzzle** (I) because you it takes a special shape as it is formed from the addition of amino acids as a puzzle takes shape as the pieces are added to the puzzle.

5. **Protein** is like a **varied bead necklace that is twisted around itself and then packed into a uniquely shaped box** (I) because a protein is a whole chain of amino acid (beads) that twist around each other to form the shape of the protein.

6. **Protein** is not like a **river** (X) because a river is made of water which is inorganic and protein is an organic material.

7. **Protein** is like a **sentence in a special language** in that some proteins act as enzymes to carry a message to speed up a specific chemical reaction.

8. **Protein** is like a **fuel** (I) but it is not the best fuel for the body because carbohydrates and fat are used as fuel by the body first. **Protein** can be used as fuel for the body but that is not the best use for proteins because it is less efficient and can result in too many waste products and it can even mean that your own body structure would be dismantled.

9. **Protein** is like an orchestra conductor (I) because some proteins act as enzymes which direct the body's chemical reactions like a conductor controls the musicians.

10. **Protein** is not like a **machine** (X) because a machine is nonliving and protein is part of the living world.

11. **Protein** is not like a **train of identical boxcars** (X) because a protein is made of a chain of different kinds of amino acids not identical amino acids like the identical boxcars of a train.

12. **Protein** is like a **key that turns a machine off and on** (I) because protein enzymes control whether cells turn on or off the processes of chemical reactions.
APPENDIX N: WHO WILL SYMBOLIZE US? [ANALOGICAL ACTIVITY 2]

Title: Who Will Symbolize Us?
Name: ______________________________________________________________
Subject: ______________________________________________________________
Group: ___________________________ # of Students _________________
Names of Group Members: ______________________________________________

Purpose: To choose an animal that will represent the nature of science and its characteristics as understood by the group.

Materials: Who will signify us? guidesheet
reference materials about animals
pen or pencil/ typewriter or computer
emblem construction material:
  options - poster board, construction paper, fabrics.....
  pen, pencil, markers, paints......
  glue, stapler, sewing needle and thread .......

Guide to Action:
1. The group should have a discussion of what they know about science and the way scientists work. Jot down your ideas as you brainstorm about the nature of science and the characteristics of scientists. Jot down your ideas in this space:

2. Your group will choose an animal that will represent the nature of science and its characteristics as understood by your group. The group will consider one animal suggested by each member of the group. For this to be an informed decision, each member must research his or her animal, and share this information with the group. Information regarding the following areas should be collected: anatomy, physiology, behavior, ecology, special capabilities, life history, popular images etc.

List the name of the animal chosen by each student researcher

<table>
<thead>
<tr>
<th>Animal</th>
<th>Student Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Record information here about the animal you chose.
3. The group should now debate the pros and cons of each animal proposal. Allow each member to first argue for the animal he/she researched. Each member should try to explain how the animal can be connected metaphorically to the nature and characteristics of science. All members of the group should listen respectfully to each presentation. After the presentations, the discussion should be conducted by allowing each member the opportunity to speak in turn.

4. A vote for the animal should be taken.

5. Record the name of the chosen animal, and its connections to the nature and characteristics of science as the group sees them.

Animal: ______________________________________________________

What connections can you make between this animal and science.

________________________________________________________________

________________________________________________________________

________________________________________________________________

6. Construct an emblem for your group that is based on your interpretation of this animal as a metaphor for science.

Materials have been provided for you to use in making this emblem. Be creative. Your emblem will signify your group for the rest of the year. Note: you may use this space to sketch your suggestions for the emblem.

7. Present your group members and your emblem in an oral class presentation.
APPENDIX O: WHO WILL SYMBOLIZE US? [HYPOTHEtical RESPONSES TO ANALOGICAL ACTIVITY 2]

Title: Who Will Symbolize Us?
Name: ____________________________________________
Subject: nature of science
Group: __________________________________________ # of Students __________________
Names of Group Members: ______________________________________________

Purpose: To choose an animal that will represent the nature of science and its characteristics as understood by the group.

Materials: Who will signify us? guidesheet
reference materials about animals
pen or pencil/ typewriter or computer
emblem construction material:
options - poster board, construction paper, fabrics.....
pen, pencil, markers, paints.......
glue, stapler, sewing needle and thread .......

Guide to Action:
1. The group should have a discussion of what they know about science and the way scientists work. Jot down your ideas as you brainstorm about the nature of science and the characteristics of scientists. Jot down your ideas in this space:

   Scientists are curious and work hard. They are smart. They want to solve problems. They hypothesize and do experiments to find out if they guessed right. They keep trying even if it takes a long time. They are observant. They may work alone or as a team of scientists. The whole world is their laboratory.

2. Your group will choose an animal that will represent the nature of science and its characteristics as understood by your group. The group will consider one animal suggested by each member of the group. For this to be an informed decision, each member must research his or her animal, and share this information with the group. Information regarding the following areas should be collected: anatomy, physiology, behavior, ecology, special capabilities, life history, popular images etc.

List the name of the animal chosen by each student researcher

<table>
<thead>
<tr>
<th>Animal</th>
<th>Student Researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ant</td>
<td>Benjamin</td>
</tr>
<tr>
<td>Salmon</td>
<td>Juanita</td>
</tr>
<tr>
<td>Leopard</td>
<td>Meng</td>
</tr>
<tr>
<td>Chimpanzee</td>
<td>Jamal</td>
</tr>
<tr>
<td>Eagle</td>
<td>Kenyatta</td>
</tr>
</tbody>
</table>

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Record information here about the animal you chose

The chimpanzee has hands like people, but its foot can also grasp like a hand. It is very hairy and has eyes that both face forward to see. A chimp lives in trees but spends a lot of time on the ground. It wanders a lot in search of food. Chimps live together with other chimpanzees. They are sociable, curious, excitable, and intelligent. They even have mechanical skills to make tools from the things around them.

3. The group should now debate the pros and cons of each animal proposal. Allow each member to first argue for the animal he/she researched. Each member should try to explain how the animal can be connected metaphorically to the nature and characteristics of science. All members of the group should listen respectfully to each presentation. After the presentations, the discussion should be conducted by allowing each member the opportunity to speak in turn.

4. A vote for the animal should be taken.  
   3 votes for chimpanzee, 2 votes for salmon

5. Record the name of the chosen animal, and its connections to the nature and characteristics of science as the group sees them.

Animal: chimpanzee

What connections can you make between this animal and science.  
The chimp is intelligent and curious like scientists. The chimp searches all over for food like scientists search all over for answers to the problems they are trying to solve. A chimp may go off alone but spends a good bit of time with his social group like a scientist may work alone or with a whole group of scientists interested in the same problem. Chimps are mechanical and make tools like scientists have to make instruments and be mechanical to use them. The chimp has eyes that let it see in perspective and be observant like a scientist is observant. Chimps get excited and so do scientists when they discover something new.

6. Construct an emblem for your group that is based on your interpretation of this animal as a metaphor for science.

Materials have been provided for you to use in making this emblem. Be creative. Your emblem will signify your group for the rest of the year. Note: you may use this space to sketch your suggestions for the emblem.

7. Present your group members and your emblem in an oral class presentation.
APPENDIX P: CAN YOU MAKE THE CONNECTION? [ANALOGICAL ACTIVITY 3]

Title: Can You Make the Connection?
Subject: __________________________________________
Student Group: ___________________ # of Students: ___________________
Names: _______________________________________________________

Purpose: To explore an analogy in depth to understand what you can learn about the scientific concept from the analogy.

Materials: "Can You Make the Connection" guide sheet
pen or pencil / typewriter or computer

Guide to Action:

1. Describe or define the scientific concept of __________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________

2. What do you know about ________________________(the familiar analog)?
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________

3. Fill in this chart listing the similarities between the target scientific concept and the familiar analog

   Shared Characteristics: How are the analog and the target alike?

   Analog: ___________________ Target: ___________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________

4. Explain in your own words your understanding of the scientific concept based on the analogy that __________ is like ________________________________.
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________
   _______________________________________________________________

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5. List ways in which the targeted scientific concept and the analog differ from one another.

Unshared Characteristics: How are the analog and the target not alike?

Analog: ____________________  Target: ____________________
________________________________________
________________________________________
________________________________________
________________________________________

6. Can you now add other important characteristics to your explanation of ________
________________________________________
________________________________________
________________________________________

7. Does this analogy help you to understand the scientific concept ________
better? Explain.
________________________________________
________________________________________
APPENDIX Q: CAN YOU MAKE THE CONNECTION? [HYPOTHETICAL RESPONSES TO ANALOGICAL ACTIVITY 3]

Title: Can You Make the Connection? [Hypothetical Responses]
Name: ________________________________
Subject: Respiration
Student Group: ___________________ # of Students __________
Names of Group Members _____________________________

Purpose: To explore an analogy in depth to understand what you can learn about the scientific concept from the analogy.
Materials: Can You Make the Connection? guidesheet
pen or pencil / typewriter or computer
Optional materials for demonstration of fire burning sugar in crucible:
sugar, crucible, match, tripod, a test tube to collect smoke vapor test tube holder,
protective goggles, bunsen burner attached to gas supply
Guide to Action:
1. Describe or define the scientific concept of respiration.
   Respiration is the chemical process by which the energy in food is released in cells and converted to ATP energy for use by all the cells of the body. Respiration involves chemical reactions that breakdown food molecules into smaller molecules while releasing energy. All organisms must respire in order to live because all organisms need energy. Oxygen is required for aerobic respiration.
   Optional demonstration of sugar burning in crucible: If your teacher has decided to include this demonstration, you should be very observant of the whole process. This observation may be helpful in answering the next question.

2. What do you know about a fire (the familiar analog)?
   Fires are very hot and they can burn you if you come near them or touch them. Fires give off light. For a fire to occur, fuel, oxygen, and something to get the fire started is required. As the fire burns, the fuel is broken down into different substances. Smoke goes into the air. A black ash remains in the end. A fire can burn something very rapidly. In fact, it seems to speed up in the case of some fires.

3. Fill in this chart listing the similarities between the target scientific concept and the familiar analog.
   Shared Characteristics: How are the analog and the target alike?
   Analog: fire  Target: respiration

<table>
<thead>
<tr>
<th>Requires fuel-ex. Wood</th>
<th>requires fuel-food glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires oxygen</td>
<td>requires oxygen</td>
</tr>
<tr>
<td>Breakdown process</td>
<td>breakdown process</td>
</tr>
<tr>
<td>Releases energy and water</td>
<td>releases energy and water</td>
</tr>
<tr>
<td>Releases some heat energy</td>
<td>releases some heat energy</td>
</tr>
<tr>
<td>Needs activation energy</td>
<td>needs activation energy</td>
</tr>
</tbody>
</table>

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4. Explain in your own words your understanding of the scientific concept based on the analogy that respiration is like fire.

Respiration is like a fire in that respiration releases energy through breaking down food, just as a fire releases energy through breaking down a fuel such as wood. The presence of oxygen is required for burning just as oxygen is required for aerobic respiration. Some of the energy released in either process is in the form of heat. A byproduct of both processes is water.

5. List ways in which the targeted scientific concept and the analog differ from one another?

Unshared Characteristics: How are the analog and the target not alike?

<table>
<thead>
<tr>
<th>Analog: fire</th>
<th>Target: respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>occurs in the nonliving world</td>
<td>occurs in the living world</td>
</tr>
<tr>
<td>leaves a carbon residue</td>
<td>releases carbon dioxide</td>
</tr>
<tr>
<td>rate of reaction uncontrolled</td>
<td>rate of reaction controlled</td>
</tr>
<tr>
<td>one chemical reaction</td>
<td>many chemical reactions</td>
</tr>
<tr>
<td>releases light and heat energy</td>
<td>releases heat energy but stores energy as ATP</td>
</tr>
</tbody>
</table>

6. Can you now add other important characteristics to your explanation of respiration?

While some of the released energy is lost as heat, much of the energy released by respiration is stored as ATP, whereas the energy of a burning fuel is released as heat and light. Burning involves one chemical reaction, but respiration is a very complex process that requires many different chemical reactions. Burning is a process that occurs in the nonliving world, but respiration is a process that occurs within living bodies. Respiration is a very controlled process that is regulated by specific enzymes, whereas, the fire is basically uncontrolled except perhaps through external means such as wind or the amount of fuel made available. A byproduct of a fire is a carbon ash, but a byproduct of respiration is gaseous carbon dioxide.

7. Did this analogy help you to understand the scientific concept respiration better?

Yes. It helps to think of respiration as the fire of life because it provides the energy that is needed to make life occur, just like a fire may be needed to provide the energy for something. It is helpful to think of food as fuel for respiration. It is also helpful to think of the ways that respiration and fire are different, because these dissimilar traits are also important to understanding the process of respiration. It is important, for example, to emphasize that respiration is a very controlled process such that only a controlled amount of heat is released, so that the living organism isn't consumed by respiration like a fire would consume.
APPENDIX R: CAN YOU EXPERIENCE THIS? [ANALOGICAL ACTIVITY 4]

Title: Can You Experience This?
Student Group: __________________________ # of Students __________________________
Name: __________________________________________

Purpose: __________________________________________________________________________
__________________________________________________________________________________

Materials: __________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

Guide to Action: ______________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________
__________________________________________________________________________________

Analysis Report:
What was your problem? __________________________________________________________________

How did you go about solving your problem? __________________________________________________________________

Did you have to make some assumptions using this method of investigation? If yes, what were the assumptions? __________________________________________________________________

Did you have any problems following the procedure that may have been a source of error? __________________________________________________________________

How confident are you of the results of your investigation? __________________________________________________________________

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MAKING the CONNECTIONS

Sometimes it is easier to understand something new, if it can be understood in terms of something one is already familiar with. You have completed an activity that was designed to ultimately help you understand a new and strange concept. The activity is to serve as the familiar known thing. It will be called the analog. The new and strange concept will be called the target. An analogy compares two different things on the basis of some shared characteristic. The analog and the target will not be the same in every way.

Think about the activity you just completed. This ______________ activity may be thought of as an analog for the target______________________________

How do you think the analog and the target are alike?
List the ways:

Analog:__________________ Target:______________

Can you think of ways in which the analog and the target are not alike?

Analog:__________________ Target:______________

Does it help you to understand ____________________________(target)
better when you think of it as like ________________________ (analog)?

Explain______________________________________________________

__________________________________________________________
APPENDIX S: CAN YOU EXPERIENCE THIS? [HYPOTHETICAL RESPONSES TO ANALOGICAL ACTIVITY 4]

Title: Can You Experience This? [Hypothetical Responses]
Subject: Classification of Life
Student Group: _____________________ # of Students _____________________
Name:_______________________________________________________________

Purpose: To understand the classification of life

Materials: bag with hardware, pen, paper, construction paper, ruler

Guide to Action: Each student group must obtain a bag of hardware. Each bag contains a unique set of hardware. Separate the hardware items into two different groups based on similarity in a significant characteristic. Continue this process of subgrouping based on shared characteristics of group items, until all items have been placed into an appropriate individual category. Construct a dichotomous key to guide the classification of hardware according to your subgroupings.

Analysis Report:
What was your problem? To classify hardware into sub-categories and to construct a dichotomous key to guide the classification of hardware according to the group constructed classification system.
How did you go about solving your problem? We used similarities in characteristics to form groups and then subgroups. We tried to pick the most significant or important characteristic at each point of subdividing groups.
Did you have to make some assumptions using this method of investigation? Yes, if yes, what were the assumptions? We assumed that the observations of physical characteristics of the hardware were accurate. We assumed that we picked the characteristic of greatest importance or significance at each point in the classification subgrouping.
Did you have any problems following the procedure that may have been a source of error? We may have made bad decisions about the importance of a characteristic to the classification of the hardware. We may have made incorrect observations of physical characteristics of the items.
How confident are you of the results of your investigation? We are fairly confident.
MAKING the CONNECTIONS

Sometimes it is easier to understand something new, if it can be understood in terms of something one is already familiar with. You have completed an activity that was designed to ultimately help you understand a new and strange concept. The activity is to serve as the familiar known thing. It will be called the analog. The new and strange concept will be called the target. An analogy compares two different things on the basis of some shared characteristic. The analog and the target will not be the same in every way.

Think about the activity you just completed. This classification of hardware activity may be thought of as an analog for the target classification of life.

How do you think the analog and the target are alike? List the ways:

Analog: classification of hardware
- Divide hardware into groups from largest to smallest
- Pick the characteristics for groupings in order of most significance
- Rely on observations
- Develop dichotomous key to classification system

Target: classification of life
- Divide living things into groups from largest to smallest: kingdom, phylum, class, order, family, genus, species
- Pick the characteristics for groupings in order of most significance
- Rely on observations
- Develop dichotomous key to classification system

Can you think of ways in which the analog and the target are not alike?

Analog: classification of hardware
- Hardware is nonliving
- Classification based only on easily observed physical structure
- Classification based on simple functions for hardware

Target: classification of life
- Life refers to living things
- Classification based on more than easily observed physical structure (e.g., internal anatomy, detailed morphology, cellular structure, molecular structure -DNA and proteins)
- Classification based on complex functions of living things (e.g., embryology, development, reproduction)

Does it help you to understand classification of life (target) better when you think of it as like classification of hardware (analog)? Yes.

Explain. A hands-on experience with making a simple classification system helps me to understand how complex living things could also be classified based on shared characteristics. It also makes me realize that people have to make decisions that may be hard to make when constructing a classification system.
APPENDIX T: CAN YOU FIND A SOLUTION IN THE STORY? [ANALOGICAL ACTIVITY 5]

Title: Can You Find a Solution in the Story?

Subject: ______________________________________________________________

Student Group: _____________________ (#) Students _____________________

Names: _____________________________________________________________

Purpose: To discover a solution to your problem by finding the connections between your problem and a story analog.

Materials: Can you find a solution in the story? Guide Sheet
pen or pencil / typewriter or computer
Problem Text and Story Text

1. Read the problem text.
What is the problem? _________________________________________________

2. Read the story text.
What is the goal? ___________________________________________________

What resources are available? _______________________________________

What actions can be taken? _________________________________________

Are there any restrictions or constraints? _____________________________

What is the plan for solution of the problem? _________________________

What is the outcome? _______________________________________________

3. Read the problem text. Keep in mind the story text you just read as it may help you solve this problem.
What is the goal? ___________________________________________________

What resources are available? _______________________________________

What actions can be taken? _________________________________________

Are there any restrictions or constraints? _____________________________

What is the plan for solution of the problem? _________________________

What is the outcome? _______________________________________________

4. Did the story text help you think of a successful solution to the problem? ______

If yes, how? ______________________________________________________

If no, how did you think of your solution? ______________________________
APPENDIX U: PART 1 MODIFIED PROBLEM TEXT AND STORY TEXT

[ANALOGICAL ACTIVITY 5]

Problem Text: (Modified from Gick and Holyoak, 1980)

As a doctor, you must decide how to treat your patient who has a malignant stomach tumor. Unless this tumor is eliminated, your patient will not survive. Unfortunately, an operation is not possible. You have available a machine that can deliver rays to the tumor. You face a dilemma. If you use very high energy rays, the tumor would be eliminated, but these high intensity rays would also destroy too much good tissue on their route to the tumor. Less energetic rays of lower intensity would not harm the good tissue, but would also be ineffective against the tumor. How can you eliminate the tumor using the rays, but not damage the patient’s good tissue in the process?

Story Text (Modified from Gick and Holyoak, 1980)

A dictator took over and cruelly ruled a little country. He exercised his rule from his well-built fortress, which was located in the center of this little country of farms and small towns. People could reach the fortress by traveling along the multitude of roads that came from all parts of the country but ended at the fort. A good general wanted to overthrow this dictator and knew that he had an army that was strong enough to capture the fortress, if he could use the force of all his soldiers at once. From a spy, the general learned that all the roads were mined. Since the dictator too needed to use the roads, men could move down the roads cautiously in small groups. But if the general sent his entire force down a road to approach the fortress, the mines would explode. Furthermore, the dictator had sworn to destroy villages if such an attack was undertaken. The general could not follow his plan to send his soldiers all together down a road because of the risk of losing soldiers and possibly bringing harm upon the villagers.

The general cleverly changed his plan. He broke his forces into small groups of soldiers and sent these small units to all the country’s roads leading to the fortress. When all the soldiers were in place, the general ordered his men to move toward the fortress. They avoided the mines and all arrived at the fortress at the same time. The general’s used his full attack strength to attack and take control of the fortress and get rid of the dictator.

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APPENDIX V: CAN YOU FIND A SOLUTION IN THE STORY? [HYPOTHETICAL RESPONSES TO PART 1 OF ANALOGICAL ACTIVITY 5]

Title: Can You Find a Solution in the Story? [Hypothetical Responses]
Subject: Tumor treatment
Student Group: __________________ (#) Students __________________
Names: ______________________________________________________
_____________________________________________________________

Purpose: To discover a solution to your problem by finding the connections between your problem and a story analog.

Materials: Can You Find a Solution in the Story? Guide Sheet
pen or pencil / typewriter or computer
Problem Text and Story Text

1. Read the problem text. What is the problem?
The patient is sick with a cancerous tumor that must be destroyed. The effective high intensity radiation kills too many good cells but a lower intensity ray would not be effective.

2. Read the story text.
What is the goal?
use the military to take over a fort that is held by the enemy

What resources are available?
a large number of experienced soldiers

What actions can be taken?
the soldiers may be divided in any way chosen, the soldiers may move, the soldiers are capable of attacking the fort

Are there any restrictions or constraints?
An all out direct attack by the soldiers would result in too many deaths of the soldiers because the roads have mines planted along their paths.

What is the plan for solution of the problem?
If the soldiers were divided into smaller groups, each smaller group could navigate along one of the roads leading to the fort. They could avoid the mines by being very careful of where they walked and having an advance person check for mines. All would arrive at the fort at the same time and attack the fort.

What is the outcome?
The fort will be captured by the soldiers.

3. Read the problem text again. Keep in mind the story text you just read as it may help you solve this problem.
What is the goal? use the high intensity rays to get rid of the cancerous tumor

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What resources are available?
x-ray machines that can generate directed radiation of different intensities

What actions can be taken?
X-rays may be sent to the tumor. The intensity of the rays may be varied and the X-rays can be directed from multiple points.

Are there any restrictions or constraints?
The high intensity rays will kill the tumor cells, but they will also kill healthy body cells; whereas, a low intensity ray alone will not hurt good cells, but it will not breakdown tumor cells either.

What is the plan for solution of the problem?
Send low intensity rays toward the tumor from many different directions at the same time.

What is the outcome?
The tumor will be destroyed by the radiation but damage to healthy cells will be minimized.

4. Did the story text help you think of a successful solution to the problem? yes
If yes, how?
The story of the general dividing up his army into smaller units to attack from all directions suggested the strategy of using the radiation but in units of smaller intensity that are directed from all directions at the same time to attack and destroy the tumor.
If no, how did you think of your solution?
Problem Text: Water

All the farmers in the country of Hungry depend on water from their river, the Given River, which overflows during one time of the year. If farmers upstream retain too much of the overflowing water, there is not enough water left below stream for the rest of the farmers. If the farmers do not find some way to keep some of the water, their crops dry up and the water is lost into the sea downstream. Also if the farmers upstream try to keep too much of the water they face the danger of the water carrying away their fertile soil, and yet they truly want to keep as much of this water for their needs as they can. It is in the best interest of all the farmers that they find some way to share this bounty of water in a fair way. There are social pressures that also work against a too greedy farmer, and yet the pressure on the farmer to keep as much water as possible is also there because he wants bountiful crops to grow on his farm. These farmers are not rich and therefore are unable to use expensive technological devices to solve their problem. They have available the manual labor of their large families and sometimes friends. They have the usual implements for farming (e.g. shovels, ploughs, buckets etc.) in a third world country. The government is poor and does not have the money to carry out any kind of supervisory function. How do these farmers accomplish their task?

Story Text: Peanuts

In the land of Starvation, there are many poor and hungry people living together in temporary quarters to survive a time of famine with the help of the United Nations. It is difficult to get supplies to this remote region so when the food arrives it is vital that all the people share in the food that arrives and that no one is greedy and takes more than his fair share. There is great social pressure not to take more than your fair share, but the pressure of hunger is also great on the individuals to avoid starvation. If the food is shared fairly, it is likely that another shipment of food will arrive in time to keep the people from starving. Sacks of peanuts, a very nourishing food, arrived on one particular shipment. It was decided that everyone would line up in a row in family groups. The sacks were carried down the middle of the row and peanuts were poured into the hands of each person until they had all that their hands could hold. Once the hands were full, they were pushed away by the next person in line and that next person would catch peanuts in his or her hands. No one was allowed to use cups or pots to catch the peanuts, only hands were allowed. A person could receive only the one hands full of peanuts on that day. Everyone received enough food to satisfy their hunger for that day, although most of the people still wished that they could have gotten more of the peanuts because of the uncertainty of the future.
APPENDIX X: DOES A PICTURE EQUAL 1,000 WORDS? [ANALOGICAL ACTIVITY 6]

Title: Does a Picture Equal 1,000 Words?

Subject: ________________________________

Student Group: _______________________ (#) Students ______________________

Names: _____________________________________________________________

Purpose: to explore your present understanding of __________________________ through picture analogies.

Materials: pictures, pen or pencil

Guidesheet: "Does a Picture Equal 1,000 Words?"

Guide to action:

First list each ______________________________________________________.
1. ________________________________________________________________
2. ________________________________________________________________
3. ________________________________________________________________

Now students should discuss ___________________________________________

Carefully study the pictures. Based on your knowledge of ___________________, match each picture to a _____________________________________________.

Write a paragraph to accompany each picture. You should tell what the picture means to you in relationship to _________________________________.

Analysis of Picture #1 ________________________________________________

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

Analysis of Picture #2 ________________________________________________

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

Analysis of Picture #3 ________________________________________________

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

[Note: guidesheet may be modified to accommodate the number of pictures.]
APPENDIX Y: DOES A PICTURE EQUAL 1,000 WORDS? [HYPOTHETICAL RESPONSES TO PART 1 OF ANALOGICAL ACTIVITY 6]

Title: Does a Picture Equal 1,000 Words? [Hypothetical Responses]
Subject: states of matter
Student Group: ___________________ (#) Students ___________________
Names: __________________________________________________________

Purpose: to explore your present understanding of states of matter through picture analogies.

Materials: pictures, pen or pencil
Guidesheet: “Does a Picture Equal 1,000 Words?”

Guide to action:

First list each state of matter
1. solid
2. liquid
3. gas

Now students should discuss states of matter.

Carefully study the pictures. Based on your knowledge of states of matter, match each picture to a state of matter.

Write a paragraph to accompany each picture. You should tell what the picture means to you in relationship to a state of matter.

Analysis of Picture #1 Military unit picture represents a solid state of matter. The soldiers are standing at attention very close together like particles of a solid are very close together and arranged in a set pattern. The soldiers are not moving very much like particles in a solid move very little. The soldiers are not using much energy like particles in a solid have low kinetic energy.

Analysis of Picture #2 Class reunion picture represents a liquid state of matter. The people at the class reunion are farther apart than the soldiers like particles in a liquid are farther apart than in a solid. The people are free to move around in the space ribboned off for the party like particles of a liquid are free to move around and take the shape of their container. The people are using energy to move around more than the soldiers like particles of a liquid have more kinetic energy of movement than particles in a solid.

Analysis of Picture #3 Soccer game picture represents a gaseous state of matter. The soccer players are far apart like particles of a gas are farther apart. The soccer players are free to move all over the place even beyond the field but they also can come in contact with each other as well like the particles of a gas move freely all over but they also may collide with each other. The soccer players are expending much energy in running around like particles of a gas possess a lot of kinetic energy.
APPENDIX Z: DOES A HANDS-ON EXPERIENCE EQUAL 1,000 WORDS?
[ANALOGICAL ACTIVITY 7]

Title: Does a Hands-On Experience Equal 1,000 Words?

Subject: _____________________________________________________________

Student Group: ___________________ (#) Students ______________________

Names: ____________________________________________________________

Purpose: to explore your present understanding of __________________________ through hands-on experience analogies.

Materials: pictures, pen or pencil

Guidesheet: “Does a Hands-On Experience Equal 1,000 Words?”

Materials for hands-on activities

Guide to action:

First list each____________________________________________________.

1. ________________________________________________________________

2. ________________________________________________________________

3. ________________________________________________________________

Now students should discuss ________________________________________.

Do the directed hands-on activities at each lab station. Based on your knowledge of _____________________, match each hands-on activity to a characteristic of _______________________________.

Write a paragraph to accompany each set of hands-on experiences. You should tell what the hands-on experiences mean to you in relationship to: _______________

Analysis of hands-on experiences # 1

Analysis of hands-on experiences # 2

Analysis of hands-on experiences # 3

[Note guidesheet can be modified to fit the number of lab stations with hands-on activities]
APPENDIX AA: DOES A HANDS-ON EXPERIENCE EQUAL 1,000 WORDS?
[HYPOTHETICAL RESPONSES TO ANALOGICAL ACTIVITY 7]

Title: Does a Hands-on Experience Equal 1,000 Words? [Hypothetical Responses]
Subject: Invertebrate Phyla
Student Group: ____________________ (#) Students ____________________
Names: ____________________________________________________________

Purpose: to explore your present understanding of Invertebrate Phyla through hands-on experience analogies.

Materials: pictures, pen or pencil
Guidesheet: "Does a Hands-On Experience Equal 1,000 Words?"
Materials for hands-on activities

Guide to action:
First list each Invertebrate Phylum.
1. Porifera
2. Cnidaria
3. Platyhelminthes
4. Nematoda
5. Annelida
6. Mollusca
7. Arthropoda
8. Echinodermata

Now students should discuss invertebrate phyla.

Do the directed hands-on activities at each lab station. Based on your knowledge of invertebrate phyla, match each hands-on activity to a characteristic of organisms in that invertebrate phylum.
Write a paragraph to accompany each set of hands-on experiences. You should tell what the hands-on experiences mean to you in relationship to the targeted invertebrate phylum.

Analysis of hands-on experiences #1 Porifera
The synthetic foam with holes represents the holes in the sponges of Phylum Porifera. The Phylum name means "hole bearer." The foam soaks up the water like water moves into the sponge. When the water is squeezed out the top of the foam it is like water coming out a big hole at the top of a sponge.

Analysis of hands-on experiences #2 Cnidaria
The paper cup represents the hollow insides of organisms in Phylum Cnidaria. The two cups together represent the two tissue layers. The string sparklers attached to the cup represent tentacles. The tacks attached to the sparklers represent the stinging barbs called nematocysts. The phylum name is derived from the name of the cells (cnidocytes) that hold these barbs.
Analysis of hands-on experiences #3  _Platyhelminthes_
The long flattened clay shape represents the flat worm body of Phylum _Platyhelminthes_ which means “flat worm.” The one hole in the clay represents the one opening for food to go in and waste to go out. Cutting the worm lengthwise suggests bilateral symmetry.

Analysis of hands-on experiences #4  _Nematoda_
The skinny round clay shape represents the round unsegmented body form of nematodes. The cut threads signify the shape of these worms and the meaning of the phylum name of _Nematoda_. The two holes in the clay signify two openings – one for the mouth and one for the anus.

Analysis of hands-on experiences #5  _Annelida_
The long round clay with grooves cut in it suggests the segmented round worm body form of annelids. The ring like grooves signify the meaning of the phylum name _Annelida_. The holes in the front and the back signify a mouth and an anus for these worms.

Analysis of hands-on experiences #6  _Mollusca_
The foam signifies the soft body of molluscs and also the phylum name meaning. The shells signify the shells made by many molluscs. The cellophane over the foam represents the mantle which makes the shell of molluscs that have shells.

Analysis of hands-on experiences #7  _Arthropoda_
The corks signify the hard body exoskeleton of arthropods. When two corks are put together, this represents the cephalothorax and abdomen of spiders and crustaceans. When three corks are put together, this represents the head-thorax-abdomen of insects. The wires bent many times represent the segmented appendages and the meaning of the phylum name _Arthropoda_—“jointed feet.”

Analysis of hands-on experiences #8  _Echinodermata_
The cut out star represents the star shape of many echinoderms and the pentaradial (5-part round) symmetry. The star placed in water suggests that echinoderms live in the sea. It also signifies the water vascular system of echinoderms. The tooth picks stuck in the star represent the “spiny skin” and the meaning of the phylum name _Echinodermata_.

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APPENDIX BB: CAN YOU SAY IT THROUGH PICTURES? [ANALOGICAL ACTIVITY 8]

Title: Can You Say It Through Pictures?

Subject: _____________________________________________________________

Student Group: ______________________ (#) Students ______________________

Names: _____________________________________________________________

Purpose: To rely on visual thinking to construct a collage of pictorial analogies that represent your knowledge of __________________________________________.

Materials: Collage materials such as pictures, photos, newspapers, drawings etc. scissors, markers, paints, colors, pens, pencils, poster board, manila folders, construction paper

Guidesheet: "Can You Say It Through Pictures?"

Guide to Action:

1. Discussion of Knowledge of Target Subject

Student groups should discuss their knowledge of ____________________________ You should list the complete information that you plan to convey through your collage. List information or concepts:

1. _________________________________________________________________
2. _________________________________________________________________
3. _________________________________________________________________
4. _________________________________________________________________
5. _________________________________________________________________
6. _________________________________________________________________
7. _________________________________________________________________
8. _________________________________________________________________
9. _________________________________________________________________

2. Brainstorming for Picture Analogs

Now you should decide on pictures that could represent your information or concepts by way of analogy. For example, if you want to represent an eye working, you might think of a picture of a camera. Your group may come up with more than one idea of a picture that could be the analog for the target. Name pictures that could represent the concept. (Place next to number that corresponds to concepts listed in step 1.)

1. _________________________________________________________________
2. _________________________________________________________________
3. _________________________________________________________________
4. _________________________________________________________________
5. _________________________________________________________________
6. _________________________________________________________________
7. _________________________________________________________________
8. _________________________________________________________________
9. _________________________________________________________________

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You may draw your own pictures. You may search through magazines, photos, newspapers, advertisements etc. for pictures that could represent one item of information through analogy. Try to find at least one picture that can symbolically represent each listed concept. Remember these pictures are not supposed to be literal representations, so for our example, you would not choose a picture of an eye to place on the poster. Instead, you might select a picture of some kind of camera.

4. Assembly of collage.
It is time to make your collage. Plan out the whole project before you begin to apply glue. You want your product to be pleasing to the eye, as well as challenging to the mind. Feel free to be creative. The size of your project is limited to ________________, but you may choose any shape, color, and design you wish. This activity requires your subjective interpretation of. This means that there will be many different but effective ways to carry out the project. Let the artist in you unite with the scientist for an exciting exploration.

5. Key to Collage
You must attach a key to your collage. The key should identify each picture and explain what it represents. For example, “A camera captures pictures like an eye collects visual images.” This key is required because not all viewers will be able to guess the entire meaning of the collage, either because of incomplete knowledge of the subject or perhaps simply a failure to make the interpretive connection that you intend.

Subject of Collage

Key to Collage - include Symbolic Picture with its Target Concept
1. ____________________________________________________________
2. ____________________________________________________________
3. ____________________________________________________________
4. ____________________________________________________________
5. ____________________________________________________________
6. ____________________________________________________________
7. ____________________________________________________________
8. ____________________________________________________________
9. ____________________________________________________________

6. Share Collage with Class
Share your collage with the class. First, without the key, let students try to uncover the significance of the pictures in your collage. Later, you may explain the undeciphered pictures.
APPENDIX CC: CAN YOU SAY IT THROUGH PICTURES? [HYPOTHETICAL RESPONSES TO ANALOGICAL ACTIVITY 8]

Title: Can You Say It Through Pictures? [Hypothetical Response]
Subject: Digestive System
Student Group: ______________________ # of Students ______________________
Names: ___________________________________________________________________

Purpose: To rely on visual thinking to construct a collage of pictorial analogies that represent your knowledge of the digestive system.

Materials: Collage materials such as pictures, photos, newspapers, drawings etc.
scissors, markers, paints, colors, pens, pencils, poster board, manila folders, construction paper
Guidesheet: "Can You Say It Through Pictures?"

Guide to Action:
1. Student groups should discuss their knowledge of the digestive system. You should list the information that you plan to convey through your collage.

List information or concepts:
Digestive system consists of the following parts and functions:
1. mouth with tongue and teeth - cuts, tears, smashes, and crushes
2. esophagus moves food along to stomach
3. mucus protects the digestive organs
4. enzymes from organs breakdown food into smaller molecules
5. stomach uses acid to help digest food
6. pancreas adds enzymes and baking soda to small intestines
7. gall bladder adds bile to help digest fats
8. digested molecules are absorbed into blood stream
9. colon reabsorbs excess water and compacts solid waste
10. waste is ejected out

2. Brainstorming for Picture Analogs
Now you should decide on pictures that could represent your information or concepts by way of analogy. For example, if you want to represent an eye working, you might think of a picture of a camera. Your group may come up with more than one idea of a picture that could be the analog for the target. Name pictures that could represent the concept

List of pictures:
knife and hammer gasoline tank with cap train in a tunnel gasoline scissors
salt and pepper shakers set of sieves burnt holes in a fabric sponge garbage compactor soap trash bag

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   You may draw your own pictures. You may search through magazines, photos, newspapers, advertisements etc. for pictures that could represent one item of information through analogy. Try to find at least one picture that can symbolically represent each listed concept. Remember these pictures are not supposed to be literal representations, so for our example, you would not choose a picture of an eye to place on the poster. Instead, you might select a picture of some kind of camera.

4. You may now assemble your collage. Plan out the whole project before you begin to apply glue. You want your product to be pleasing to the eye, as well as challenging to the mind. Feel free to be creative. The size of your project is limited to one poster board, but you may choose any shape, color, and design you wish. This activity requires your subjective interpretation of the digestive system. This means that there will be many different but effective ways to carry out the project. Let the artist in you unite with the scientist for an exciting exploration.

5. You must attach a key to your collage. The key should identify each picture and explain what it represents. For example, "A camera captures pictures like an eye collects visual images". This key is required because not all viewers will be able to discern the entire meaning of the collage, either because of a lesser knowledge of the subject or perhaps a failure to make the interpretive connection that you intend.

6. Share your collage with the class. First, without the key, let them try to uncover the significance of the pictures in your collage. Later, you may explain the undeciphered pictures.

Collage of the Digestive System
Key: Symbolic Picture - Meaning
1. Knife and hammer represent the teeth in their role of cutting, tearing, and grinding
2. Cap on the gasoline tank suggests the closed mouth that needs to be opened in order to take in fuel in the form of food
3. Train in a tunnel that connects two sides of a mountain is like the esophagus that transports food from the mouth to the stomach.
4. Vaseline suggests the slippery and moist mucus that helps to lubricate the digestive tract
5. Scissors symbolize the enzymes that split up the food molecules like a scissors can cut paper into smaller and smaller pieces.
6. Salt and pepper shakers are used to represent the pancreas ready to add different enzymes to the small intestine to aid digestion.
7. Soap is used to represent the bile that helps to break up fat into smaller globules.
8. Burned holes in a fabric allude to the powerful action of the acid produced by the stomach.
9. Set of sieves refers to the different size molecules produced through digestion and the final filtering through to the bloodstream.
10. Sponge represents the absorption of water by the colon. It could also allude to absorption of food molecules in the small intestines.
11. Garbage compactor targets the compaction of waste in the large intestine.
12. Trash bag is used to suggest the elimination of waste by the digestive tract.
APPENDIX DD: STUDENT PERCEPTIONS SURVEY

Student Name: ______________________________________________________
Activity: ___________________________________________________________
Date(s) of Activity: ___________________________________________________
Date of Evaluation ____________________________________________________

Please answer these questions honestly. Positive, neutral, and negative comments will all provide useful information for improving this activity.

[Note: Students used the following Section 1 for evaluation of Pilots and Activity I – II]

1. Circle the adjective/s in each grouping that you believe apply to your experience with this activity.
   A. too easy easy comfortable hard very hard
   B. boring interesting OK exciting ordinary
   C. clear confusing complex simple complicated
   D. restrictive open-ended well structured tedious creative
   E. fun routine novel dull unusual

[Note: Students used the following Section 1 for evaluation of Activities III – VIII]

1. Circle the adjective/s in each grouping that you believe apply to your experience with this activity.
   A. easy very hard comfortable too easy hard
   B. boring interesting OK exciting ordinary
   C. clear confusing complex simple understandable
   D. restrictive open-ended well-structured tedious creative
   E. fun typical extraordinary dull unusual

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2. Circle the types of activities that you engaged in during this activity:

<table>
<thead>
<tr>
<th>Researching</th>
<th>Estimating</th>
<th>Thinking</th>
<th>Feeling</th>
<th>Communicating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculating</td>
<td>Evaluating</td>
<td>Discussing</td>
<td>Problem solving</td>
<td></td>
</tr>
<tr>
<td>Categorizing</td>
<td>Analogizing</td>
<td>Fighting</td>
<td>Choosing</td>
<td>Observing</td>
</tr>
<tr>
<td>Hypothesizing</td>
<td>Creating</td>
<td>Drawing</td>
<td>Experimenting</td>
<td></td>
</tr>
<tr>
<td>Learning</td>
<td>Remembering</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Using a rating system from 1-5, rate the following aspects of this activity.

| 1 = bad | 2 = poor | 3 = okay | 4 = good | 5 = excellent |

Please feel free to make suggestions for improvement.

First Record: Number of students in group ____________

Time spent on activity__________________________

Ages of group members__________________________

_____ A. Number of students in groups

_____ B. Method of selection of groups

_____ C. Time involved in activity

_____ D. Directions for activity

_____ E. Teacher input

_____ F. Age level for activity

_____ G. Motivation

_____ H. Enjoyment

_____ I. Challenge

_____ J. Knowledge Gain

4. Please make any additional comments that you may have regarding this activity. Any comments or suggestions are appreciated. Write comments on the back of this page.
APPENDIX EE: INITIAL INTERVIEW QUESTIONS

1. Describe yourself.
2. How do you learn something?
3. What do you see yourself doing in the future?
5. Describe your family.
6. Do you see yourself as a leader or a follower?
7. What did you think about the simile activity?
8. Did the simile activity help?
9. How would you describe your thinking during the simile activity?
10. Tell me about your group. How does it work?
11. Did you group change your mind about anything?
12. Did you find it easier to find similarities or dissimilarities?
13. How did you make those similarity connections?
APPENDIX FF: FINAL INTERVIEW QUESTIONS

1. What do you think was the chief goal of the special activities we did this year?
2. Overall, how do you view these activities as compared to traditional activities?
3. What was different about the activities?
4. How well did these activities fit your learning style?
5. Did you pick up strategies for learning science from engaging in these activities?
6. Give your metaphor for teacher's role in these activities.
7. If asked to choose a metaphor for your role in these activities, what would it be?
8. Think back to the beginning of the year, to what you learned about the cell. If I said "A cell is like a city," what city roles would you assign to each organelle?
9. "Cell is like a city," what city roles would you assign to each of the organelles?
10. Any suggestions for improvements?
11. Any praises?
APPENDIX GG: SMILE RUBRIC AND RATING SCALE

SMILE is an evaluation instrument that helps guide judgement of a student's level of analogical development as expressed during his or her participation in specific analogical activities. The letters SMILE signify:

S - Selection of analog
M - Mapping of analog and target
I - Inference from the analogy
L - Level of expressed analogical development
E - Evaluation of analogy

The rating scale ranges from 0 to 5 for each step of analogizing: (S) selection, (M) mapping, (I) inference, and (E) evaluation. The rating numbers are indicators of the student's working level for each step in analogizing. The rating for (L) level indicates the student's level of expressed analogical development. It is calculated as the average of the ratings for the four steps in analogizing. This scale is intended to assist evaluation of a student's analogical development. It requires qualitative judgement of a justifiable rating of the student's performance for each step in analogizing. The scale identifies specific criteria for student ratings from 0 to 5 for each of the four steps in analogizing.

Selection

0 = teacher selects analog - student does not receive
1 = teacher selects analog - student receives
2 = teacher selects analogs - student(s) choose from teacher selections
3 = teacher and students brainstorm together to select analog
4 = student groups brainstorm together to select analog
5 = student individually generates and selects analog
Mapping

0 = teacher maps similarities and differences of analog and target - student does not receive

1 = teacher maps similarities and differences of analog and target - student tracks this analysis

2 = teacher uses guided strategy with student participation in mapping of similarities and differences of analog and target

3 = student groups independently map similarities of analog and target

4 = student groups independently map similarities and differences of analog and target

5 = individual student independently maps similarities and differences of analog and target

Inference

0 = teacher makes inferences from analogy - student does not receive

1 = teacher makes inferences from analogy - students track this analysis

2 = teacher used guided strategy with student participation in making inferences from analogy

3 = student group makes inferences from analogy with teacher input

4 = student group independently makes inferences from analogy

5 = individual student independently makes inferences from analogy

Evaluation

0 = teacher judges analogy for biology learning potential - student does not receive

1 = teacher judges analogy for biology learning potential - student does receive

2 = class with teacher guidance judges analogy for biology learning potential

3 = student group with hints from teacher judge analogy for biology learning potential

4 = student group independently judges analogy for biology learning potential

5 = individual student independently judges analogy for biology learning potential
Calculation of the average of the student's ratings on the four steps of analogizing yields a rating for the student's expressed level of analogical development during a particular analogical learning activity. Calculation of an average of L ratings for a student during a specified time period could yield a number that would roughly represent a student's expressed level of analogical development.

**Level of Expressed Analogical Development**

0 = nonparticipant

1 = teacher dependent when analogizing

2 = teacher and class dependent when analogizing

3 = teacher and peer group dependent when analogizing

4 = peer group dependent when analogizing

5 = individual independent when analogizing

This evaluation instrument was developed by Hackney and Wandersee in 1996 to assist in the analysis of student development of analogical thought as students participate in a year-long sequence of analogical activities that target biology. The SMILE ratings are suggestive of a student's ability to analogize. Note that the rating scale numbers do not avoid the subjective qualitative judgement of the evaluator for they are generated through such judgement. The SMILE rubric and criteria based rating scale provide some helpful guidelines for making such qualitative judgements. These judgements must still be grounded in analysis of the data of student analogical artifacts (e.g., taped group interactions, written responses on analogy guidesheets, products of analogical activities) and teacher observations and field notes.
Title: Can You Make the Connection?
Name: Julia
Subject: Respiration

1. Describe or define the scientific concept of the processes that release chemical energy for use by the cell.

2. What do you know about fire (the familiar analog)?
   burn, chemical change, need oxygen, releases heat (energy, light energy) -> carbon + H2O, need fuel

3. Fill in this chart listing the similarities between the target scientific concept and the familiar analog.

<table>
<thead>
<tr>
<th>Shared Characteristics: How are the analog and the target alike?</th>
<th>Analog: fire of life</th>
<th>Target: respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>chemical change</td>
<td>chemical change</td>
<td>chemical change</td>
</tr>
<tr>
<td>need fuel (ex. Wood)</td>
<td>need fuel (food)</td>
<td>need O2</td>
</tr>
<tr>
<td>release energy</td>
<td>release energy</td>
<td>release energy</td>
</tr>
<tr>
<td>water released</td>
<td>water released</td>
<td>water released</td>
</tr>
</tbody>
</table>

4. Explain in your own words your understanding of the scientific concept based on the analogy that respiration is like the fire of life.
   Respiration and fire of life are chemical changes that need fuel and oxygen to release energy + water

5. List ways in which the targeted scientific concept and the analog differ from one another?

<table>
<thead>
<tr>
<th>Unshared Characteristics: How are the analog and the target not alike?</th>
<th>Analog: fire</th>
<th>Target: respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>light</td>
<td>no light ATP energy is stored</td>
</tr>
<tr>
<td>rapid process</td>
<td>rapid process</td>
<td>slow process</td>
</tr>
<tr>
<td>C6H12O6 + O2 -&gt; C + H2O</td>
<td>C6H12O6 + O2 -&gt; H2O + CO2</td>
<td>series of chemical reaction</td>
</tr>
<tr>
<td>chemical reaction</td>
<td>chemical reaction</td>
<td>in cells of organism</td>
</tr>
<tr>
<td>outside living things</td>
<td>outside living things</td>
<td>in cells of organism</td>
</tr>
</tbody>
</table>

6. Can you now add other important characteristics to your explanation of respiration?
   Fire of life and respiration are different in that fire use light, have a rapid process, chemical reaction and is burned outside of living things. Respiration has no light, have a slow process, series of chemical reactions and in cells of organisms

7. Does this analogy help you to understand the scientific concept of respiration better? Explain.
   Yes, it compares two things alike and at the same time different. You can grasp a better concept of the subject.
These notes explain Julia's SMILE scores. In this class, the students helped to map the similarities and differences by brainstorming ideas first about fire and then about respiration. The mapping was accomplished with teacher and students' participation. Julie seemed to have a reasonable grasp of respiration except that her equation for respiration left off the energy produced. Equations may simply pose a different level of complexity for students, because Julia did not mention the release of energy and water in her written explanation of the similarities between fire and respiration. The different carbon products (carbon and carbon dioxide) for fire and respiration were identified in listing differences between the two processes.

In the judgement of this researcher, Julia earned the following SMILE scores for this analogical activity: (a) 1 for (S) selection because the teacher selected the analog of fire for the target of respiration and the student received; 2 for (M) mapping because the teacher used a guided strategy with Julia participating in mapping of similarities and differences of analog and target; (c) 2 for (I) inference because the teacher used a guided strategy with active student participation in making inferences from the analogy; (d) 2 for (E) evaluation because the class with teacher guidance judged the analogy for biological learning potential; and (e) 2 for (L) level of expressed analogical development. This SMILE level was calculated by adding together the four scores and dividing by 4. This resulted in a score of 1.75 that rounds to 2. This level of expressed analogical development indicates that the student was teacher and class dependent when analogizing.
Title: Can You Make the Connections?
Name: Trisha
Subject: Respiration

1. Describe or define the scientific concept of respiration. Process that releases chemical energy produced by the cell.

2. What do you know about fire?
   - Hot (heat), destruction, chaos, need oxygen, need match (activation energy), need right conditions (dryness), need fuel, gives out light energy, sound - crackling.

3. Fill in this chart listing the similarities between the target scientific concept and the familiar analog.

<table>
<thead>
<tr>
<th>Shared Characteristics: How are the analog and the target alike?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog: fire</td>
</tr>
<tr>
<td>chemical change</td>
</tr>
<tr>
<td>Oxygen</td>
</tr>
<tr>
<td>fuel (fossil)</td>
</tr>
<tr>
<td>release heat energy</td>
</tr>
<tr>
<td>releases water</td>
</tr>
</tbody>
</table>

4. Explain in your own words your understanding of the scientific concept based on the analogy that respiration is like fire.
   - They both need air to breathe, they need fuel, they both need activation energy, releases some form of carbon, releases heat energy and releases water. It is a chemical reaction.

5. List ways in which the targeted scientific concept and the analog differ from one another.

<table>
<thead>
<tr>
<th>Unshared Characteristics: How are the analog and the target not alike?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog: fire</td>
</tr>
<tr>
<td>Releases some form of C</td>
</tr>
<tr>
<td>Light energy</td>
</tr>
<tr>
<td>Uncontrolled</td>
</tr>
<tr>
<td>1 step RX</td>
</tr>
</tbody>
</table>

6. Can you now add other important characteristics to your explanation of respiration?
   - Controlled rx, CO2 heat and chemical energy ATP many RX _ C6H12O6 + O2 -> H2O + CO2 + energy

7. Does this analogy help you to understand the scientific concept of fire better? Yes. Explain.
These notes explain Trisha's SMILE scores. This activity was a class activity in which the teacher took a highly didactic role. The students in this class needed to improve their understanding of respiration. Trisha, a hard working average student, at first appeared to have kept up with the class and wrote down most of the points raised. The problem was that she failed to give an explanation for her “yes” that the fire analogy helped her to understand the scientific concept. Even more problematic was her apparent confusion because she listed the scientific concept that she was trying to understand as fire not respiration. Fire is a scientific concept too, so Trisha's confusion of the analog and the target was understandable. This just demonstrates that average students may need more reinforcement of the concept of analog and target. Trisha continued to use the word breath and mentioned air rather than oxygen at times.

Trisha earned the following SMILE scores for this analogical activity: (a) 1 for (S) selection because Trisha received the teacher-selected analog; (b) 1 for (M) mapping because Trisha tracked the teacher's mapping of similarities and differences between the analog and target; (c) 1 for (I) inference because the teacher made inferences from the analogy and Trisha tracked this analysis; 0 for (E) evaluation because the teacher judged this analogy for biology learning potential but the student did not receive; and 1 for (L) level of expressed analogical development. This SMILE level was calculated by adding together the four scores and dividing by 4. The score of .75 rounded to 1. This level of expressed analogical development indicates that Trisha was teacher dependent when analogizing.
VITA

Marcella Wichser Hackney was born on September 29, 1947 in New Orleans, Louisiana. She was the third girl and middle sibling of five children born to Dr. Celeste G. Wichser and Eileen Leach Wichser. She married Dr. William P. Hackney on December 28, 1968. She graduated with her bachelor of science degree in science education from Louisiana State University in New Orleans in the spring of 1969. Marcella taught chemistry and Honors Biology I during the 1969-70 school year at Dominican High School in New Orleans. After this brief teaching experience, Marcella directed her full efforts for the next decade towards her family. The Hackney family quickly grew to six with the births of Amy, Philip, Madeleine, and Ryan in the space of five years.

Marcella, under the guidance of Dr. J. Michael Fitzsimons, professor of Zoology and Physiology, earned the degree of Master of Natural Science at Louisiana State University in the fall of 1984. This master’s program provided her with a solid science background so that she was prepared to return to the science classroom. She returned to teach first at an academic magnet middle school for 1985-86, then to an academic magnet high school from 1986-98. At the middle school she taught life science, comparative anatomy, and microbiology. At the high school, she taught all levels of biology, oceanography, and environmental science. She was awarded the National Association of Biology Teachers’ 1990 Outstanding Biology Teacher (OBTA) award for Louisiana. She served as science department chair for three years.

During her 1991-92 sabbatical, she began her work in a doctoral program in curriculum and instruction at Louisiana State University. Under the guidance of her major professor, Dr. James H. Wandersee of the Department of Curriculum and Instruction, Marcella gained a theoretical and practical basis for the focus of her
doctoral work— the use of analogies for improving biology learning of high school students. With Wandersee, she presented twice at the National Association of Biology Teacher national conventions and co-authored a related article in Adaptation, the journal of the New York Biology Teachers Association. She earned the degree of Doctor of Philosophy in May, 1999.
Candidate:  Marcella Wichser Hackney

Major Field:  Curriculum and Instruction

Title of Dissertation:  High School Biology Students' Participation in a Year-Long Sequence of Analogical Activities: The Relationship of Development of Analogical Thought to Student Learning and Classroom Interactions

Approved:

[Signatures]

Examiners:

Michael Fitzgerald
Catherine Cuttino
Peter Morgan
W. Lamar Flinn

Date of Examination:
March 5, 1999