The Rhyming Peg Mnemonic Device Applied to Learning the Mohs Scale of Hardness

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ABSTRACT

The rhyming peg mnemonic device, appropriate for learning an ordered set, is used to teach Mohs hardness scale. Students begin by learning the "pegs" – a set of words, each rhyming with a number from one to ten, to which each mineral will be linked. Students then study, interpret, make additional connections with, personalize, and visualize a set of illustrations that associates each mineral with its peg word, number, and attributes. This technique is effective because it is meaningful, helps students organize information, provides many associations, uses the creative thinking skill of visualization of images, and focuses student attention. The following poem contains couplets describing each of the ten mnemonic drawings.

See the sweating, slipping sun,
Rating **talc** as number one.
Buy a gypsy's **gypsum** shoe,
Or a scratched-up pair of two.
Trim the cave-rock **calcite** tree,
Always branching into three.
Shut the bulging **fluorite** door,
That the toothpaste labels "four."
Fear the crossed-bone killer hive
With an **appetite** for five!
Orthoclase-tipped music sticks,
Beat a rhythm pounding six.
Seven jars, all cloudy **quartz**
Hold crystals from heaven's parts
Then a heavy **topaz** skate,
Does a looping figure eight.
Sanded off **corundum** vine,
Had red ruby roses nine.
But the pecking **diamond** hen,
Gets a perfect score of "10"!

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A mnemonic device is a memory tool that allows the brain to remember information that would otherwise be difficult to recall. The basic principle of mnemonics involves using as many different stimuli to encode information as possible so that many different parts of the brain are involved in storing the event, thereby creating multiple pathways to retrieving the information.

Human brains evolved to code and interpret complex stimuli involving the five senses, spatial positions, emotions, and language. All these are used daily in modeling our sophisticated world and are stored effectively in memory. Unfortunately, some important geoscience information, such as the Mohs hardness scale, is presented to students as a colorless printed table to be memorized for future application in mineral identification. Although language is one of the most essential evolutionary human features, it is only one way humans learn and encode memories. This article will focus on applying effective mnemonic devices to learning important tabular information using the example of the Mohs scale for determining mineral scratch-hardness, one of the most useful properties in mineral identification.

MOHS SCALE OF HARDNESS

The hardness of a mineral is a measure of how tightly the atoms are held together within it. There are several tests for hardness that determine somewhat different properties. The Mohs scale, devised by German mineralogist Friedrich Mohs (1825), measures the scratch or abrasion resistance of a specimen compared to a standard set of common minerals. See Table 1 for the Mohs scale. Information on Friedrich Mohs and his other important contributions to mineralogy can be found in Staples (1964). If the point of a mineral of known hardness scratches a smooth, clean face of a specimen, the specimen is ranked as softer. By comparing the results of several scratch tests, the relative hardness of a specimen can be determined. Additionally, other common materials can also be used to gauge a specimen's hardness. These are also shown in Table 1.

Several factors contribute to the hardness of a mineral, particularly bond strength, and bond density, the number of bonds per unit volume in the structure. Bond density is important because the linkage of atoms across planar regions may be weak owing to an uneven distribution of bonds within the structure. Covalent bonds are very strong because atoms achieve attachment through electron sharing. Diamond, the hardest naturally occurring substance, has a three-dimensional covalently bonded structure. Ionic bonds are strong owing to the attraction of a positively charged electron-donor cation to its neighboring negatively charged electron-recipient anion. Smaller and more highly charged cations typically produce stronger bonds than larger or lower-charged cations. Metallic bonds occur when the outer shell of electrons is stripped, leaving positive ions closely packed together surrounded by electrons that hold the atoms together. In general, metallic bonds result in tough, ductile, plastic materials whereas covalently bonded and ionicly bonded substances are brittle. However, the hardness of metallic bonds varies over a wide range. Weak van der Waals bonds form between molecules that have a nonsymmetrical distribution of charge. The negative part of one molecule is attracted to the positive part of another, forming a weak bond. Talc, one of the softest minerals, exhibits van der Waals bonding between more tightly-bonded layers in its structure.

Bond density also affects mineral hardness, much in the same way that the number and arrangement of pieces of tape on a package determines the security of its wrapping. Mohs hardness depends only on the

Mineral	Mohs Hardness	Mohs Hardness of Common Items	Hardness of Minerals Knoop Indentation Test (kg/mm^2)*	Hardness of Minerals Vickers Hardness Test with 50 g load$^+$
Talc	1		N/A	47
Gypsum	2	~2.2 fingernail	32	60
Calcite	3	~3.2 copper penny	135	105-136
Fluorite	4		163	175-200
Apatite	5	~5.1 pocketknife ~5.5 glass plate	360-493**	
Orthoclase	6	~6.5 steel needle	560	714
Quartz	7	~7.0 streak plate	710-790**	1103-1260
Topaz	8		1250	1648
Corundum	9		1635	2085
Diamond	10		8000-8500**	

Table 1. Mohs hardness scale for minerals and common items with comparison values from the Knoop indentation test. * Data taken from Knoop, Peters, and Emerson, 1939 ** Variation owing to orientation of test surfaces +Data taken from Taylor, 1949

resistance that a smooth surface offers to scratching, i.e., the resistance of a crystal structure to stress and an expression of the structure's weakest bonding. This resistance may be related to different interionic distances and valences when more than one cation is present and the uneven distribution of bonds. Because of the complexity of interatomic interactions and geometries of structure, the hardness of a mineral cannot always be easily predicted. Additionally, hardness may vary depending on the direction of applied stress. Both kyanite and calcite show significant differences in hardness depending on direction of scratching, most other materials do not show significant differences. For example, kyanite varies with H = 7 across the width of the crystal, but H = 5 parallel to the crystal length. The structure of chains of Al-O octahedra paralleling the length of the crystal explains these differences in hardness.

Mineral hardness is a diagnostic characteristic that aids in mineral identification. It can be a useful attribute in an expert system as described by Miller and Manns (1997). Hardness is a property that makes minerals valuable in everyday life. Dowse (2000) lists some common minerals and their industrial applications owing to hardness. The simplicity and portability of the Mohs hardness test makes it especially useful for identification of minerals in the field. In particular, it facilitates the rapid differentiation of common colorless crystals such as calcite or quartz for discriminating "soft" rocks such as carbonates or sulfates from "hard" rocks composed primarily of silicates.

The Mohs scale is not a linear scale: each increment of one on the scale does not indicate a proportional increase in hardness. For instance, the progression from calcite to fluorite represents an increase in hardness of about twenty percent, whereas the progression from corundum to diamond reflects an increase of almost four hundred percent.

In order to determine absolute mineral hardnesses, several other tests that measure the resistance of a surface to indentation under a steadily applied stress have been devised. The Vickers hardness test uses a square-based diamond pyramid tip that is pressed into the material. The diagonal of the square impression is then measured (along with two other parameters because impressions often bulge into barrel shapes) to gauge the area impressed. Hardness, expressed as kg/mm^2, is the average pressure acting over the area of the indentation and is determined by dividing the load by the surface area of the impression (Brace, 1960). Taylor (1949) discusses the correlation between the Vickers scale and Mohs hardness scale. The Knoop hardness test (Winchell, 1945) uses an elongate diamond pyramid tip as the indenter and smaller loads.

Because indentation hardness techniques require large expensive loading machines, high-powered microscopes, and time-consuming specimen preparation, these methods are usually associated with engineering materials laboratories. Geology students in most public school or college settings are more often asked to memorize and apply the Mohs Scale in mineral identification because of its diagnostic utility, accessibility, and low cost. This paper will explore effective ways of committing the scale to memory.

HOW MEMORIES WORK

Carter (1998) explains the process of how memories are produced in the brain. "Memories are groups of neurons that fire together in the same pattern each time they are activated" (p. 160). The links between individual neurons that connect them as a single memory are formed as the stimulus is first encountered, then strengthened as subsequent stimuli (another encounter, rehearsal or review, or replay during sleep) cause them to fire again. If they fire together enough times, they become permanently bonded, so that when one fires, the other automatically fires. Thoughts, ideas, sensory perceptions, and feelings are all represented in the brain as different patterns of firing neurons. The human brain has almost limitless capacity for memory; the main problem is retrieval of stored information. The more numerous or the stronger the connections made between memories, the easier they are to retrieve, or "remember".

BASIC PRINCIPLES OF MNEMONICS

Higbee (1996) describes five basic principles on which virtually all learning and memory are based: meaningfulness, organization, association, visualization, and attention. These will be discussed below and applied to learning the Mohs Scale of Hardness.

MEANINGFULNESS

The meaningfulness of information to the learner determines the ease with which material is learned. For example, an early study by Lyon (1914) showed people memorized meaningful sets of information more rapidly: a list of 200 nonsense syllables took one and a half hours, a 200-word prose passage took less than a half hour, and 200 words of poetry took only ten minutes. Familiarity, rhyming, and patterns contribute to meaningfulness. The more familiar a person is with a subject, the easier it is for that person to understand, make associations, and remember information about that subject. Rhyme can be used to impose meaning on material that is not inherently meaningful, as when children memorize the alphabet by singing a song, or remember a grammar rule, "i before e, except after c." Finding an underlying pattern, rule, or principle in the material will make the learning task easier also.

Mineral names denote mineral composition, structure, properties, locality, or commemorate a scientist working in the field; there is no relationship between the mineral name and its position on the hardness scale. To a student who is a novice in earth science, the hardness scale initially represents a mostly meaningless list of words. A student with prior interest in minerals or gems may recognize some terms. However, a student familiar with mineral structures may be able to see the underlying principle of bond strength, thereby connecting weak van der Waals bonding between talc layers with the mineral's extreme softness and covalently bonded carbon atoms with that mineral's superior hardness.

ORGANIZATION

Material in a person's long-term memory is organized so that one does not need to search every stored idea to locate information. Research (Folarin, 1981; Strand, 1974; Masson and McDaniel, 1981) shows that presentation of information in organized categories assists students in learning material. In fact, people who merely organized the information remembered it as well as those who were instructed to study and learn the material. Organization is valuable because it can make material more meaningful and can help a person "chunk" information. Because short-term memory holds only about seven pieces of information (Miller, 1956), in contrast to the almost infinite capacity of long term memory, grouping of information into categories or chunks can, in effect, expand its capacity.

Minerals of the Mohs Scale of Hardness can be organized according to structure and bond type. The hardest minerals tend to have tightly bonded structures with smaller, more highly charged cations (carbon and aluminum) and more covalent bonding. Silicate minerals with framework structures follow. Softer minerals are composed of larger cations held in ionic bonds to larger anions or phosphate, carbonate, or sulfate groups. The softest minerals (gypsum and talc) have layered structures and weaker bonds, in particular, van der Waals bonding in talc.

ASSOCIATION

Making a connection between something you want to remember and something you already know allows tagging of the new information for easy retrieval. Associating new information with yourself or events in your personal life has been shown to be particularly effective (Baddeley, Lewis, and Nimmo-Smith, 1978; Keenan, Brown, and Potts, 1986). Association helps memory by making information more meaningful. The more a person knows about a topic, the more connections he/she can make. The greater the number of connections to a fact in memory, the greater the number of pathways a person can make to that information. There is evidence that information is represented in memory as a network of associations among concepts, even if these multiple associations were not purposely made at the time the information was learned (Anderson, 1983).

The set of drawings that are later presented as a mnemonic device for learning the Mohs Hardness Scale contain many extra associations detailed in Table 2. Having the student personalize these associations by handling mineral specimens or recalling experiences with cave formations, sandpaper, plaster, or gems will help the student make personal connections.

VISUALIZATION

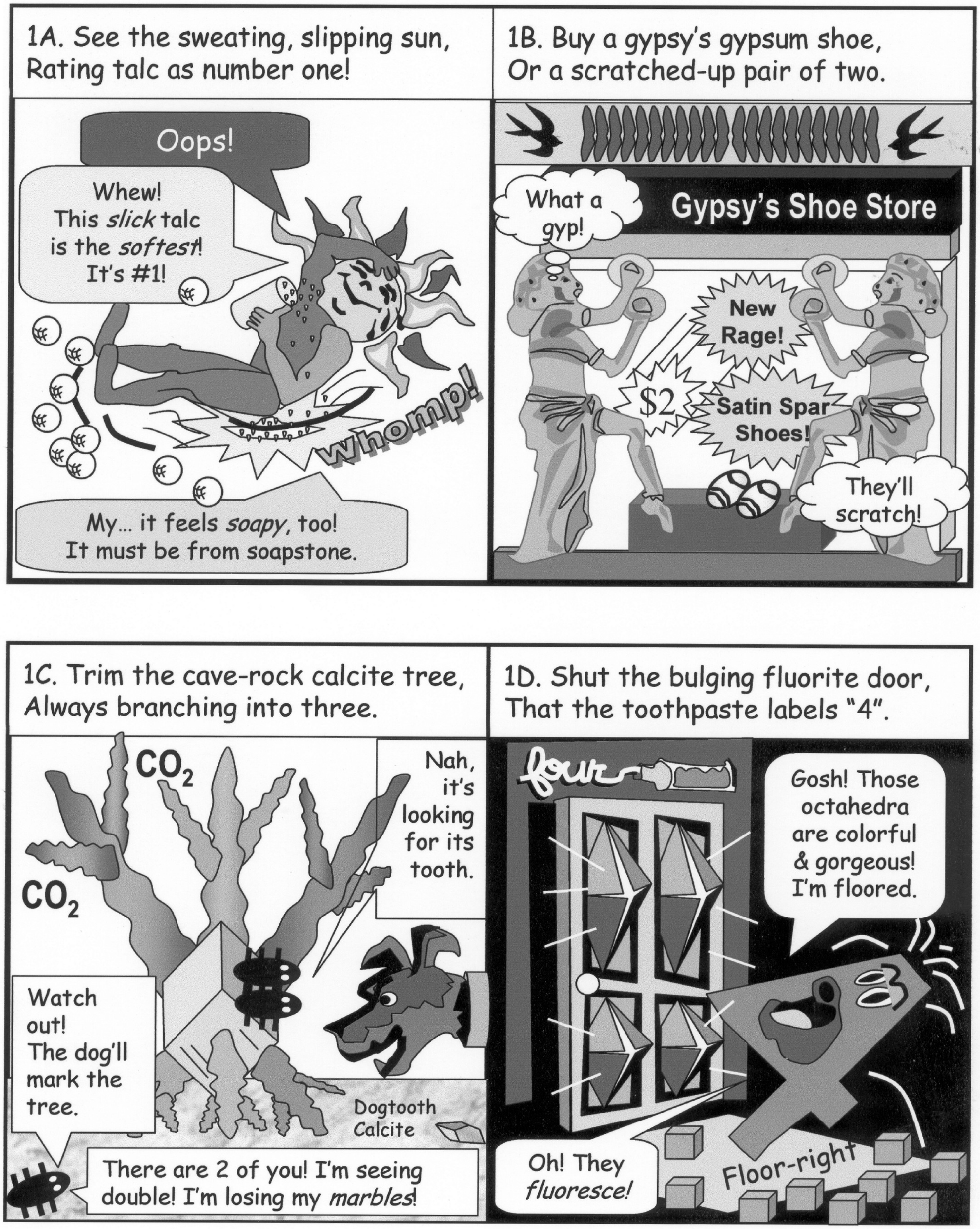
A person's eyes contain nearly seventy percent of the body's sensory receptors, making humans intensely visual organisms. Millions of signals are sent every second along the optic nerves to the brain's visual processing centers. Humans take in more information visually than through any of the other senses (Wolfe, 2001).

Research published as early as 1894 (Kirkpatrick) established that mental imagery (picturing the objects, events, or ideas words represent) improves memory for verbal material. This happens for two reasons. First, images are inherently more memorable than words. Secondly, words that evoke visual images are recorded twice in the brain: as both verbal and visual memory. The most effective imagery involves association and interaction between the two ideas being connected (Bergfeld, Choate, and Kroll, 1982; Kee and Nakayama, 1980), is vivid (clear, distinct, strong) (Ahsen, 1986; Reisberg et al., 1986) and perhaps bizarre (Einstein and McDaniel, 1987; Wollen and Margress, 1987). One reason imagining interaction between mental images may be effective is because it is a form of chunking that allows one image to represent the relationship between two or more items (Begg, 1982). Viewing pictures has an even stronger effect on memory than instructions to visualize (Alesandrini, 1982). After studying a picture, close your eyes and try to actually "see" the images from the drawing. In addition to recalling details of the images, try to imagine the images moving and interacting. Then substitute one image into the place of the other, so that they switch positions and actions. This may make for a bizarre scene, but so much the better – bizarre images tend to be novel and this uniqueness aids memory. Finally, exaggerate one or both in size or number. These techniques will make the images more vivid.

The mnemonic images provided in this article present concrete, vivid images of minerals interacting with their Mohs Hardness Scale numbers, such as the number four being floored by the beauty of fluorite

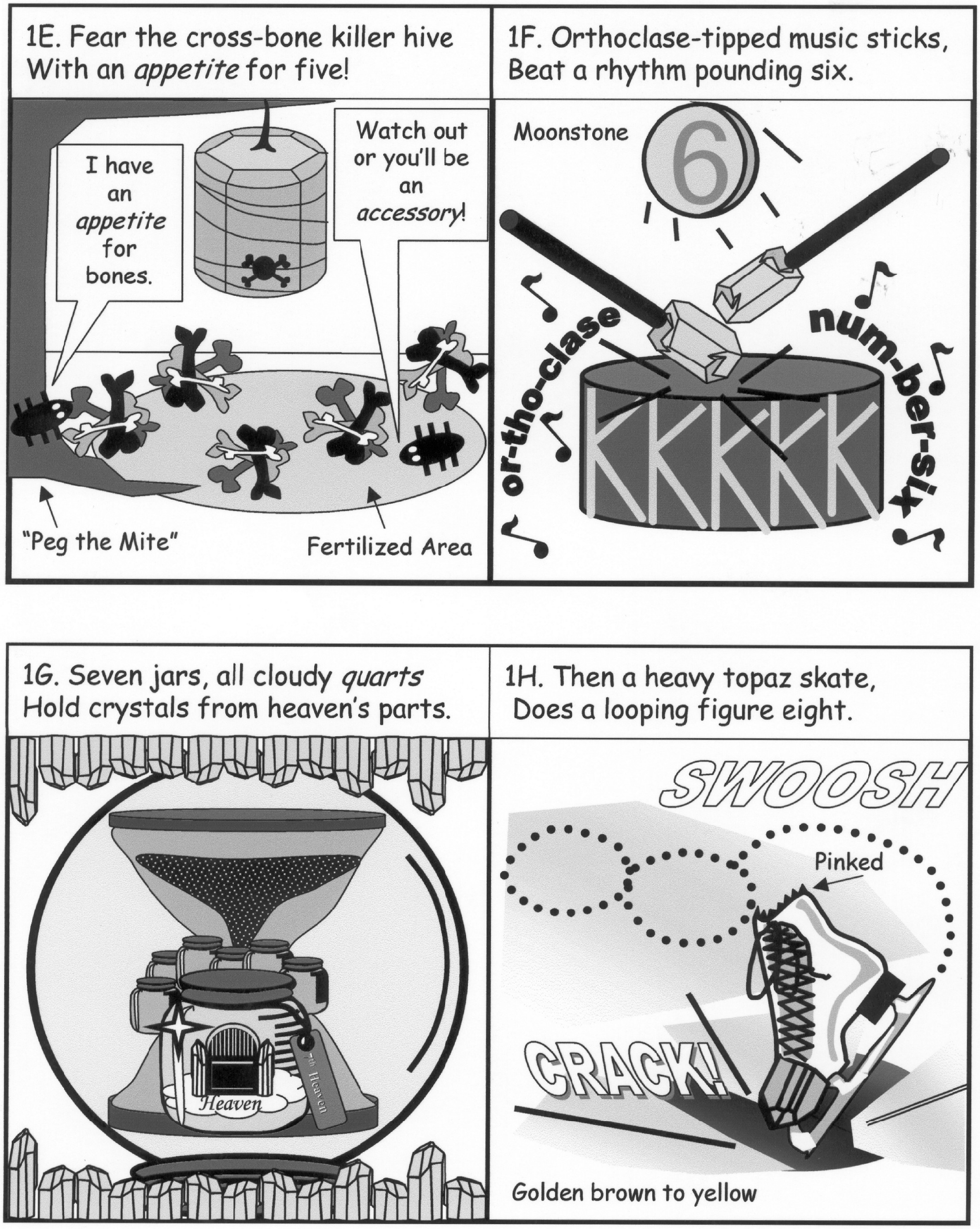
Hardness and Mineral	Scenario	Figure Number and Facts Portrayed in the Drawing
1. Talc	A sweating sun applies talcum powder, slips in the spill, and lands on a soft mound of talc. The sun also realizes the talc has a soapy feel.	1A.Talcum powder is a talc product. Talc is very soft, slick, and soapy with lubricating properties. Soapstone is composed of talc.
2. Gypsum	Sparring alabaster gypsy statues in front of Gypsy's Shoe Store think satin spar (gypsum) shoes will scratch too easily.	1B. Alabaster and satin spar (the gypsy statues are *sparring*) are varieties of gypsum that are easily carved into statues and other ornamental items. Gypsum scratches easily. Gypsum crystals may have swallowtail or fishtail twins shown in decorative molding and swallows' tails.
3. Calcite	A carbonate stalactite tree with a rhomb trunk gives off three-atom carbon dioxide molecules. A dog searches for its broken dogtooth calcite on the marble ground.	1C. Calcite is a carbonate mineral that forms stalactites. The carbonate molecule contains three atoms. Calcite cleaves into rhombohedra. A clear Iceland Spar rhomb shows double refraction. Calcite scalenohedral crystals are often called "dogtooth" calcite because of resemblance to a hound's canine tooth. Metamorphosed limestones (calcite) become marble.
4. Fluorite	The number 4 is floored by the four fluorite octahedra on the door of room 4 (written in fluoride toothpaste). The floor is made of cubes of fluorite.	1D. Fluorite is mined to provide the fluoride in toothpaste. Fluorite can be cleaved into beautiful octahedra. Fluorite occurs in many colors. Fluorite crystals fluoresce in the dark. The floor is made of cubes of fluorite because the most common habit of fluorite is cubic. Cubes have right angles, hence the name "floor-right" or fluorite.
5. Apatite	A killer hive has five piles of apatite-rich bones – a five course meal.	1E. The hive is shaped like an apatite crystal with a hexagonal prism habit. Apatite is a phosphate mineral found in teeth and bone. It is often used to make fertilizer. Apatite is a common accessory mineral in igneous rocks and occurs as crystals in pegmatites (Peg the mite = pegmatite).
6. Orthoclase	Carlsbad-twinned orthoclase crystal drumsticks beat: "or-tho-clase-num-ber-six" under a glowing moonstone.	1F. Orthoclase crystals often exhibit Carlsbad twinning. Moonstone is a gem variety of orthoclase. Orthoclase is one of the "K"-spars (shown by K's on the drum).
7. Quartz	Inside an amethyst geode is a crystal ball showing sand falling through an hourglass and seven quart-sized quartz jars holding pieces of heaven.	1G. Geodes are usually composed of quartz. Most sand grains are quartz. Quartz is often transparent and colorless – like glass. Glass is made from quartz sand. Crystal balls were originally made from quartz crystals. Quartz crystals have the six-sided habit shown.
8. Toapz	A topaz crystal-toed skate inscribes a figure eight but the heavy mineral falls through the ice.	1H. Topaz is a gem classically having a golden brown to yellow color. Topaz has the crystal form shown. Topaz is a heavy mineral. Pinking (here a play on two meanings of pinking) is a heating process by which a brownish topaz in permanently changed to a rose-colored gem.
9. Corundum	A ruby-bearing rose vine is sanded away by corundum paper.	1I. Corundum, called "Emory", is used in sandpaper and as an abrasive. Ruby is red gem-quality corundum. Other colors of gem-quality corundum are sapphires (It's a fire = It's sapphire).
10. Diamond	A diamond hen wins a hardness contest with a score judges' of "10" by pecking a rough diamond into a gem.	1J. Diamonds are precious gems. Diamonds have a high index of refraction and adamantine luster (hence, the four judges must wear sunglasses). Diamonds can be cleaved (pecked) along four directions.

Table 2. Mineral facts shown in mnemonic drawings.



octahedra and a topaz-crystal-toed skate making a figure eight. Students should elaborate upon the images provided and make them their own. They should imagine the characters or images of each scene in motion, switching places, and becoming exaggerated in size or number. Ownership and personal adaptations of the images will enhance learning. Perhaps the most effective use of the presented drawings would be as a model for students to follow in devising their own vivid, interactive images. The thought and effort put into devising one's own images along with the higher degree of meaningfulness inherent in one's own ideas makes self-generated images superior (Jamieson and Schimpf, 1980).

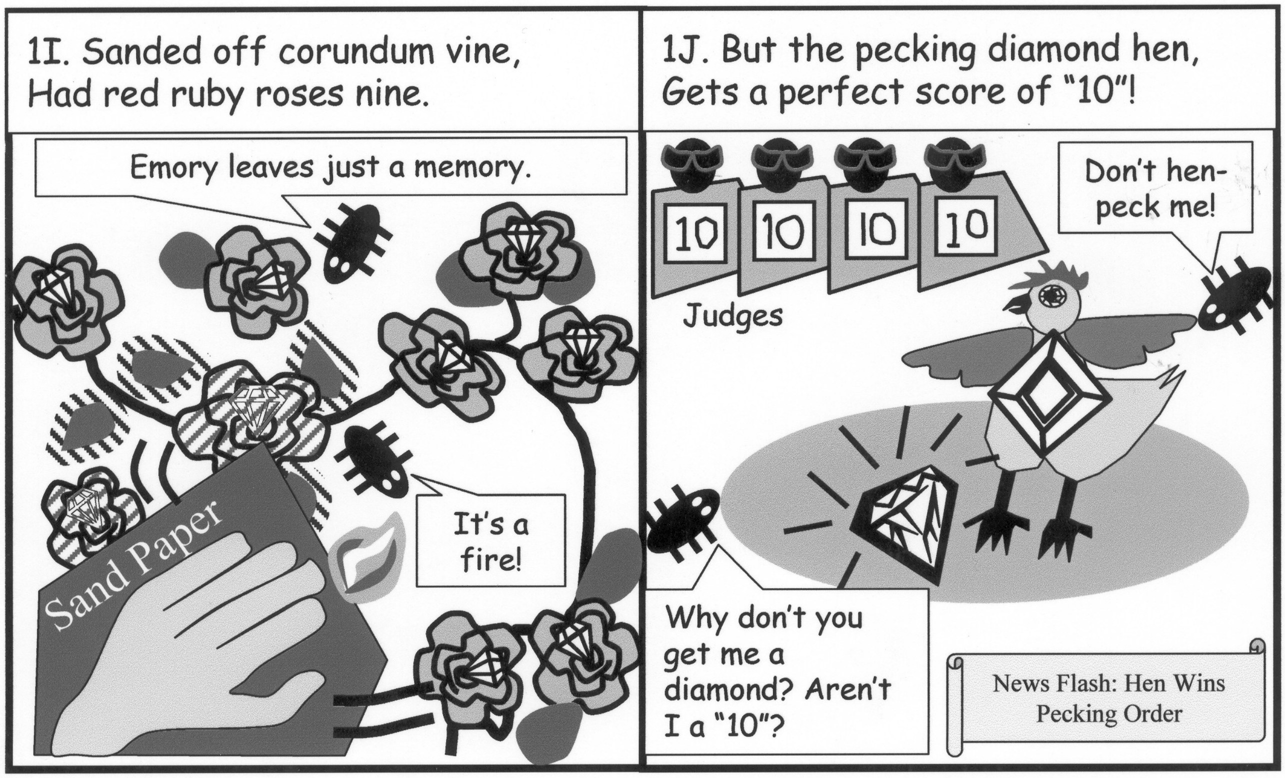
Yager (2000) discussed the need for more creativity in science instruction, noting that knowledge and process skills are most often the entire focus of science lessons. He presents a six-domain model of science education that fits with the visions encompassed by the Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) and the National Science Education Standards (National Research



Council, 1996). Domain III of this model is titled "Imaging and Creating." It includes, among other concepts, visualizing and producing mental images, and combining ideas and objects in new ways. The exercises presented in this article will provide an opportunity for students to practice these creative thinking skills and broaden their experience of science.

ATTENTION

In order for someone to remember a piece of information, that person must first pay attention to it, concentrate on it, and learn it in the first place. Much of what is blamed on a "bad memory" was not learned in the first place. A person can really only focus on one thing at a time. Research indicates that attention to learning tasks correlates more highly with school achievement than does the time spent on task (Wittrock, 1986). Mnemonic devices help students focus attention on the material being learned because they tend to be novel, more interesting, and more engaging than rote learning. Analysis, elaboration, or creation of mnemonic devices involves the student in active learning. However, in order for a student to benefit from a mnemonic technique, the student must actually focus on and apply the technique (attention). Allowing students the freedom



to personalize a mnemonic devise promotes ownership and may serve to motivate students.

FIRST LETTER MNEMONICS

A sentence composed of words whose first letters are the same as the initial letters in the list of words being memorized is a useful mnemonic device. Most music students will recognize the phrase "Every Good Boy Does Fine" as naming the lines of a musical staff E, G, B, D, and F. Several sentences have been offered for learning the Mohs scale. Plummer (2002) suggests "The Gem Cutters From Adelaide Must Queue To Cut Diamonds (substituting microcline for orthoclase). Another interesting sentence is: "The Geologist Can Find An Ordinary Quartz – Tourists Call Diamond" (Kriman, 2002). Here are two more that go beyond first letters on most words: "Talented Gymnasts Can Flaunt Apparel Others Question, Totally Confounding Divas," and "Talkative Gypsies Cackle Fluently, Appreciating Ordinary Quips To Comical Deviling." First letter mnemonics, though useful because of their compactness, do not carry the rich associations and meaning that pictorial mnemonics bring, as will be shown below.

THE PEG MNEMONIC DEVICE

Learning the Mohs Hardness scale requires not only that minerals be memorized, but also their positions on the list, or degrees of hardness be known. A mnemonic device perfect for this application is the Peg mnemonic system, which was introduced in England around 1879 by John Sambrook. (Paivio, 1979, p. 173). The Peg system creates a mental filing system by associating numbers with concrete nouns in a meaningful way – often by rhyme. In the system employed in this paper, the following words will be used to represent each number: one-sun; two-shoe; three-tree; four-door; five-hive; six-sticks; seven-heaven; eight-skate; nine-vine; and ten-hen. These rhyming words can be learned with little effort– many of them are already associated with numbers because of nursery rhymes. The Peg system is so-named because these rhyming words form mental pegs upon which a person "hangs" words to be remembered. Therefore, each mineral of the Mohs Hardness Scale will be associated with the object assigned by rhyme to the corresponding hardness. In this way, "sun" and "talc" will be linked together and "one" will automatically be associated with talc because it is the number that rhymes with sun.

There is considerable research evidence supporting the effectiveness of the Peg system (Bellezza and Bower, 1982; Higbee, 1996). Studies of college students memorizing word lists showed that students could recall about 7 of 10 words without the Peg system, and 9 out of 10 with the Peg system (Higbee, 1976). The system works for younger learners as well: junior high students using the Peg system were able to recall twice as many words as their peers not using the system, immediately after study, one week later, and even five months later (Elliot and Gentile, 1986).

The Peg system was used to teach high school and junior high school students with learning disabilities mineral hardness (some substitutions were made for minerals on the Mohs Scale), along with several other tasks such as colors and uses of minerals, and information about dinosaur extinctions (Mastropieri, Scruggs, and Levin, 1987). For all tasks, the researchers found the Peg system to be more effective than traditional instruction. In the hardness scale trials, students were divided into three conditions, all of which devoted the same amount of time to the learning task. In one condition, students learned the minerals of the hardness scale through direct questioning and review by a teacher, whereas in the second condition, students were allowed to study the scale on their own. In the third condition, students used the Peg mnemonic device during which they were shown ten different drawings of objects representing minerals interacting with a corresponding peg word (a pie supported by sticks represented the mineral pyrite with a hardness of six in one drawing). Results of this study indicated that student performance after mnemonic instruction (75% correct) was statistically superior to direct questioning (28% correct) and free study (36% correct) (Bishop, Lewis, and Sutherland, 1976). In a second study, these results were again replicated for a group of seventh graders without learning disabilities.

In addition to the cognitive effectiveness of increased recall, Higbee (1994) reports that college students using the rhyming peg mnemonic to learn common sayings in numerical order rated the task easier and more fun than peers learning the same material without the use of mnemonics on their own or with others in a practice group. This suggests that the effort in learning a mnemonic may be repaid not only in increased performance, but also in student motivation.

MNEMONIC DRAWINGS FOR LEARNING THE MOHS SCALE

A set of ten drawings to be used with the peg rhyming mnemonic for learning the Mohs scale of hardness are shown in Figure 1 A-J. Students should first memorize the ten key words that rhyme with each number - the pegs (given previously). Then provide the drawings to students working in small groups and ask them to identify facts related to each mineral that are portrayed in the drawings. Facts are listed in Table 2. Students may add additional ideas to the drawings or modify them to personalize, increase detail, insert humor, or make further connections. Finally, students should practice visualizing images as suggested previously under the heading Visualization.

OTHER APPLICATIONS OF THE PEG MNEMONIC DEVICE

The rhyming peg mnemonic device is particularly useful when a set of ordered names or concepts, such as the Mohs Scale of Hardness, needs to be memorized. Geoscience students may find it helpful in learning the periods of the geologic time scale. Some ordered sets related to minerals are the succession of minerals in Bowen's discontinuous or continuous reaction series, the sequence of silicate structures based on complexity of silicon-oxygen tetrahedra (single tetrahedron, hexagonal ring, single chain, double chain, sheet structure, framework structure), the order of interference colors seen under a polarizing microscope and atomic numbers of elements in the periodic table. The hardness of a particular mineral or minerals unrelated to a sequence can be remembered using corresponding peg words. For example, pyrite, rutile, feldspars, and epidote all have hardness of about six on the Mohs scale. Visually connecting these minerals with "sticks", the mnemonic peg word for six, (perhaps by imagining the minerals as components of a shish kabob on a stick) will help a student remember each mineral's hardness.

Of equal importance to academic success abilities, are everyday life skills. The peg device can be applied to any situation where a number needs to be remembered in association with an object or event. For example, a woman wanting to remember a friend's birthday on May 9th (fifth month, ninth day), might picture the friend's face on a large hive (peg word for five) entwined with a vine (peg word for nine).

REFERENCES

Ahsen, A., 1986, Prologue to vividness paradox, Journal of Mental Imagery, v. 10, p. 1-8.

Alesandrini, K. L., 1982, Imagery eliciting strategies and meaningful learning, Journal of Mental Imagery, v.6, p. 125-40.

American Association for the Advancement of Science, 1993, Benchmarks for science literacy, Oxford University Press, New York, 418 p.

Anderson, J. R., 1983, Retrieval of information from long-term memory, Science, v. 220, p. 25-30.

Baddeley, A. D., Lewis, V., and Nimmo-Smith, I., 1978, When did you last...?, in M. M. Gruneberg, P. E. Morris, and R. N. Sykes (eds.), Practical Aspects of Memory, New York, Academic Press, 786 p.

Begg, I., 1982, Images, organization, and discriminative processes, Canadian Journal of Psychology, v. 36, p. 273-90.

Bellezza, F. S., and Bower, G. H., 1982, Remembering script-based text, Poetics, v. 11, p. 1-23.

Bergfeld, V. A., Choate, L. S., and Kroll, N. E., 1982, The effect of bizarre imagery on memory as a function of delay: a reconfirmation of the interaction effect, Journal of Mental Imagery, v.6, p. 141-58.

Bishop, M. S., Lewis, P. G., and Sutherland, B., 1976, Focus on early science, Columbus, Ohio, Merrill.

Brace, W. F., 1960, Behavior of rock salt, limestone, and anhydrite during indentation, Journal of Geophysical Research, v.65, p. 1773-1788.

Carter, R., 1998, Mapping the mind, London, Weidenfeld and Nicolson, 224 p.

Dowse, M. E., 2000, Everyday minerals, Journal of Geoscience Education,v. 48, p. 571.

Einstein, G. O., and McDaniel, M. A., 1987, Distinctiveness and the mnemonic benefits of bizarre imagery, in M. A. McDaniel and M. Pressley, Imagery and related mnemonic processes, Theories, individual differences, and application, p. 79-102, New York, Springer-Verlag, 470 p.

Elliot, J. L., and Gentile, J. R., 1986, The efficacy of a mnemonic technique for learning disabled and nondisabled adolescents, Journal of Learning Disabilities, v. 19, p. 237-41.

Folarin, B. A., 1981, Is grouping of words in memory a fast or slow process?, Psychological Reports, v.48, p. 355-58.

Higbee, K. L., 1976, Mnemonic systems in memory: Are they worth the effort?, Paper presented at the meeting of the Rocky Mountain Psychological Association, Phoenix, AZ, May.

Higbee, K. L., 1994, More motivational aspects of an imagery mnemonic, Applied Psychology v. 8, p. 1-12.

Higbee, K. L., 1996, Your memory: How it works and how to improve it, New York, Marlowe and Company, 265 p.

Jamieson, D. G., and Schimpf, M. G., 1980, Self-generated images are more effective mnemonics, Journal of Mental Imagery, v. 4, p. 25-33.

Kee, D.l W., and Nakayama, S. Y., 1980, Automatic elaborative encoding in children's associative

memory, Bulletin of the Psychonomic Society, v. 16, p. 287-90.
Keenan, J. M., Brown, P., and Potts, G., 1986, The self-reference memory effect and imagery, Paper presented at the meeting of the Psychonomic Society, New Orleans, November.
Kirkpatrick, E. A., 1894, An experimental study of memory, Psychological Review, v. 1, p. 602-09.
Knoop, F., Peters, C. G., and Emerson, W. B., 1939, Sensitive pyramidal-diamond tool for indentation measurements, U. S. National Bureau of Standards, Research Paper No. RP1220, The Bureau's Journal of Research, v. 23, p. 39-61.
Kriman, A. M., 2002, Mohs hardness scale, Online information Available: http://www.plexoft.com/SBF/M04.html Accessed November 15, 2002.
Lyon, D. O., 1914, The relation of length of material to time taken for learning and the optimum distribution of time, Journal of Educational Psychology, v. 5, p. 1-9, 85-91, 155-163.
Masson, M. E., and McDaniel, M. A., 1981, The role of organizational processes in long-term retention, Journal of Experimental Psychology, Human Learning and Memory, v. 7, p. 100-10.
Mastropieri, M. A., Scruggs, T. E., and Levin, J. R., 1987, Mnemonic instruction in special education, in M., A. McDaniel and M. Pressley, Imagery and Related mnemonic Processes, Theories, Individual Differences, and Application p. 358-376, New York, Springer-Verlag, 470 p.
Miller, G. A., 1956, The magical number seven, plus or minus two. Some limits on our capacity to process information, Psychological Review, v. 63, p. 81-87.
Miller, J. W., and Manns, M. L., 1997, Expert systems as a tool for teaching mineral and rock identification, Journal of Geoscience Education, v. 45, p. 147–149.
Mohs, F., 1825, Treatise on mineralogy, or the Natural history of the mineral kingdom, translated by William Haidinger, 3 volumes, A. Constable & Co., Edinburgh.
National Research Council, 1996, National science education standards: Observe, interact, change, learn, National Academy Press, Washington, DC, 262 p.
Paivio, A., 1979, Imagery and verbal processes, Erlbaum, Hillsdale, NJ, 608 p.
Plummer, P., 2002, Communication cited in Nield, Ted. Teaching Resources: Mnemomania. Available online at http://www.geolsoc.org.uk/template.cfm?name=Mnemonics, accessed November 15, 2002.
Reisberg, D., Culver, L. C. , Heuer, F., and Fischman, D., 1986, Visual imagery: When imagery vividness makes a difference, Journal of Mental Imagery, v. 10, p. 51-74.
Staples, L. W., 1964, Friedrich Mohs and the scale of hardness, Journal of Geological Education, v. 12, no. 3, p. 98-101.
Strand, B. Z., 1974, Effects of instructions for category organization on long-term retention: Journal of Experimental Psychology, Human Learning and Memory, v. 1, p. 780-86.
Taylor, E. W., 1949, Correlation of the Mohs's scale of hardness with the Vickers's hardness numbers, Mineralogical Magazine, v. 28, p. 718-721.
Winchell, H., 1945, The Knoop microhardness tester as a mineralogical tool, American Mineralogist, v. 30, p. 583-595.
Wittrock, M. C., 1986, Students' thought processes. in Merlin C. Wittrock (ed.), Handbook of research on teaching 3rd ed., p. 297-314, New York, McMillan, 1037 p.
Wolfe, P., 2001, Brain matters: Translating research into classroom practice, Alexandria, VA, Association for Supervision and Curriculum Development, 207 p.
Wollen, K. A. and Margres, M. G.,1987, Bizarreness and the imagery multiprocess model, in M. A. McDaniel and M. Pressley, Imagery and related mnemonic processes: Theories, individual differences, and application, p. 103-27, New York, Springer-Verlag, 470 p.
Yager, R. E., 2000, A vision for what science education should be like for the first 25 years of a new millennium, School Science and Mathematics, v. 100, p. 327-341.