Mineral Classification – What's in a Name?
Notes for Instructors

This exercise is only slightly modified from one originally written by Dave Mogk. Mogk's write-up is below. It includes excellent notes, including the pedagogical basis for the activity.

MINERAL CLASSIFICATION—WHAT'S IN A NAME?

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"The purpose of classification is not to set forth certain and final truths, but rather to be used as stepping stones towards greater understanding."
L.C. Graton

Objectives: This is an introductory exercise that is designed to 1) help students develop their observational, descriptive, and interpretive skills; 2) place mineral classification schemes in a rational context based on the students' observations as well as a historical perspective; 3) prepare students for more detailed coverage of material by encouraging them to "be scientific" and 4) demonstrate effective teaching practices using a constructivist approach, collaborative learning, and peer assessment. This exercise can be used as an "ice breaker" early in the course to encourage students to get to know each other and to work together, to become familiar with determinative tests that will be used throughout mineralogy, and to allow the instructor to observe "baseline" student performance as an aid in planning future activities to better address student needs. Additional notes for instructors are keyed to the text. (Notes 1 and 2).

Background: Students should be familiar with basic determinative mineralogy: hardness, cleavage, general crystal forms, luster, color...things that can readily be observed in hand sample (see exercise by Ken Bladh, this volume). If students are not familiar with these properties, they should be encouraged to review this material from introductory texts, or better yet, sets of minerals that display these properties. (Note 3).

Materials: Sets of common rock-forming minerals should be provided which display the breadth of physical properties that can readily be observed in hand sample. Use whatever minerals are readily available from your collections. However, two features should be built into the teaching sets: 1) include numerous varieties of the same mineral (e.g. terminated quartz crystals, massive quartz, smoky quartz, chert; rhombohedral calcite, dogtooth spar, etc.), and 2) numerous minerals that have the same crystal form (e.g. cubic pyrite, galena, halite; prismatic amphibole, tourmaline, etc.). Twenty to thirty different samples can be used, depending on materials available and amount of time that can be allotted to this exercise. (Note 4). A suggested list of minerals would include:

pyrite	galena	halite	marcasite
calcite (rhomb)	calcite (dogtooth)	gypsum (selenite)	chalcopyrite
quartz crystal	massive quartz	smoky quartz	sphalerite
plagioclase (with twins)	microcline/orthoclase	kaolinite	magnetite
olivine	hornblende	tourmaline	biotite
pyroxene	hematite (red, earthy)	hematite (specular)	muscovite

Reference for this exercise: Mogk, D. (1997) Mineral Classification -- What's in a Name? In, Teaching Mineralogy, J. B. Brady, D. W. Mogk, and D. Perkins, eds., Mineralogical Society of America, pp. 37-42.

Assignment: Develop a classification system that will differentiate and organize the members of the "mineral kingdom". Use the physical properties you can observe in hand sample to develop the criteria for organizing your classification system. Your system must have the following characteristics:

1) the system must be expandable, so that you can use it to classify new minerals that may be discovered;
2) the system must be reproducible, so that other scientists can use your criteria to come to make the same interpretation about mineral classification that you have originally determined;
3) the system must be easily applied by other workers who will need to use it effectively in the field or in the lab.

Work in small groups (3-4) to develop your classification system. You will have to come to a consensus about which properties should have the highest priority, which properties are useful for general discrimination of minerals, and which properties may be diagnostic of specific minerals. (Note 5). Your final product should be a taxonomic "tree" with a written description of how to systematically use your procedures to classify minerals. (Note 6).

THERE IS NO "RIGHT" ANSWER. However, you should be prepared to justify your reasons for selecting the order of the criteria for your classification system. As a starting point, you may want to develop a series of "yes or no" types of questions; e.g. is it metallic, is it soft, etc. You will encounter some difficulties and apparent contradictions as you develop your system. For further insight into this problem, read the article by Robert Hazen, "Mineralogy: A Historical Review" (Journal of Geological Education, 1984, v. 32, p. 288-298). How can you use the observations, interpretations, and arguments of the "formalists" vs. the "naturalists" to <u>revise</u> your classification scheme? (Note 7)

Reflection: (Note 8)

1. What problems were encountered by early scientists who believed that "form and only form should be used for the classification of minerals"?

2. What problems were encountered by early scientists who developed classification systems based on "empirical" or natural properties of minerals?

3. What was the contribution of James Dwight Dana to the problem of mineral classification?

4. What physical properties used in your classification scheme are qualitative and which are quantitative? What are the benefits and limitations of each type of observation?

5. What can the physical properties of minerals tell you about fundamental principles in nature? (e.g. structure and composition of minerals, etc.). Based on your observations, what other information would have helped you develop your system? How could you have obtained this information?

6. Historically, what technologies became available that brought new evidence to this controversy? What new evidence became available to address the physical and chemical properties of minerals?

7. What technologies are currently available to aid with the identification and characterization of chemical and physical properties of minerals? (Note 9)

Assessment: (Note 10)

Trade your classification system and "user's guide" with another group. Each group should then assess how effective the classification system is. Pick out a number of representative samples and use the system to see if you get the same answer as the original group. Did you run into difficulties in making decisions about the properties of some of the minerals? Take a new mineral (provided by your instructor) and see how this system works for a new material? Is this system internally consistent (i.e. you get the same answer for the same types of minerals)? Is it easy to use? Provide constructive advice on problems you may have encountered, and provide some suggestions on how you could solve this problem. This is not a grade--it is meant to be an informative review that allows you to help your colleagues better perform their tasks.

Notes for Instructors:

1. Cognitive psychology has demonstrated that there is a hierarchy of developmental skills that include observation, description, interpretation, and integration in the progression of higher order-reasoning. This exercise presents an opportunity for students to exercise their observational skills, to confront the need for precise description of natural phenomena, and to begin to interpret their observations towards an organized understanding of the natural world.

2. This exercise is built upon the underlying principles outlined in Project 2061 Science for All Americans (AAAS, 1989). In particular, Chapter 12 makes recommendations about "Habits of Mind": curiosity, openness to new ideas, skepticism, observation skills (keep a notebook that accurately describes observations made, use appropriate instruments to make direct measurements), communication skills (express orally and in writing the basic ideas covered, be comfortable and familiar with standard vocabulary, organize information, participate in group discussions...), and critical response skills (logical conclusions from evidence, use of analogy, discrimination of fact and opinion).

   Chapter 13 (Science for All Americans) addresses "Effective Learning and Teaching": what students learn is influenced by their existing ideas, progression in learning is usually from the concrete to the abstract, people learn to do well only what they practice doing, effective learning by students requires feedback, and expectations affect performance. Specific recommendations for improving learning activities include: start with questions about Nature, engage students actively, concentrate on the collection and use of evidence, provide historical perspectives, insist on clear expression, use a team approach, do not separate knowing from finding out, de-emphasize the memorization of technical vocabulary, welcome curiosity, reward creativity, encourage a spirit of healthy questioning, avoid dogmatism and present science as a process not as unalterable truth.

   The recent review of undergraduate science education, "Shaping the Future, New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology" (NSF 96-139) calls for, "All students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry." The most important component of successful research and educational activities lies in the process of discovery, and students should be given every opportunity to discover fundamental concepts and principles in their regular coursework.

3. All students will come to class with preconceptions or misconceptions about the subject, usually based on limited personal experience. When presented with new information, most students will attempt to append this new material onto their own incomplete or inaccurate understanding of a subject, rather than coming to a true understanding of the subject. The basis of a constructivist approach is that students should be given the opportunity (required) to discover inaccuracies in their own understanding, and to "construct" a new understanding based on a more appropriate interpretation. For example, confusion about planar surfaces that may either be a crystal faces or cleavage planes is the type of problem that plagues many students. By working with numerous examples of different types of cleavages and crystal forms, students should be able to determine for themselves the criteria needed to distinguish these features.

4. Ambiguity is purposefully built into this exercise so that students will confront a) natural variation which they can expect in the field, and b) the historical dilemma encountered by mineralogists and natural scientists up until the time of Dana. This historical development will be further discussed below.

5. Collaborative learning is an effective way to get students to formalize, articulate, and defend ideas. There is a wealth of literature that describes the effective use of collaborative learning (see contribution by Srogi, this volume). And most of us do collaborative science, so the students should get used to doing science in this mode.

6. Similarly, there is an extensive literature on the use of effective writing practices in science education. It is essential that students come to value clear and concise writing as part of their pre-professional training.

7. Revision is an important component of constructivist approaches, as students are informed by new information from either direct observation, or from other sources (such as earlier literature)

8. In the "learning cycle", four elements for effective learning are identified: individual and/or group planning; concrete experience and observation; considered reflection on the experience with synthesis and abstract conceptualization; and testing of newly developed concepts in new situations. Of these components, the reflective stage is often omitted--students typically finish an exercise without further consideration of how the results relate to earlier experiences, other bodies of knowledge, or future implications.

9. This question will help make connections to the current situation in mineralogy--and will set up a transition to other units that will cover crystallography, crystal chemistry, etc. In particular, it will help students see the context of what we think we know, and how we can determine/measure/analyze minerals to reveal fundamental properties.

10. Peer evaluation continues the learning process, helps to transfer some of the responsibility for class activities to the students, and relieves some of the burden of the instructor. However, the guidelines for evaluation must be clearly established. The first and most important rule is that *ad hominem* attacks on other students will not be tolerated. It should also be made clear that the evaluation is of the <u>product</u> not the <u>person</u>. My experience has been that my students have been brutally frank and honest in their evaluations. Students have little patience (less than my own) for sloppy work that wastes their time. Peer evaluation is part of our professional life, whether in academics, industry or government, and students should be made to feel comfortable about the need for review and revision of their work.

You may want to use both an internal and external review of the work--the external review would be of the project itself conducted by another group to determine the effectiveness of the classification schemes. The internal review could be made by the members of a given group to evaluate the contributions made by each team member. It is also worthwhile to periodically ask students to do a personal review, to see what they feel they contributed to and learned from the project.

This type of project also allows the instructor to do his/her own audit of the students at the start of the course. Part of "student-centered learning" is to become aware of the strengths, weaknesses and preferences of each student. Informal observation of the students working in groups will help to give you an idea of which students are leaders, who prefers to work alone or in groups, who has an aptitude to be analytical or synthetic, etc. This type of baseline data for your class can give you valuable information on how to adjust subsequent exercises to reinforce the strengths of some students, and to help design activities that can address other weaknesses (i.e. this provides the basis for "formative" evaluation of class activities for the rest of the term).

11. This exercise presents a historical perspective, as students see that the classification system we use is the product of a long evolution of contributions. It also demonstrates that students can be part of this continuum. Perhaps the most important lesson is that classification itself is not the ultimate goal of a course in mineralogy, although it is a necessary and requisite step. The properties we observe in minerals are the manifestations of other fundamental principles of Nature, and through detailed study of minerals we can find out more about the way the world operates. As Calvin said to Hobbes in his final frame: "Let's go explore..."

12. When I have used this exercise on previous occasions, I found that about 75% of the students tended to adopt the "natural history" mode of classification, and about 25% adopted the "crystal form" mode. Nature or nurture? I think that there may actually be some "born" crystallographers out there! If you adopt or adapt this exercise, I'd be interested in knowing if you notice a similar bifurcation of approaches among your students.