USING COOPERATIVE LEARNING TO TEACH MINERALOGY (AND OTHER COURSES, TOO!)

LeeAnn Srogi
(Department of Geology & Astronomy)
Lynda Baloche
(Department of Childhood Studies & Reading)
West Chester University, West Chester, Pennsylvania, 19383
esrogi@red1a.wcupa.edu

INTRODUCTION

This chapter is concerned primarily with how the content of a mineralogy course can be organized so that the students are more active and conscientious learners. It is fairly common for students to work in groups in mineralogy labs, if only to maximize available resources. Effective lessons that help students go beyond just "working in a group" can be designed with careful application of a conceptual model of cooperative learning (Johnson et al., 1993), and many strategies, or structures (Kagan, 1992), that are simply ways to organize groups efficiently. This chapter is divided into three sections: Section I briefly describes the fundamentals of cooperative learning: why it's important and what is essential. Section II describes a variety of cooperative learning structures and their uses. Section III provides more detailed descriptions of cooperative learning activities specifically for a mineralogy class.

SECTION I: AN OVERVIEW OF COOPERATIVE LEARNING

What the research says about active learning and cooperative learning

Astin (1991, 1993) investigated 88 environmental factors to determine what influenced the academic achievement, personal development, and overall satisfaction of college undergraduates at 159 baccalaureate-granting institutions. He found that, in general education courses, the content and structure of the curriculum were far less important than the quality of interaction among students and between faculty and students -- that *how students approach* their courses and *how faculty deliver* the curriculum are more important than the curriculum itself. The findings support research indicating that a crucial factor in education is the degree to which the student is actively engaged in the educational experience. Astin's results suggest that efforts in curriculum reform might place emphasis on pedagogy and on the interpersonal and institutional context in which learning occurs.

Reflecting in the *Harvard Assessment Seminars: Second Report*, on a multi-year study of "what works" in undergraduate education, Light (1992) writes, "students who get the most out of college, who grow the most academically, and who are the happiest, organize their time to include interpersonal activities with faculty members, or with fellow students, built around substantive, academic work." Cooperative learning is a way for faculty to structure such positive interactions into their courses. Cuseo (1992) defines cooperative learning as a learner-centered instructional process that requires small, intentionally-selected groups of students to work interdependently on well-defined learning tasks.

Research in cooperative learning that focuses specifically on classroom climate and interaction (Johnson et al., 1991b) indicates that positive peer relationships are essential to success in school and that isolation and alienation are predictors of failure. When students drop out of college, they often report failure to establish a social network and failure to become involved in

their classes. Structuring academic course work to encourage cooperative interaction helps students build a sense of community that centers around their academic lives.

Research in cooperative learning that focuses specifically on achievement indicates that positive peer relationships also help students learn. Carefully designed cooperative interaction can be used to help students to: (a) share their knowledge and cultural perspectives with others; (b) articulate what they are learning in ways that help them to reconceptualize and extend their thinking; and (c) dig past the superficial. Cooperative learning results in improved critical thinking when compared to traditional lecture (McKeachie et al., 1986), and is well suited to solving complex, open-ended problems (Qin et al., 1995).

Cooperative interaction in university classrooms can help students learn essential "real life" skills. The world of work increasingly demands that individuals know how to coordinate their efforts with others on the job, know how to build trust and consensus, be good at perspective-taking and problem-solving, and be able to take initiative (Kelley and Caplan, 1993; Krackhardt and Hanson, 1993).

Mineralogy courses afford some of the best opportunities in the geology curriculum for students to work together cooperatively to solve substantive, rigorous problems. Just as students can master a body of information and become more skilled scientists over the semester, so they can also become more skilled at relating to people and working together through practice.

Promoting cooperation: a conceptual key to successful group learning experiences

Everyone who has used groups during instruction knows that merely placing students into groups and telling them to work together does not insure high-level learning or high-quality peer interactions. There are "barriers to cooperation" (Johnson and Johnson, 1994) that include:

- a lack of group maturity -- groups need time and experience to develop into high-functioning groups;
- going with the first, and often dominant, response -- groups need time and encouragement to generate many possible answers and solutions that include the efforts of all members and they need to learn how to recognize and choose which ideas to pursue;
- goofing off -- groups need to help all members learn to work hard so that everyone contributes and no one feels like a sucker;
- a fear of disagreement or conflict -- groups need to learn to manage differences of opinion and use differences to build better understanding; and
- a lack of ability or motivation to attend to both task and maintenance aspects of groups work -- groups must learn how to get the job done while simultaneously maintaining and building their interpersonal relationships.

Groups need time and practice to overcome each of the barriers identified above. **It is *critically important* that cooperative learning groups be used repeatedly throughout a course**; that's why this chapter does not just describe the "cooperative learning lab." As you will see, that does not mean you have to completely change your entire course. Small opportunities for students to interact constructively in class on a weekly basis (or more often) can make a big difference. When there is a careful application of a conceptual model of cooperative learning to specific course content, using a well-chosen structure to organize group work, students are less likely to be hampered by the barriers to cooperation and are more likely to:

- become actively engaged in learning;
- understand the material at a deeper level;
- practice and improve their skills in oral communication, problem solving, and collaborative inquiry; skills that are essential to the conduct of science.

Essential elements of cooperative learning

The conceptual model of cooperative learning includes five basic elements (adapted from Johnson et al., 1993): positive interdependence, simultaneous interaction, individual responsibility, interpersonal and small-group learning skills, and reflection and planning.

Positive Interdependence. When positive interdependence is clearly structured and understood, group members perceive that they and their work are linked for mutual benefit, that the efforts of each group member will be unique, and that the unique efforts of all members will help to maximize success. Among the ways that group members can be helped to understand that they are interdependent are through goal, resource, or role interdependence. A group sharing a set of mutual goals is fundamental to cooperative learning. The instructor clearly delineates the goals, which may be a product, a better level of understanding, or the achievment of some criteria on an assessment. Sharing resources such as materials or information is a common occurrence in mineralogy labs and can be used to promote interdependence. Role interdependence means having students in a group fulfill a set of complementary and interconnected roles in order to complete their tasks and maintain good working relationships within the group. Role interdependence can be effective at helping to equalize participation and reduce problems of differential status among group members.

Simultaneous Interaction. Students promote each other's learning by: (a) helping, sharing, and encouraging efforts to learn; (b) building both personal and academic support systems for themselves and each other; and (c) establishing norms of hard work and success. In order to promote successful simultaneous interaction, instructors need to be quite proactive when groups are formed. In general, it is best to keep groups small -- pairs for sharing, triads for diversity and a variety of ideas, foursomes to challenge the collaborative skills of group members and add complexity. Groups larger than four tend to be time-consuming and often leave some members feeling left out. It is generally best when instructors assign membership. Heterogeneity is key when assigning students to groups; not just heterogeneity by ability, but heterogeneity by gender, social status, ethnic or economic background, learning styles, collaborative skills, content preferences, and the like. In many cases, random assignment of students to groups may work well, particularly for base groups and informal groups. Students may clamor to select their own groups, but self-selected groups inevitably result in differential status and rejection that make it difficult, if not impossible, to achieve high-quality cooperation.

Individual Responsibility. Carefully building individual responsibility into group work helps to insure that students understand and contribute to the group's work and that students can individually apply the skills or concepts learned. It is important that group members know they cannot "hitch-hike" on the work of others. Common ways to structure individual responsibility include individual exams, individual journals or logs, and randomly calling on individual students to present their groups' answer.

Interpersonal and Small-Group Learning Skills. Groups do not function effectively if students do not have and use leadership, decision-making, trust-building, communication, and conflict-management skills. Some collaborative skills are essential for getting the task done, other skills are essential for building and maintaining working relationships. It is critically important that instructors address these skills directly and that students understand them.

Reflection and Planning. When students work together in groups, it is essential that they evaluate how well they have achieved their academic goals and plan what goals are still to be achieved. It is also important that they examine *how* they have reached these goals by working with others and how well they are building and maintaining their peer relationships. Reflection and planning is usually formulated by the instructor, who might ask students to focus on themselves, on each other, or on their group as a whole. For instance, an instructor might say,

- "On a scale of one to five, how well did you remember to consider all ideas?"
- "What one concept is more clear after your discussion than before? What concept remains unclear and needs more of your attention?"
- "Turn to the person on your left and tell them one thing they contributed today that helped you learn something new."
- "As a group, evaluate your plan. Did you follow your plan? Was your plan useful?"
- "How might you modify your plan for the next lab session?"
- "Where in the work place might you need to use consensus building skills? Where in your life could you practice these skills?"

Sections II and III give some examples of how these essential elements of cooperative learning are woven into different types of activities or structures. While it is not necessary to use a particular structure, they are helpful in organizing effective groups and emphasizing positive interdependence. Don't be put off by some of the names of the structures, which may seem "elementary." The underlying theory from social psychology is sophisticated, and they do work in college classrooms! The names are just mnemonic devices for some of the vast number of different ways to organize student work within groups.

Three types of cooperative learning groups

Cooperative interaction can be incorporated into courses through the use of informal, formal, and base groups. One or more types can be used together to help create rich, authentic, learning opportunities. The following provides more detailed information on each type of group.

Cooperative base groups. Base groups are long-term, four or five member, heterogeneous groups with the purpose of providing academic and social support. Students remain in the same base group for the duration of a course, so that the base group personalizes the course experiences. Base groups typically meet for a few minutes at the beginning of almost all classes, thereby smoothing the transition from outside to inside the classroom. Base groups provide encouragement and support in mastering the course content and skills, thinking critically and creatively about the course content and its applications to life experiences and vocation. Students can arrange to make up work following an absence through their base group members. In some cases, base group members may exchange phone numbers for this purpose, although this may not be appropriate for some classes or students.

Routines that are established by the instructor, and then continue without constant instructor intervention, are essential to well-functioning base groups. For instance, the base group routine might include:

- quick discussion of important events in students' lives (the students *will* discuss these things anyway; establishing a routine may bring students' attention back to class more quickly);
- a peer review session of practice problems, some peer editing, generating questions from or brief discussion of assigned reading;
- progress reports and problem solving about long-term individual assignments;
- collection and distribution of course work (a real time-saver in large classes).

One possible extension of the base group concept is their use as the foundation for out-of-class study or discussion groups. The *Harvard Assessment Seminars* (Light, 1990; 1992) found that students who form study groups report that they learn more and enjoy their academic work more. Even students who report that they prefer to work alone, benefit academically from being required to participate in a study group. Over time, study groups become a kind of social support network. Interestingly, women were found to be far less likely to join or start a study group than

men. One of two suggestions made most often by students in the study was that instructors encourage student study groups, even make them part of the course syllabus. The routine and structure of in-class base groups can provide students with a head start for the development of meaningful out-of-class meetings.

Base groups (meeting in or out of class) are not the place for high stakes academic work; i.e., work that has a direct and significant impact on students' grades. Most base groups do not have any formal or graded academic tasks. However, in some classes, base groups are given out-of-class tasks, such as an "exam" or "movie night" requiring substantive, collegial discussion structured around course readings or other assignments. In a field techniques course, students were required to complete a semester-long project in groups of about 3 students as the major portion of their grade. Having students meet and work in class in base groups with different membership provided a sounding board for students to discuss problems with their project groups, and significantly improved the functioning of most project groups. Activity 1 in Section II describes the format of a base group activity developed for an upper-level education course.

Informal Groups. Informal cooperative learning groups (Johnson et al., 1992) are short-term, heterogeneous groups. Instructors select members at random or intentionally. Informal groups are typically used during relatively long, direct-teaching episodes such as lectures or videos. Informal groups also can be used in combination with formal work groups in order to provide a change of pace, move students around the class, and promote peer discussion. The primary purposes of informal groups are to help:

- create a mood conducive to learning;
- focus student attention on the material that is to be learned;
- maintain student attention by dividing the material to be learned into shorter segments;
- create regular opportunities for oral rehearsal, semantic organization, and elaboration to help students process cognitively the material being taught;
- provide opportunities for students to identify misconceptions and gaps in knowledge within the relatively safe context of a small group;
- provide learning opportunities for all students within a group, reducing isolation and mitigating status differences in the classroom;
- promote the benefits of giving and receiving peer explanations; and
- provide closure.

Using informal cooperative learning groups with direct instruction can be as simple as asking a question and, instead of treating the question rhetorically or having students raise their hands and respond in front of the entire class, asking students to turn to the person next to them for discussion. Providing closure can be as simple as using the last 5 minutes of class to have students discuss a question that helps them summarize and synthesize the material that has been presented.

When applying cooperative learning, it is useful to consider how students will group and with whom they will talk. Most instructors can arrange the seating in their classrooms so that "turn to your partner" or "discuss in your foursome" is quite simple. However, many students have a tendency to always sit in the same spot near the same people. It may be important to ask students to move out of their seats to talk with classmates, in order to reduce feelings of isolation and to increase opportunities for community building. Several activities for informal groups in Section II are designed to move students around the classroom in interesting ways. Students are commonly resistant to moving around, but moving among groups generates more ideas and can significantly improve skills. If you regularly use structures that ask students to move around the classroom, resistance will diminish.

Sometimes it is useful to provide guidance about how students should talk, for how long, and with whom. Such guidance can mitigate some of the status differentials that exist in all classrooms. Status differentials within groups may be perceived by the instructor as immutable personality traits; in reality, however, students have different types of status in different life situations, and status is not necessarily a reflection of academic performance. In simplest terms, the student who dominates the group does not always have the right answer! Several cooperative learning structures described in Section II can help to equalize participation and learning opportunities for all students in a group; for example, by requiring students to share ideas in turn, or by preventing a student from speaking a second time until every student has spoken once.

The informal group structures in Section II are arranged roughly in order of increasing complexity and sophistication. Each example provides information about what is good about that particular structure, and what interpersonal and small-group learning skills are practiced in the structure. For example, to promote the interpersonal skill of good listening, each student can be asked to present the ideas of another member to the group. The word "informal" can be deceptive as a description. Informal groups may look and feel quite casual in the classroom, but instructors who use informal groups know that thoughtful planning can greatly enhance effectiveness. By browsing through Section II, you can get a good idea of which structures work in different kinds of classroom settings or with different kinds of content objectives.

Formal Groups. Formal cooperative learning groups (Johnson et al., 1992, 1993) are carefully structured, heterogeneous groups, in which members work together to complete specific tasks which may take a class period or several months. Membership is stable over that time. The distinction between informal and formal groups is not always sharp, but the level of complexity, both of the work content and the depth of peer interactions, is greater in formal groups. As you can see by browsing in Section II, most formal group structures involve material that is complex enough that students benefit from examining the material in pieces or from different perspectives, and then synthesizing and reconceptualizing the material. In formal learning groups, students share:

- a goal to maximize the learning of all members;
- both individual and group responsibility for their learning goals;
- specific work goals that are to be accomplished cooperatively;
- opportunities and obligations to learn and use the interpersonal and small-group skills that are needed to get the job done and build and maintain effective peer relationships; and
- opportunities and obligations to reflect on, and analyze, both learning and peer interaction.

When students need to work and stay together to get the job done, positive interdependence is key. Resource interdependence is common and may be used as a major learning device in an activity. Role interdependence is useful when a task is complicated or controversial. If formal groups are used to complete tasks that require considerable out-of-class work, or that have significant impact on the students' grades, it is critically important to devote some class time to the group work in order for all students to reap the benefits of learning cooperatively. Cooperative learning should never become just an excuse to direct students to "learn it together on your own time."

Groups can benefit from learning about other groups' work. Typically, intergroup sharing consists of groups standing and reporting what they have done. This is time consuming and often boring. Worse yet, only one group can talk at a time, which does not provide opportunities for students to actively process and reconceptualize the work of their peers. Cooperative learning structures that provide alternatives are listed in Section II.

A conceptual model of lesson design incorporating cooperative learning

There are so many elements, so many structures, and so little time. How do you decide what and how to implement? Certain principles of learning and lesson design, well summarized by Hunter (1982), can be used to make informed decisions and maximize learning opportunities.

Anticipatory set. An anticipatory set serves as a kind of warm-up or motivator to focus the students' attention on what is to be learned. A set can be used, for example, to determine what students already know about a subject. Anticipatory sets can be incorporated into any kind of cooperative learning group at the beginning of the work in order for students to share what they know, find out what others know, and motivate everyone to work together to learn more.

Understanding the objective. It is helpful if students understand the purpose of what they will be doing or learning, and how the experience fits into the larger picture of the course. It is helpful if students understand that *how* they are being asked to learn impacts on *what* and *how much* they are learning. This can be incorporated into progress checks, typically conducted by base groups or long-term formal groups.

Input and modeling. Students need to learn basic information and skills so that they can organize, reorganize, and extend them to more complex concepts and processes. Informal learning groups can be used to keep students active and to give them opportunities to reconceptualize the material being presented during lecture or demonstration. When it seems appropriate for students to take the lead in organizing, explaining, and reconceptualizing information, formal work groups are a good choice.

Practice. Students need opportunities to practice using the information, concepts, and skills they are learning. In general, having students practice independently should follow some sort of guided practice so that both instructor and students are reasonably confident that independent practice will help students to move towards fluency rather than to reinforce mistakes. Cooperative learning groups of all types are ideal venues for students to conduct guided practice and discuss results of independent practice.

Closure. Closure, reflection, and planning are essential for high-quality learning and community building in the classroom. The purpose of closure is to help students reflect on what has been learned as well as what needs to be learned, on how it has been learned as well as how it might be learned. Students benefit from having a brief closure activity at the end of *each* class, so it is important for instructors to resist the temptation to lecture or allow a lab to continue until the last possible moment of class. The one-minute paper, developed by Charles Schwartz at the University of California at Berkeley, (Cross and Angelo, 1988), is one way to integrate closure into the instructional routine. A few minutes before the end of class, students are asked to respond to two basic types of questions: (a) What was the most important/meaningful/useful thing you learned today?; and (b) What question do you still have or what remains unclear? These questions may be discussed or answered in any type of cooperative learning group. When students have worked together in formal groups, closure generally should include some reflection on how the group has worked together, as well.

Assessment: Checking for understanding. Checking to insure that students are learning the information and/or skills needed to accomplish the course objectives may be in terms of a formal (summative) assessment, or a less formal (formative) assessment. Checking for understanding does not necessarily mean something instructors "do" to students; students can learn to check their own understanding and that of their peers. Formative assessment can be incorporated into cooperative learning designs in many ways; for example, through one-minute papers, instructor monitoring of group work, and carefully selected questions for reflection and

planning. Cooperative learning structures may be used to help a group probe the understanding of individual members, or to help students check that they understand others' ideas.

Cooperative learning can help to separate learning opportunities (or formative evaluations) from testing (or summative evaluations), and can help the instructor to more clearly define and distinguish the role of each in determining students' grades. This distinction helps instructors to develop a grading strategy that reduces students' anxiety that grades may be dependent upon less conscientious members of a group. There is not necessarily a direct connection between summative assessment and cooperative work. Individual responsibility checks, in the form of tests, papers, and the like, are quite often independent of the group work that has helped students to develop and deepen the understanding that is to be assessed. However, when it seems reasonable to combine assessment with some group product or process, there are a few principles to keep in mind:

- keep the stakes within reason -- one group project, good or poor, should not make or break a student's grade;
- connect group responsibility and assessment with individual responsibility and assessment -- facilitate this by asking groups to hand in their group work plus individual preparation and contributions in the same folder;
- ask groups to participate in the development of criteria to assess group work; and
- ask groups to develop their own contracts for group work so that each student articulates what, and how, they are expected to contribute to the group.

SECTION II. EXAMPLES OF COOPERATIVE LEARNING STRUCTURES

Base Groups

1. Base Group Exam

About three weeks before the exam due date, you will each receive a list of discussion questions. To complete the group exam, you must meet with your base group and discuss the content of your assigned readings plus other readings you have done. Find a comfortable spot for your group to meet and plan to spend about three hours together. (Sometimes base groups find it useful to divide this meeting into two sessions). The purpose of the group exam is to have a thorough, intellectually stimulating, creative, fun, and practically useful discussion. More specifically, the task is to demonstrate deeper understanding of the assigned reading. In addition, the group discussion should provide an opportunity to generate ways to apply the concepts we focus on in class.

Remember: This task is to be accomplished cooperatively.

The responsibilities of each base-group member are as follows:

- ✓ Choose two questions to prepare for the discussion. (Make sure these questions are different than the ones others are preparing.)
- ✓ Prepare answers and discussion items based on your readings, course experiences, and other resources. You will be the group expert for your questions.
- ✓ Prepare for the group discussion by developing handouts, visuals, or anything else that you think will help your group understand the material--use good teaching techniques!
- ✓ Come to the exam prepared to contribute to the discussion and to think critically and creatively. Bring to the discussion (a) a typed synopsis of your response to each question with relevant page numbers in assigned readings, (b) copies of relevant written information to facilitate discussion, and (c) supplemental materials.

When your group meets for the exam, cover at least one question from each member. Since each member has come prepared to discuss two questions, your group should be able to engage in rich discussion.

While at the group meeting your job is to:

- ✓ Stick to the question.
- ✓ Be conscious of the time.
- ✓ Be specific, positive, and descriptive.
- ✓ Encourage constructive disagreement.
- ✓ Take responsibility for both the task and maintenance actions in the group. (Your group has a task to accomplish and the discussion should also be enjoyable and satisfying.)

To document that the group discussion exam has taken place, and that the criteria for passing has been meet by all group members, each member will be required to sign a certification form. Make sure that there are no free-loaders. Do not sign off for a group member unless s/he arrived for the exam fully prepared and participated actively in the discussion of each question.

Group grade: Each group will be expected to submit a summary report consisting of:

- ✓ the certification form;
- ✓ a list of the questions discussed with a summary of answers and conclusions generated;
- ✓ a description of the procedures followed; and
- ✓ a subjective evaluation of the learning resulting from the experience. Each group member should be an integral part of this summary writing and should proof-read all the work.

Individual accountability: On the day the project is due, individual group members will hand in copies of the materials they prepared of the discussion.

Informal group structures

What's good about these structures: They are simple to use. Students have an opportunity to think by themselves. All students have an opportunity to share their ideas and hear the ideas of others. In the Three-Step Interview, students also hear their ideas explained by a peer, explain the ideas of a peer, and hear the ideas of three peers.

Interpersonal and small-group skills: Sharing an idea, careful listening, asking clarifying and probing questions, and paraphrasing.

2. Think Pair Share (Lyman, 1992)
Group size: two
1. Instructor asks a question or poses a problem. Students think by themselves.
2. Students pair and discuss their ideas.
3. Individual students are called upon to share their answers (or the answers of their partners) with the whole class.

3. Think Pair Square
Group size: two and four
1. Instructor asks a question or poses a problem. Students think by themselves.
2. Students pair and discuss their ideas.
3. Each pair teams up with another pair and shares in their foursomes--a square.

4. Three-Step Interview (Kagan, 1992)
Group size: two and four
1. Instructor asks a question or poses a problem. Students think by themselves.
2. Students pair. Within pairs, students each spend a moment or two sharing their ideas and being interviewed by their partners.
3. Each pair teams up with another pair and creates a foursome. Within foursomes, students each share their partner's ideas with the other pair.

Informal group structures that mitigate issues of status and motivation

What's good about these structures: They are fairly simple to use. Students think by themselves. All students, regardless of status, have opportunities to share their own or their group's ideas and to hear the ideas of others. Accountability is enhanced because all students are equally likely to be asked to report, or ideas are written down before discussion, or students are obligated to share the group's ideas with other groups. Sharing can be equalized to lessen status problems by asking students to share one at a time. These structures can help instructors avoid typical questioning patterns that may be related to perceptions of ability or issues of race or gender. It helps students move past perceptions of "She always calls on him," or "He only calls on me when he thinks I don't know the answer."

Interpersonal and small-group skills: Sharing an idea, taking turns, careful listening, asking clarifying and probing questions, paraphrasing, moving in an organized way, or being responsible for the group's work.

Informal group structures that mitigate issues of status and motivation, continued

5. Numbered Heads Together (Kagan, 1992)

Group size: Three or four
1. Students count off in their groups.
2. Instructor asks a question or poses a problem. Students think by themselves.
3. In groups of three or four, students discuss their ideas.
4. Instructor uses numbers to randomly call on students to report on group discussions.

6. Group Interview

Group size: three or four
1. Instructor asks a question or poses a problem. Students think by themselves.
2. Each student is "interviewed" for a minute or two by the other members of the group.

7. Pens in the Middle

Group size: three or four
1. Instructor asks a question or poses a problem. Students think by themselves.
2. In groups of three or four, students share their responses. When students share, they each place a pen or pencil in the center of the group to mark a contribution. Students can not share a second idea until all pens are in the middle.
3. An instructor might monitor the group by picking up a pen, asking whose idea the pen represents, and asking that person or a different group member to describe the idea.

8. Roundrobin (Kagan, 1992)

Group size: three or four
1. Instructor asks a question or poses a problem. Students think by themselves.
2. In groups of three or four, students "go around" and, in turn, share their responses.
3. Sometimes instructors find it useful to have students count off. They can then help organize the sharing by saying, "Start with person # 3 and share clockwise."
4. Instructor may use numbers to randomly call on students to report on group discussions.

9. Roundtable with Roundrobin

Group size: three or four
1. Instructor asks a question or poses a problem. Students think and write by themselves. Writing responses before sharing helps when groups have status problems, when one or more members are not motivated, or when students find it hard to express their own ideas.
2. In groups of three or four, students "go around the table" and, in turn, share responses.
3. Sometimes instructors find it useful to have students count off. They can then help organize the sharing by saying, "Start with person # 3 and share clockwise."
4. Instructor may use numbers to randomly call on students to report on group discussions.

Informal group structures that mitigate issues of status and motivation, continued

10. Stirring Up the Class

Group size: three or four

1. Students count off in their groups.
2. Instructor asks a question or poses a problem. Students think by themselves.
3. In groups of three or four, students discuss their ideas.
4. All students # 1 rotate one group and share their old group's discussion and answers with the new group.
5. Instructor asks a question or poses a problem. Students think by themselves.
6. Students discuss their ideas.
7. Rotation procedure is repeated. This time, students # 2 rotate two groups and share their old group's discussion and answers with the new group.

Informal group structures particularly useful for review and closure

What's good about these structures: These structures work well for review and closure. Students have an opportunity to move around the room and share with several peers. All students have an opportunity to share their ideas, see how their ideas relate to the ideas of others, and give and receive feedback.

Interpersonal and Small-Group Skills: Sharing ideas, careful listening, asking clarifying and probing questions, offering or asking for help or information, adding to the ideas of others, giving and receiving feedback, paraphrasing, synthesizing or summarizing information, moving in an organized way.

11. Mix-Freeze-Pair (Kagan, 1992)

1. Students mill, or mix, around the room. When the instructor says freeze, students stop.
2. When the instructor says pair, students form pairs--turning to the person closest to them.
3. Instructor asks question.
4. Students discuss question.
5. Process is repeated several times so that students have an opportunity to talk with several peers. When there is an odd number of students in the class, each grouping will result in one trio. Part of the routine might be: Ask the trio to raise their hands and then announce, "The next time we pair, make sure that these three classmates are all in pairs--not in a trio."

12. Find Someone Who Knows or **Treasure Hunt**

1. Instructor creates a worksheet related to academic content (Find Someone Who Knows) or to personal information (Treasure Hunt).
2. Students mill around the room and gather information from their peers. Students may be asked to sign a worksheet when they provide a piece of needed academic information.
3. Students share information they have gathered. This can be done as a whole class, in base groups or work groups; it can be written or entered by computer on some type of chart or graph.

Informal group structures particularly useful for review and closure

13. Rotating Review (Kagan, 1992)

Group size: three or four

1. Instructors asks a series of questions or presents several topics. These are posted around the classroom--on large pieces of paper or on blackboards.
2. Each group of students is assigned to one topic or question. They move to that area, discuss the idea for a moment, and write a response.
3. The instructor signals. All groups move to the next question or topic, read what has been written, write comments or questions, and add something new. This continues until the groups return to their first positions. (It is helpful if each group uses a different color chalk or marker.)

14. Inside-Outside Circle or **Mad Hatter's Tea Party**

1. Students form two circles--the inside circle faces out and the outside circle faces in. (If the classroom lacks floor space, two smaller concentric circles will work.) In Mad Hatter's Tea Party, students face each other in two lines.
2. Instructor asks question or presents a discussion topic.
3. Students talk with their partners. This can be done freely or can be directed by the instructor. For instance: "People in the outside circle, you have one minute to explain your position. If you are in the inside, you may ask questions but not share your own ideas."
4. Students move to new partners--it is easier for the outer circle to rotate. In Mad Hatter's Tea Party, either one line shifts or both lines shift but in opposite directions.
5. When students move to a new partner, they might first paraphrase what their old partner said before beginning a new discussion.
6. Pairs are determined by the movement of the circles or lines. This may be preferable when there are inclusion or status difficulties in a classroom or when free movement may be too chaotic.

Informal group structures particularly useful for making comparisons or discussing controversies

What's good about these structures: These structures emphasize exploring ideas thoroughly, comparing and contrasting ideas, and making careful distinctions among differing opinions. Students have opportunities to move around the room, think by themselves, declare their ideas and preferences publicly, and learn about the ideas and preferences of others.

Interpersonal and Small-Group Skills: Sharing ideas, stating your opinion, careful listening, asking clarifying and probing questions, offering or asking for information, adding to the ideas of others, giving and receiving feedback, paraphrasing, making distinctions, synthesizing or summarizing information, moving in an organized way.

Informal group structures particularly useful for making comparisons or discussing controversies, continued

15. Corners (Kagan, 1992)

1. Instructor announces the corners. Corners are often related to student preferences or choices: "For the lab, would you rather make observations about the effects of water, sunlight, temperature, or soil acidity on plant growth?" You might ask students to make comparisons or applications: "The most important metal today is gold, iron, copper, or aluminum?" You might ask students to think in analogies and metaphors: "Is research on the Internet--'A Highway To Heaven,' 'Easy Street,' 'A Long And Winding Road,' or 'A Road Less Traveled'?"
2. Students each think (and perhaps write) by themselves.
3. Students move to their preferred corners.
4. Students discuss their reasons with others in their same corner. (Three-step Interviews or Group Interviews might be used if students have a difficult time sharing or listening.)
5. Students are called on to paraphrase the different ideas they have heard in their corners. (Students who went to the same corner may have different reasons for doing so.)
6. Students might be asked to paraphrase--verbally or in writing--reasons for all four corners.
7. Corners might be used to form work groups: Students from the same corner--students with similar interests or preferences--could work together; students from different corners--students with different interests or preferences--could work together.

16. Value Lines

1. Instructor announces a statement or question with two poles and implied "shades of gray" in between. Like corners, these statements help students discuss preferences and choices, make comparisons and applications, or encourage metaphorical thinking. For mineralogy, using Value Lines to explore the asbestos controversy is an obvious choice.
2. Students think by themselves.
3. Students position themselves on an imaginary line--asking questions and explaining their positions so that they know where to stand.
4. Once students are in line, they might talk with those near them to hear why others have chosen similar views. The line might also be "folded in half" so that students with extreme positions have an opportunity to hear views that are different from their own.

Formal group structures

What's good about these structures: All students, regardless of status, have an opportunity to share their information and gather information of others. Students have an opportunity to practice many cognitive skills--including sequencing, descriptive language, deciding what is important, looking for details, comparing, contrasting, and synthesizing. Students have opportunities to conceptualize, reconceptualize, and teach information or procedures to others.

Interpersonal and Small-Group Skills: Sharing information (and knowing when and what information is needed), careful listening, taking turns, asking clarifying and probing questions, offering or asking for information, adding to the ideas of others, giving and receiving feedback, paraphrasing, making distinctions, organizing, synthesizing or summarizing information, teaching.

17. Jigsaw (Aronson et al., 1978)

Group size: three or four

1. Instructor divides material into sections--one section for each student. Students are assigned to groups (call these Groups 1).
2. Students prepare their own section of material--they read, conduct an experiment, solve a problem, etc. This preparation might be done alone--in class or for homework--or with a "preparation partner," depending on the nature of the assignment and abilities of the students.
3. Students each meet with one or more people from a different group who has/have learned the same material. The purpose of this group is both to review and reconceptualize the material and to plan how the material might be best taught or presented to teammates in Group 1.
4. Students move into their "Groups 1" and present their work to the other members. Instructors encourage students to ask questions and engage in genuine discussion--not just passive listening.
5. A summary or synthesis product results from the group work to provide closure for the task.
6. Students process the presentations and the information they have learned. Sentences such as "You helped me learn this material when you . . ." and "One new idea I learned today was . . ." are useful prompts for processing.
7. Individual mastery of students is assessed.

Formal group structures, continued

18. Blind Hand

Group size: three or four

1. Instructor divides material and each student receives one (or two) piece(s) of material.
2. Students each examine their own piece of material to make sure they can describe the details.
3. Students work together to determine the sequence or to describe the entire event that they each "have a piece of." The rules of Blind Hand are:
   a. You can tell (or read) what is on your paper, but you can't show it.
   b. You can ask questions.
   c. You can take notes and share your notes.
4. Once students think they have determined the sequence or solved the problem, they put their resources together, in sequence, and look at "the whole picture." Before they check their work, it is often useful to ask students to reflect, as individuals, about how confident they are that their group's work is "accurate" or "makes sense."
5. Students process their work together. Planning how to proceed is often an essential skill with Blind Hand and it may be useful for students to discuss "Did we have a plan?" "Did our plan work?" "How did we decide what was important?"

Formal group structures that involve investigations of controversies or projects

What's good about these structures: Students have many opportunities to think for themselves, to make choices, to share information and experiences with others, to participate in collective inquiry, to develop well-reasoned arguments, and to practice the skills of idea differentiation, perspective taking, and consensus building. The research on the Academic Controversy structure suggests that students develop both greater understanding of the subject matter and good skills for managing controversy constructively (Johnson and Johnson, 1992). A topic such as the environmental hazards of mineral dusts or the costs and benefits of resource extraction might be particularly appropriate for Academic Controversy. The steps of a Group Investigation, when well planned and facilitated by a skilled instructor, help students to have both the opportunity and the responsibility to contribute to the classroom learning community.

Interpersonal and Small-Group Skills: Many skills are used in these complex, long-term structures, including making choices, planning, asking questions, integrating ideas, taking perspective, building reasoned arguments, disagreeing in an agreeable way, extending the ideas of others, and integrating different ideas into coherent positions.

Formal group structures that involve investigations of controversies or projects, continued

19. Academic Controversy (Johnson and Johnson, 1992)

Group size: four

1. Instructor prepares statements to be discussed.
2. Students are assigned to groups of four. Within each foursome, students are assigned a partner and a position. Students work with partners to prepare reasoning for positions.
3. Each student meets in a "preparation pair" with a student from another group who has prepared the same position. The purpose is to reconceptualize and share materials and strategies.
4. Students meet again in their original pairs, compare notes and finish preparing positions. "Our best case is. . . ."
5. Each pair of students presents their position to the original foursome while the other pair listens and takes notes. "The answer is . . . because. . . ."
6. The two pairs enter into an open discussion. "Your idea is wrong because. . . . My idea is right because. . . ."
7. The two pairs reverse perspectives. Each pair now prepares a new argument.
8. The two pairs present their new arguments and points of view. "Our position now is . . . because. . . ."
9. The two pairs drop advocacy and work together to build a well-reasoned synthesis. "Given what we now know, our best reasoned judgment is. . . ."

20. Group Investigation (Sharan and Sharan, 1992, 1994)

Background: The instructor begins by choosing a problem that is worth investigating and can be investigated in a variety of ways. The instructor collects information. This helps the instructor to determine if the overall problem is "doable" and helps the instructor to "get organized." These materials help to motivate students and provide students with a "starter kit" of resources. The instructor presents the general problem, question, or topic that is to be investigated.

1. The class scans their resources, discusses their interests and priorities, determines subtopics, and organizes into research groups.
2. The groups plan their investigations. They further refine their questions, divide their work, and assign roles to help them manage their work as a group.
3. The groups carry out their investigations. The instructor is an active facilitator--helping groups plan, organize, and pace their work and helping them develop and use the skills they need to build and maintain their interpersonal relationships.
4. The groups plan their presentations. During this phase, the groups must decide what they have learned in their investigations and how to organize and present their findings. Presentations need to be interesting and need to include each group member. Sometimes representatives from each group form a steering committee to schedule the presentations of different groups.
5. The groups make their presentations.
6. The groups evaluate their work--as individuals, as groups, and as a class.

Presenting results in interesting ways

What's good about these structures: All students, regardless of status, have an opportunity and responsibility to share and gather information, and to practice giving and receiving feedback about work. Students have an opportunity to practice many cognitive skills, including the use of descriptive language, deciding what is important, looking for details, comparing, contrasting, and synthesizing. Everyone gets to talk at once in an organized manner.

Interpersonal and Small-Group Skills: Sharing and comparing ideas, asking questions, moving in an organized way, giving descriptive, positive feedback.

21. Gallery Tour (Kagan, 1992)

Group size: three or four

1. Students have worked together, in their small groups, to solve a problem, complete an experiment, or create a visual such as a story map, chart, graph, etc. This structure is best used when groups have produced a tangible product.
2. These products are hung or otherwise displayed around the room.
3. Students rotate, with their work groups, around the room to visit and discuss each display. (This is best done in an organized way with some signal from the instructor to indicate when it is time for students to move.) Typically students take notes or each group leaves a piece of descriptive feedback at each display. This can be done by using post-its or by using feedback forms that have been specifically designed for the particular activity.
4. Students return to their own work. They might discuss the feedback that has been left by other groups; they might discuss how their work was the same or different than other work they saw; they might add an idea to their work that they gleaned from the work in another group.
5. Students process their work together.

22. One-Stay Three-Stray

Group size: three or four

1. As with the Gallery Tour, this structure is used when group products are displayed.
2. Students count off in their groups.
3. The #1 person in the group rotates one group, the #2 person rotates two groups, and, in a group of four, the #3 person rotates three groups. (Each one of these steps is best done one-at-a-time to eliminate confusion.) One person stays "home." Students are now in totally new groups.
4. The person who "stayed home" now explains their old group's work to the visitors. The visitors frequently take notes and often ask questions to make sure they understand. The visitors give one piece of specific positive feedback to the home group representative about that group's work. They thank the representative for staying home to explain the group's work.
5. Everyone moves back to their home team. First, the person who stayed home tells the other group members what positive things the visitors have said about their work. Next, persons #1, #2, and #3 explain what they have seen in different groups--comparing and contrasting the ideas and formats to their own.
6. Students process their work together.

SECTION III: EXAMPLES USING COOPERATIVE LEARNING IN MINERALOGY

Using informal groups on the first day to begin creating the cooperative classroom

The first day of class can be used to advantage to set the tone for the entire course. Usually mineralogy is an upper-level course for majors, but students may not be ready to begin complex material on the first day. At West Chester, sophomore-level "Minerals and Rocks" is one of the first courses majors take. It is beneficial to use the first class period for the students to get to know one another, for the instructor to gather useful information about the students, and to begin establishing a climate of cooperation.

1. The first activity in the class is used for students to get to know one another and to make the transition from outside to inside the classroom. For example, the instructor may use the Three-Step Interview structure. After roll is called, students are divided into groups of two. For example, in a class of 17, students count off from one to eight, then find the other person(s) with the same number to create seven groups of two (numbers 2-8) and one group of three (number 1). Other methods can be used to put students into groups at random; for example, by handing out index cards with numbers or colored dots ("find someone with the same/different color"); or even by having students select one of a group of minerals ("find the other person with the same/different mineral"). Groups are then directed to "take five minutes to interview each other and find out: your partner's name (first and last); what degree program or major s/he is in; and ONE thing your partner did this summer or over winter break." The instructor tells the groups to make sure everyone has a chance to speak, and that each student will introduce the other to a new group in the next step. This requires students to listen carefully as well as talk. After five minutes, the instructor then directs each pair (or threesome) to join up with another pair, either by proximity, by numbers (e.g., odd numbers together), or by some other method. The new groups (of four or five members) are given five minutes for each student to introduce his/her partner to the new people, thus completing the Three-Step Interview.

2. Additional group activities can be used to collect information that will be useful to the students and to the instructor. For example, the instructor may want to know when and where each student took introductory chemistry, and if anyone has taken a more advanced chemistry course. The instructor may wish to assign students to heterogeneous base groups (or work groups) based on the number of credits completed or specific interest in geology. In order to facilitate the formation of out-of-class study groups, the instructor may want to group students based on other courses they are taking (e.g., calculus or historical geology). This type of information is easily and quickly collected on the first day by giving each group of four or five students one large index card and asking one person in each group to record the information. Having the instructor designate the recorder prevents the common occurrence of groups automatically designating a female member to be the recorder. The instructor can equalize sharing and listening by directing the students to speak in turn beginning with the recorder. A student other than the recorder can be designated to introduce the group members to the class, in order to increase participation by all group members and to connect groups with the rest of the class. This typically takes 1-2 minutes per group for a brief introduction (in the example above with 17 total students, this would take about 4-8 minutes).

3. The instructor may use the groups for more complex tasks, such as reviewing important information on the syllabus or reviewing material from previous courses. For example, each group may be directed to focus on one small part of the syllabus, take five minutes to discuss and summarize the information, and then report to the class. Using this format, students pay more attention than when the instructor reads the syllabus to them. Having students articulate what they remember about course content from previous experiences is one of the most productive ways to use the first week of class. In the Minerals and Rocks course, for example, groups would be given a large sheet of easel paper and some colorful markers and asked to write down everything

they remember about a topic in the course, such as igneous rocks. The instructor can remind the students that they are not expected to have perfect memories, and ask them to flag information they are unsure of and write down any questions they have. These papers can then be used by the instructor as a springboard to provide an overview of the course. The papers can be brought out later in the course and used to introduce new topics, to build understanding, and to identify and correct misconceptions. Such complex work is probably not appropriate for the very first day of class, unless the class meets for several hours once a week.

4. Closure on the first day can be very simple: "Thank your partners for working with you today." More extensive closure activities, such as reflecting on the day's work, can be used if more complex tasks were accomplished.

Using informal groups during lecture

This example describes the simplest way to incorporate cooperative learning into an otherwise traditional class. Asking students to talk with each other about course content has the potential to increase preparation for and participation in class. The key is to use the structures frequently, once a week or more often, particularly during the first few weeks of class in order to establish norms. If students don't come prepared to discuss reading, this structure lets them know that that behavior is unacceptable.

1. The lecture will cover fairly technical content including previously-assigned reading. Instructor puts students in groups of three or four and students count off within groups. Instructor gives students two minutes to think about the questions: "What is one concept you think you understand from your reading?" "What is one thing you need help to clarify?" Instructor gives students five minutes to share their responses in groups, talking in turn starting with "person #2;" students are reminded that <u>each</u> member of their group needs to share responses to <u>both</u> questions within five minutes, (Roundrobin structure). While they talk, instructor walks around and listens to get a sense of how to focus the lecture.

2. Lecture begins; instructor stops about one-third to half-way through time period and puts on an overhead to present students with a problem that is related to the concept they are learning. Students think -- by themselves -- about how they might solve the problem using the information they are learning. Then students take three minutes to share their ideas with their groups and decide on at least one possible way they might solve the problem. After three minutes, instructor calls on one or more students by number and group at random to share their group's idea, (Numbered Heads Together structure). Lecture continues, incorporating additional problems or concept questions, as appropriate.

3. As an alternative to step 2 above, instructor may stop after about ten minutes and put on an overhead to present students with a problem that is related to the concept they are learning. Students think -- by themselves -- about how they might solve the problem using the information they are learning. Then students take three minutes to share their ideas with their groups and decide on at least one possible way they might solve the problem. After three minutes, instructor asks all "persons #1" to stand, rotate one group around the room, and share their group's ideas with a new group, (Stirring Up the Class structure). This process is repeated as lecture continues. The second time, "persons #2" are asked to rotate two groups; the third time "persons #3" are asked to rotate three groups; the fourth time, "persons #4" are asked to rotate.

4. For closure, instructor gives students five minutes to reflect and discuss the questions: "What is one concept that today's class helped you to clarify?" and "What concepts are still fuzzy?" Instructor asks the group to summarize responses in writing and turn in. Alternatively, instructor may ask students to write down what they think is the most important concept of the day, and have groups collect, discuss, and turn these in. Instructor uses the responses to aid in planning.

Using cooperative learning groups and worksheets as an alternative to lecturing: an example for teaching close-packed structures and coordination

The instructor is using two 90-minute lecture periods to present material on close-packed structures, cation sites, coordination, and Pauling's Rules. Lecture is kept to a minimum at the beginning and end of the periods. Instead, the instructor has created two worksheets for the students to complete during class time in order to help them to actively discover, or construct, their understanding of the concepts by playing with models of crystal structures. The cooperative learning groups are long-term (two class periods) but the interactions among group members are quite unstructured. If status or motivation issues are a problem, participation could be equalized by assigning roles to students in the groups, or by assigning specific questions on the worksheet to individual students. The instructor also could simply monitor the groups by calling on group members at random frequently during the class periods.

1. In the first 90-minute lecture period, the instructor divides the class into groups or 2-3 students. Each group is given a tray containing 20-30 styrofoam balls, all of the same size, and a worksheet with a set of instructions and questions. Over the class period, the groups arrange the balls to exhibit different types of close packing, visualize how smaller atoms could fit in the spaces between the layers of styrofoam balls, and answer questions about the atomic arrangements and concepts involving coordination number. The students have to work together, not only to complete the task and share resources, but also to hold the balls in place and keep them from rolling around the box! This subtle but effective lesson in cooperation is lost if groups are larger than 3 students.

2. During the last few minutes of the period, the instructor asks one person from each group to summarize a key piece of information, such as, "How does the size of a site change with coordination number and why?" The instructor asks each person in the class to write down any concepts that are still not clear, and gives the reading assignment from the text that covers the same material as the worksheet and anticipates the next period's material.

3. During the second 90-minute lecture period, the instructor has the students move into the same groups and discuss any questions they still have about the material. After about 5 minutes, students write the most important remaining question on a big sheet of paper or on the board. The instructor introduces the day's topic and objectives (the anticipatory set), in the process answering some questions immediately while highlighting others as topics to be clarified during the day's activity.

4. The instructor then gives each group a worksheet of questions. The groups circulate around the room examining models of different crystal structures. Each group is responsible for answering all questions on their worksheet. Another copy of the worksheet has been left at each model, and each group is also responsible for answering a subset of the questions on these worksheets. When a group arrives at a particular model, they answer all questions on their worksheet and fill in the answers to their subset of questions on the worksheet next to the model. The next group who visits that model answers a different subset of questions on the worksheet next to the model. In answering the remaining questions on their own worksheet, they may compare their answers to those of the previous group. If they disagree with any of the answers of the other group, they can put a sticker or a ? next to those answers. In this way, groups provide feedback to other groups as they circulate among the models and compare answers. The instructor circulates, but can also stay close to those models with the most difficult questions. Keeping the groups small promotes participation, but groups may have to be combined into foursomes if materials are scarce.

5. Alternatively, this same format could be used to have the groups examine specific parts of a computer program and answer questions on a worksheet. One computer in a lab room could be used in conjunction with the crystal models; students could circulate among several computers or

workstations; or students could view other groups' answers and add their own answers using a shared file or directory.

6. With about 20-25 minutes remaining in class, the instructor has the groups review their work and ask each other about any of the flagged answers. After group discussion, the instructor gives an overview of the material covered and clarifies any remaining questions and misconceptions. Just before the class breaks up, the instructor asks each person to turn to a partner in the group and, "Tell the person one thing he or she did that helped you understand or learn something in lab, or that helped the group work well together."

Using formal groups for mineral identification activities to encourage positive interdependence

Any activity that is repeated regularly during a course, such as mineral identification exercises in mineralogy, is a good choice for cooperative learning groups. The example below is designed to help groups evolve higher-quality interaction through positive interdependence (Johnson et al., 1993). The students work toward a common goal of identifying minerals by their physical properties (goal interdependence); they share mineral specimens and tools for testing physical properties (resource interdependence); and they are assigned specific roles or tasks necessary to complete the assignment (role interdependence). Role interdependence is key in promoting cooperation; if students ignore their roles at first, the instructor should be prepared to step in and guide the group back to their role assignments in order for the group to work more efficiently and learn more. The roles are rotated among all students in the group so that each student has ample opportunity to handle specimens, test physical properties, and demonstrate concepts to the group. While roles can be rotated during a single class period, it is easier and less confusing for students to play a single role during class and rotate roles over the duration of the course. Alternative structures are suggested below, depending on class size and time constraints.

1. Students are assigned to groups of three. Each student within each group is given a card with the role assignment -- tester/presenter, fact-checker, or recorder -- and the student signs his/her name on the back of the card. (These cards can be re-used to distribute roles equally among all students). The recorder is given a datasheet prepared by the instructor for recording information about the properties of the minerals. The fact-checker should have a reference source ready, turned to the pages for the day's minerals. The tester/presenter is given a testing kit containing a glass plate, streak plate, etc. If the total number of students is not divisible by three, it is better to have one or two groups of two students, a tester/presenter and a fact checker/recorder.

2. In the first scenario, the total number of minerals to be examined for the period is divided among the groups so that each group has about 3-4 minerals. Within the group, the tester/presenter begins by describing a mineral specimen to the group, performing the tests and pointing out important characteristics. The other students listen carefully and ask questions. The fact-checker checks the information in the reference book while the student is presenting and makes suggestions AFTER the presenter is done. The recorder writes down information on the datasheet, noting questions or discrepancies. The process continues until all specimens are tested and described on the datasheet. A minimum of 15 minutes is needed for 3-4 specimens.

3. As an alternative, if you have many more or fewer students than specimens, divide the mineral specimens into stations spread out in the classroom. There must be at least as many stations as there are groups of students. Try to match the number of minerals at each station with the number of students in the groups; a maximum of 4 different minerals at any one station is good. If you have many more students than minerals to be identified, you may have multiple stations of the same minerals. If you have enough samples of those minerals with different habits, you can put multiple specimens of the same mineral at each station; if not, you can have students look at more than one station. At the station, the students play the roles of tester/presenter, fact-checker, and

recorder as in step 2 above. The process continues until all specimens are tested and described on the datasheet (about 15 minutes for 3-4 specimens).

4. Discrepancies commonly arise between stated and observed properties: for example, hematite and ilmenite samples may contain magnetite; the hardness of hematite may vary greatly among samples. Students may ignore the discrepancies at first(!); but having students play specific roles helps the instructor intervene and ask pointed questions, such as "Tester, show me how this hematite scratches glass," or "Fact-checker, is ilmenite magnetic or non-magnetic," or "Recorder, why did you write down red for streak when this streak is obviously dark brown?" In this way, the instructor can facilitate deeper questioning and learning.

5. Before moving on to a new set of minerals or a new station, each group reviews and discusses its minerals and highlights the MOST DIAGNOSTIC property(ies) on the datasheet.

6. Having the students obtain information about the remaining specimens can be handled in a variety of ways. For example, each group can examine all the specimens independently, either by rotating the sample trays among the groups, or rotating groups among the stations with different mineral specimens, at regular intervals (say, 15-30 minutes). Alternatively, the recorder can stay with the specimens during the rotation process and s/he can teach the new group about the minerals. The simplest and least time-consuming alternative is to have one person in each group (typically the fact-checker or recorder) present the group's minerals to the entire class, listing only the most diagnostic properties. This has the dual advantage of enhancing accountability of the group members with more passive roles, and helping all the students to develop the ability to discriminate among properties and focus on the most important information. The recorder in the other groups writes down the information as it is presented.

7. It is very important to stress each student's responsibility outside of the group work in class. For example, students have to review the entire set of minerals outside class time before any scheduled evaluation, and to prepare by reading the appropriate material in a reference text. Having the wrong information copied on a datasheet does not let the students off the hook!

8. For the last five minutes, the instructor asks students in groups to discuss the questions: "How did the assigned roles make the work more efficient?" and "What could the group do better next time?" While this is taking place, the instructor collects the datasheets and makes photocopies for everyone in the groups (or photocopies and returns the datasheets at a later date).

Using informal groups to promote active learning during mineral identification exams

Having students talk in a structured way during an "open exam" can encourage active learning during the evaluation process. This example describes an open exam on mineral identification. Informal student groups typically re-form every few minutes as students move among the specimens to be identified, but students can work entirely alone on the exam if they prefer. Individual responsibility is promoted by having students prepare "cheat sheets" in advance, and by grading individual exam sheets; there is no group grade for this structure.

1. Students arrive in class having previously prepared "cheat sheets" with information about the minerals. The cheat sheet is graded along with the quiz, and is typically worth around 10-15% of the total grade. The cheat sheet can be a 3 x 5 card, or a double-sided 8 1/2 x 11 worksheet.

2. The instructor has placed unidentified specimens around the classroom. Students circulate among the specimens, test the properties, identify the specimens, and fill out a worksheet listing the most important or diagnostic characteristics of each specimen. Students can talk among themselves and can refer to their cheat sheets. This allows the instructor to use complex specimens that challenge the students' abilities.

3. There is an explicit "No Moocher" Policy (on the syllabus!) that gives the students autonomy: It is each student's responsibility to be prepared for the open exam; no student should feel obligated to help a student who is not prepared; and no one has the right to expect to be given answers. Students can escape "moochers" by simply moving to a different specimen.

4. Open exams typically generate a tremendous amount of discussion among students as they argue over the identification of the mineral specimens. The open format works best if repeated regularly over the course duration so that students become comfortable with the process. Students who "mooch" are quickly ostracized by the group and are easily recognizable to the instructor watching the quiz; such students simply stop mooching after one or two attempts.

5. When the students finish the quiz, they staple the cheat sheet to the exam sheet and turn them in. When all students have finished, the instructor goes around to each specimen and asks for the identification and properties. This takes 5-10 minutes and provides immediate feedback to the students so that any questions are quickly resolved.

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