CONSTRUCTING YOUR COURSE

Constructing Your Course
Table of Contents

Contents	Page No.
Read This First	1
A Road Map to *Powerful Ideas in Physical Science*	2
The Five Instructional Phases	4
Institutional Barriers	6
Research on Teaching and Learning	8
Assessment and Evaluation	12
List of References for Constructing Your Course	34
Reading List for *Powerful Ideas in Physical Science*	35

Read This First

This material is consistent with the physical science content needs of preservice elementary teachers, current research in teaching and learning, and the reform efforts proposed in national reports such as *Science for All Americans: Project 2061*, and the preliminary summaries of the National Science Standards published by the National Research Council for the National Academy of Sciences.

Powerful Ideas in Physical Science is probably different from anything you've previously encountered. It's revolutionary because it's a teaching tool in a new sense. With this six-volume, CD-ROM learning product, you can build a course using flexible materials that meet and pace your personal and conceptual needs as well as those of your students. Written by scientists who collaborated under a National Science Foundation grant, the course consists of six volumes: Light and Color, Electricity, Heat and Conservation of Energy, Nature of Matter, Force, and Motion. They are meant to be used either chronologically or in optional sections

Each volume has Instructor Materials, which are embedded with learning messages to predict and gauge individual and group response for small or large classroom settings, and Student Materials which can be copied, eliminating the need for additional textbooks. Purchasers of *Powerful Ideas in Physical Science* are granted an annual site license from the American Association of Physics Teachers to photocopy the Student Materials and associated text for constructing a course manual for their exclusive use in classes in their institutions. Participants may subscribe to the Pips-1 List Serv (on the AAPT website http://www.aapt.org) to contact others using *Powerful Ideas*.

Each page in the Instructor Notes and Student Investigations/Activities has a traditional page number in the upper left or right corner. In addition, there is also a bold-faced number or footer at the bottom middle of each page [example: **L2.4(2)**], indicating the topic, investigation and activity, and page of the specific activity. These footers are designed to help the user to easily determine their location and to cross-reference each page in the Instructor Notes with the Student Activities. Through simple, observable activities of everyday phenomena and intellectually paced investigations, the instructor of pre-service elementary school teachers can monitor student progress in developing basic physical science concepts and understanding the nature of the scientific inquiry.

The Instructor Materials encompass the **boldfaced** Student Materials. Boldfacing in the instructor section indicates identical instructor-student text.

A Road Map to *Powerful Ideas in Physical Science*

This course model is comprised of six instructional units: Light and Color, Electricity, Heat and Conservation of Energy, Nature of Matter, Force, and Motion.

These units are packaged within this self-contained instructor's resource manual. There is no separate student text; rather, student materials are included herein. This format provides instructors with flexibility in tailoring a course to the unique needs of the student audience, to existing institutional constraints, and to personal preferences for content selection and organization. If desired, instructors can design and produce their own "student text" by judiciously selecting from among the materials included or referenced in the manual.

In this format the instructor's resource manual becomes a "living document" that can continue to be improved and expanded as users find ways to enhance the materials contained in it and as new information about science teaching and learning becomes available.

Each instructional unit in the manual contains the following components:

Instructor Materials: Introduction (Overview, Acknowledgments, General Safety Considerations); Student Notions (Students' Prior Beliefs, Conceptions that Students Should Develop in the Unit); Cognitive Rationale; and Instructor Notes (Equipment List, List of Student Investigations/Activities, Student Activities with Embedded Instructor Notes, Focus on Science, Homework, Sample Assessment, List of References).

Student Materials: Student Activities; Focus on Science; Homework

The course engages students in several different types of activities. Listed below are the characteristic features of each.

Laboratory Activities

Characteristic Features:

- elicit students' prior knowledge
- may be guided by instructor or designed (in whole or in part) by students
- equipment needed is minimal
- space required for equipment is greater than a desk top
- substantial part of class period required
- powerful idea(s) developed

Interactive Demonstrations/Discussions

Characteristic Features:

- elicit students' prior knowledge
- generate valuable interaction among students and between students and instructor in a large group

- instructor demonstrates some phenomena
- powerful idea(s) developed
- not feasible to have multiple sets of equipment

Seat Activities

Characteristic Features:

- generate valuable interaction among students and between students and instructor in a large group
- low equipment needs per person, thus feasible to distribute multiple sets
- space required for equipment is no greater than a desk top
- only a few minutes needed
- powerful idea(s) developed or applied

Design Activities

Characteristic Features:

- multiple-end results
- student creativity utilized
- interesting devices or demonstrations by students
- usually include application of powerful ideas

Homework Assignments

Characteristic Features:

- students given extended time to think about and work with powerful ideas
- usually include application of powerful ideas to situations not previously discussed during class sessions

Focus on Science Readings

Characteristic Features:

- summarize powerful ideas after they have been developed during class sessions
- apply powerful ideas to everyday situations
- make connections between concepts

The Five Instructional Phases

Phase 1. Eliciting and Elaborating the Students' Ideas

Objective: To enable students to realize and express their own ideas.

Methods: Present an observable example of the phenomenon that eventually can be manipulated. Ask for a prediction of what would happen if some particular change is made and write why the prediction seems reasonable.

Personal Introspection – Students write, draw, or describe their own personal predictions and explain why they seem reasonable to them.

Objective: To discover their own raw ideas. Introverts may draw on their own internal resources, extroverts must stop and think before they blurt out their ideas.

Methods: Ask each person to write, draw, etc.

Clarification and Exchange – Students

Objective: To clarify their own ideas by articulating them to others and to discover alternative ideas. All ideas presented are critically examined.

Methods: Students engage in small-group discussion, some reporting back to the whole group (with group-developed posters or other "visual aids" as appropriate to topic); these are followed by large-group discussion. Students should keep notes on the ideas presented, the reasons for giving them, and what they personally think of those ideas. Journal entries during and after class are helpful at this stage.

Phase 2. Testing and Comparing the Ideas with Nature

Objective: To compare the student's beliefs with nature to discover if they make sense, or to search for new ideas. To find clues as to where to search for new proposals.

Methods: Small groups test the predictions, observe and record the results, identify and record matches and differences with predictions, discuss and check new ideas that arise, and report back to the group with drawings or other visual aids. If a number of possibilities have previously been proposed, this can be set up as a critical test of the ideas and students can generate charts to compare how well each checks out against the actual behavior of the phenomenon. Students should keep notes on the ideas presented, the reasons given for them, and what they personally think of those ideas. Some of this is performed as journal entries during and after class.

Phase 3. Resolving the Discrepancies between Ideas

Objective: To generate and test any new or modified ideas about the phenomena that make sense in the light of discrepancies that occurred between the predictions and the actual experiments.

Constructing New or Modified Ideas

Objective: To generate new ideas or modify existing ideas and to explain the discrepancies.

Methods: The whole group discussion evolves from reports of small groups on their experimentation results. Discussions must focus on the ideas and not be addressed to the instructor for validation or approval. Students should keep notes on the ideas presented, the reasons for giving them, and what they personally think of those ideas. Some of this may be performed as journal entries during and after class.

Evaluating New or Modified Ideas

Purpose: To test whether to believe the newly constructed ideas.

Methods: Experimenting and further discussion continue. Students should keep notes on the ideas presented, the reasons given for them, and what they personally think of those ideas. Some of this may be performed as journal entries during and after class.

Repeating the Previous Two Steps Until Ideas Appear to Stabilize

Comparing Ideas with Established Conventions

Objective: To match the newly developed ideas with the approaches and views that scientists have toward those same ideas.

Methods: Instructor provides additional reading, filmstrips, videos, etc. Students should keep notes on the ideas presented, the reasons given for them, and what they personally think of those ideas. Some of this may be performed as journal entries during and after class.

Phase 4. Applying the Ideas

Objective: To become more familiar and comfortable with the newly developed ideas through application to familiar and novel situations.

Methods: Instructor assigns personal writing, problem solving, project work, and continued journal work.

Phase 5. Reviewing and Summarizing of Ideas

Objective: To become aware of changes in ideas and familiarization with the learning process. To allow the pupils to reflect upon the extent to which their ideas have changed, why they decide to change them, and the reasons that the new ideas are plausible.

Methods: Instructor-assigned group discussion, personal writing, review of personal journals, presentations based on discussion and review of journals. Presentations could consist of a variety of visual aids and demonstrations.

Institutional Barriers

Prior to embarking on the development of *Powerful Ideas in Physical Science,* a survey was conducted of deans and department chairs across the country to determine their receptivity to the proposed course model, to elicit their input into the design of the model, and to determine the kinds of difficulties that might be encountered in implementing such a model at their respective institutions.

The more than 100 respondents to the survey were in overwhelming agreement as to the need for physical science courses which are more appropriate for future elementary teachers. One respondent, a dean from a large research university, replied with frank surprise, "Why hasn't the College of Education been banging down the door demanding that changes be made in science course offerings for future teachers?" Several respondents shared efforts undertaken by their institutions, both successfully and unsuccessfully, to provide courses more attuned to the needs of future teachers. There was general concurrence as to the difficulties which must be overcome before implementing a course such as *Powerful Ideas in Physical Science,* although the degrees of difficulty varied with the nature and size of the institution. These barriers to implementation are identified and described below.

Offering the kind of course that is most helpful for prospective elementary teachers requires greater time and effort on the part of the instructor than for most other courses. It is often difficult to find a faculty member who is willing to devote this time and effort, particularly at major research universities where many individuals accept faculty appointments primarily to pursue research. Finding a willing and capable instructor is also made more difficult by traditional faculty reward systems which recognize research and other scholarly endeavors, but pay little heed to teaching effectiveness. Consequently, it is often the "low man on the totem pole" rather than the best qualified individual who is assigned to teach the course typically taken by prospective elementary teachers. It is also not uncommon for this course, or at least the laboratory portion of it, to be taught by graduate teaching assistants.

Additionally, few science faculty have had formal training in the art of teaching, or have kept abreast of research-based developments in teaching and learning. Thus, even if a faculty member is enthusiastic about teaching a course such as *Powerful Ideas in Physical Science,* he/she may understandably lack the requisite pedagogical knowledge and skills. To this end, detailed teacher guidance is supplied in the instructor's resource manual.

Another common obstacle to implementation is that many institutions employ a traditional format for all introductory science courses which is comprised of large-lecture classes and separate, multiple-section laboratory classes. The course described here is designed for use in a class of 20-30 students seated around tables with access to running water and electrical outlets. Many departments are unwilling or unable to adopt this more desirable format because it greatly reduces the student-teacher ratio. Consequently, while *Powerful Ideas in Physical Science* has been designed for small-size classes, suggestions are provided within each unit for adapting the course to a large-lecture format.

Many departments also do not have the kinds of equipment required for a course such as *Powerful Ideas in Physical Science* or the money to purchase the requisite consumable materials. College and university budget cuts have drastically curtailed equipment expenditures and forced departments to set strict priorities for all spending. This is not a problem that is easy to overcome; however, most of the equipment and supplies required for *Powerful Ideas in Physical Science* are relatively inexpensive or can easily be found.

Finally, the survey revealed that a number of institutions had actually initiated efforts to reform the science coursework of prospective elementary teachers, but many of these efforts were short-lived. There were two primary reasons for failure. First, many reforms were undertaken through external grants and lasted little beyond expiration of funding. Second, reforms often hinged on the vision and efforts of a single individual and failed to continue if that individual resigned, retired or moved to other projects. Both of these cases indicate that to assure long-term success, there must be a real commitment on the part of both the school administration and the department faculty.

Effective use of *Powerful Ideas in Physical Science* works best in the ideal climate of a committed and qualified instructor, a supportive department chair, small-class size, appropriate classroom space, and the necessary equipment and supplies. Absence of one or more of these elements makes it more difficult, but certainly not impossible, to implement the course model.

> The American Association of Physics Teachers is committed to providing continued training and support for course users through AAPT meetings and other mechanisms. For further information on course training, contact: PSI-PET, AAPT, One Physics Ellipse, College Park MD 20740-3845. Telephone: (301) 209–3300; http://www.aapt.org.

Research on Teaching and Learning

Theoretical Base

This project provides excellent opportunity to apply much of what has been gleaned about student ideas in physical science, student learning processes, and the physics community's beliefs about teaching and learning to the development of modules used in physics courses for pre-service elementary teachers. The guiding principles for the design of modules, the filter questions, and the phases and methods of approach arise from a wide variety of research efforts that have occurred since the late 1970s. The project has had the luxury of developing modules and recommending teaching and learning procedures based on these research findings. The guiding principles for the design of modules are taken from articles by Scott, Asoko, and Driver (1991) and Richard F. Gunstone (1991). These principles form the basis for the character of the modules and the kinds of activities designed for the students. Each of these principles should be accounted for in some way within each module.

Guiding Principles

Research in teaching and learning strongly suggests that instruction should be designed around the following principles:

1. Students come to new learning situations with "prior knowledge"—beliefs about the physical world, about the roles of students and teachers, and about the nature of science. These ideas influence what students learn. It does not matter what you "say," learners hear what they believe.

   Each of us makes sense of what others say and do based on our own existing understanding of the world. Since it is known that students' comprehension is different in significant ways than the physicists', it is entirely possible for students to construct a profoundly different meaning from what we say and do than we intend and vice versa. This is why assessment and interaction are so crucial, for the instructor must monitor student thinking while students continuously check their notions against each other and those of the instructor.

2. Learning requires organizing ideas, making new connections, and building new ideas. For learning to occur, a recognized need must arise from the learner and what prompts that need is dissatisfaction with existing ideas. As long as learners in classroom experiences can construct meanings consistent with their previously existing beliefs, they will not change those beliefs. Reorganizing ideas requires "interactive" instruction strategies that occur in a social context where students are actively involved in the construction of new ideas and explaining physical phenomena.

If the school can a create a setting conducive to the resolution of these differences and where students have the opportunity to elicit and confront their own beliefs, then there is a better chance that a significant change will occur in their understandings about the world.

3. The learner must first recognize the existence and nature of his or her current conceptions. The learner next decides whether or not to evaluate the utility and worth of these conceptions. Finally, a learner chooses whether or not to reconstruct these conceptions according to new information and group discussion.

PSI-PET Filter Questions

The PSI-PET developers and field testers applied module filter questions during the initial writing/testing stage. Many of these filter questions will have been addressed in the final design of the four modules; some will require daily review within the teaching and learning setting, and all may be used to judge the results of instruction at the close of the course.

Filter Questions:

1. Are you providing students with opportunities to examine their prior knowledge? (Prior Knowledge: The learner's beliefs about the physical world, about the roles of students and teachers, and about the nature of science.)
2. Do you have mechanisms to monitor students' ideas and beliefs throughout the learning process?
3. Are opportunities being provided for students inventing and considering alternate beliefs about how the world works?
4. Are you giving students opportunities to make connections between the new ideas and their previous ideas and experiences?
5. Are you insuring that students' ideas are being treated as valuable by each other as well as the instructor in all cases?

Phases and Methods of Approach in Module Development

The phases and methods originated with Needham and Hill (Needham and Hill 1987) in a report of the Children' s Learning in Science Project at the University of Leeds and have been modified by the developers of this project. While it is recognized that not all phases are present in individual activities, the general purpose—to enable students to become aware and flesh our their own ideas—is the same.

General Methods

The general methods used begin with the presentation of a functioning example of the phenomenon which eventually can be manipulated. Instructors ask for a prediction of what would happen if some particular change is made and for the reasons that explain why the prediction seems reasonable. The purpose of this approach is to give students time for personal introspection and to discover their own ideas. Introverts have time to draw on their own internal resources and extroverts can think before they blurt their ideas. Instructors ask students to write, draw, etc., what their own personal prediction is and explain why that prediction seems reasonable to them.

During the clarification and exchange process class members clarify their own ideas by expressing them to others and discovering alternative ideas. All the ideas presented are critically examined in a small-group discussion (with group-developed posters or other visual aids as appropriate to topic) followed by reporting back to the group as a whole and subsequent large-group discussion. Students will keep notes on the ideas presented, the reasons given for them, and write what they personally think of those ideas. Some of this can be done as journal entries during and after class.

In small groups, students can test their predictions, observe and record the results, identify and record matches and differences with predictions, discuss and check new ideas that arise, and report back to the whole group. If a number of possibilities have been proposed, then this can be investigated as a critical test of the ideas and students can generate experiments to compare how well each checks out against the actual behavior of the phenomenon. The activities give students clues regarding where to search for possible answers that will adjust their thinking regarding these concepts.

To generate and test new or modified ideas about the phenomena that make sense in the light of any discrepancies that occur between predictions and actual experimental results, whole-group discussions based on reports from the small groups focuses students on the ideas rather than instructor validation or approval. Students should always keep notes on the ideas presented, the reasons given for them, and what they personally think of those ideas. Some of this could be done as journal entries during and after class. The instructor may help students evaluate these newly constructed ideas but should avoid endorsing a particular formulation or model until students have developed and articulated a strong supportive case.

The instructor compares the newly developed ideas with those of scientists who refer to these same ideas. Students should note the correspondence between the ideas developed in class and the established scientific conventions for referring to the same ideas. They will become more comfortable with the newly developed ideas through application to familiar and novel situations as well as through personal writing, problem solving, project work, and continued journal work.

An awareness of change in ideas and familiarization with the learning process allows the pupils to reflect upon the extent to which their ideas have changed, why they decided to change them, and the reasons that the new ideas are plausible and acceptable in their view of the world.

Assessment and Evaluation

Assessment is gathering information about students' knowledge, skills, abilities, and attitudes. Assessment may take many forms, for example, tests, problem sets, essays, term papers, journals, laboratory exercises, demonstrations, projects, presentations, extended investigations, interviews, concept maps, and portfolios. Use of computers and other technological tools may be an integral part of producing and recording the results of assessment activities. Evaluation is making judgments based on the information gathered. Assessment and evaluation are pivotal elements of teaching.

If teaching is viewed as synonymous with lecturing, then assessment and evaluation are seen as intrusive, taking away time from teaching. However, when teaching involves facilitating learner-centered activities, then teaching, assessment, and evaluation all blend together and enhance each other. All three are part of interesting and challenging activities related to important themes in the curriculum. Assessment and evaluation should be conducted before, during, and after each instructional unit.

Not only teachers, but also students should be engaged in assessment and evaluation because acquiring the requisite abilities and habits are a critical part of becoming a life-long learner. By having students participate in assessment and evaluation, a teacher can focus on the more substantive aspects of these tasks rather than be overly concerned with record keeping and simplistic inferences. Students can help construct tests for the class, can provide feedback to peers, and can respond on self-assessment sheets.

If evaluations are to be more than opinions, they must be grounded by valid and reliable assessment tools. Performance assessment measures (which elicit from students the behaviors targeted in curriculum goals) should be used more than objective tests (which elicit from students the behavior of choosing the correct response to multiple choice, true-false, and matching questions). To reduce rewards for memorization and routine skills and to increase rewards for critical thinking and complex problem solving, students should have access to books, calculators, and other sources of information during test taking and other assessment activities.

Assessment should be as authentic as possible (given in complex and realistic rather than fragmented and contrived contexts). Authenticity needs to be considered for many facets of assessment including task difficulty, stimuli, spontaneity, and consequences. In authentic assessment, some locus of control rests with the student being assessed. Scoring criteria should be related to behaviors essential to success, not to behaviors easily counted or observed. Some assessment measures that allow for multiple correct responses or products should be used so students do not acquire the misconception that science questions, debates, and controversies always have one right answer. Not all assessment should be done on an individual basis; instead some assessment should be done for cooperative learning groups of students.

Behaviors assessed should be a representative sample of all the goal behaviors. Any ability consistently slighted during assessment is regarded as unimportant by students. Assessment should draw on the strengths of a range of learning styles. Evaluation should be fair to all groups of students, with no biases due to characteristics like gender or race.

A teacher's assessment and evaluation should be reported to his/her students in a clear and meaningful way. Criterion-referenced assessment instruments are better than norm-referenced ones for providing feedback. Labeling students with letter grades is not sufficient. Students should acquire a detailed picture of what they do know, rather than being overwhelmed by a summary of what they do not know. Through activities designed for assessment and through judgment of their results, a teacher should help students direct their energies productively. The end result of good assessment and evaluation should be an increase in students' motivation to learn.

Journals

A journal is a collection of student writings bound together to record the student's ideas over a period of time. The selections need not be long. Even one-half page is sufficient. However, writings should be produced on a regular schedule, for example, every class period or once a week. Each passage should be dated. Length and content requirements may be made by the instructor. Criteria for journal passages should be made explicit to students. It is inadvisable to use a complex scoring rubric for journals because that would focus students' attention on pleasing the instructor rather than on recording their own thoughts. The same amount of credit may be given for each acceptable passage, without further delineation of merit. Rewarding effort and commitment is more important in journal writing than rewarding recall of facts.

Ideally, the instructor will respond to each student's comments each time a passage is written. That might simply be a few words of praise or caution next to the relevant section in a student's journal. It might be a note to see the instructor for extra help. It might be a paragraph explaining a concept discussed in class. If short of time, the instructor could read a random sample of journals each day, making sure all students' journals are read at reasonable intervals. A limitation of this sampling method is that it does not allow the journals to be used as a record of attendance.

If the journals are a record of attendance, the instructor should keep all journals between class sessions. The instructor should make a note in a student's journal whenever that student is absent to prevent the student from adding an entry later to get credit for that day. Time saved by not taking attendance offsets the time required for journal writing.

As an alternative approach, what is written may be owned by the student with certain passages chosen for sharing with the instructor. For this approach, students may write in class or at home. Whatever approach is used, procedures need to be clear to all students before any journal writing is done.

At times, the instructor may ask students to discuss their ideas in pairs or small groups before or after writing those ideas in their journals. Another possibility is for the instructor to summarize the journal responses during a subsequent class session.

One effective method is to devote the last few minutes of each class period (with the exception of test days) for journal writing. In large classes, efficiency in passing out and collecting journals is necessary. Keeping the journals in order of assigned seats works fine. Students may return them by placing them on the last seat in their assigned row. The advantage of using the end of the class period for journals is that students who want to write longer selections can stay a few minutes after class. Otherwise, these students would keep their peers sitting idle until everyone was finished writing.

A prime advantage of journals is that the instructor can get responses from every student during every class period. This advantage is even more important in large sections than in small sections because so few students will speak out in a large group. Although students may be hesitant to write much at the beginning of the course, they will write more substantive passages later on. Students will write in journals ideas they would never say aloud in class or even tell the instructor face-to-face. The chance to express their thoughts develops the interest students have in the course and makes them more open to new knowledge and skills.

The instructor must keep confidential whatever students have shared in writing. Instructor's comments should be specific and honest. In addition, the instructor, recognizing students' sensitivities, should not make hurtful remarks. Anxious students should be given reassurance and encouragement as part of the instructor's comments to them. Students for whom English is a second language should not be berated for writing less fluently than others. Sexist and racist remarks are to be avoided conscientiously. Students need both positive and negative comments, but the balance should favor the positive ones. This will increase students' motivation to participate and to learn.

Instructors need to build students' trust. No one should be penalized through grading or humiliated for expressing ideas in the initial stages of learning about a topic. Students should not get upset with themselves for writing down thoughts they later want to change. *Learning must be viewed developmentally and not seen as a task completed.*

In their journals, relating present knowledge to prior understanding is to be encouraged as evidence of growth. Also, students may record successes in learning, ask questions about material not mastered, request an appointment to get help outside of class, give preferences for topics, comment on classroom interactions, and evaluate classroom activities. Students should periodically make affective responses, such as expressing their frustrations and satisfactions with studying physical science.

The instructor may ask for a general summary of what was learned that day or may ask for a more focused response. An example of the first type of request is

"Outline what you learned today." An example of the second type is "Describe a situation with a pair of action and reaction forces." Students may be asked to give predictions about natural phenomena, too. Another type of prompt is "Watch this demonstration. What do you observe? What inferences can you make about what you see?" Recommend to students that they may include drawings and diagrams. A quotation may be displayed with the instructions to agree or disagree with it. Instructors may ask self-assessment questions, also, like "How well prepared do you feel for the exam day after tomorrow?" or "Of the concepts which we have learned lately, which are you most confident about?" or "For which concept is your understanding the weakest?" Students may be asked to select their favorite activity in a unit and explain why they liked it, or they may be asked to select the most important idea presented in a unit.

Requiring students to put their thoughts in writing makes apparent any gaps in their thinking. By reading students' journals, the instructor can detect misconceptions and naive ideas that are held by the students. (Without this kind of feedback, it is difficult for the instructor to imagine what is in the minds of students.) Based on their expressed beliefs and understandings, class activities may be structured to help students move toward more scientifically acceptable ideas. Journals used in this manner are very good formative evaluation tools to improve courses.

Besides being valuable for assessment, journal writing is a powerful catalyst for thinking. Journals can give students practice with both inductive and deductive thinking. Writing does help clarify and organize one's thinking. Writing can even create ideas that did not exist before the writing began. Also, journals give students opportunities to apply concepts to practical, everyday situations. Journal writing improves ability to use scientific words appropriately, focuses attention on the most important concepts, and improves recall of generalizations.

Writing is learned by writing, so providing opportunities to write is worthwhile even if instruction in writing is not given. Journal writing can be a useful rehearsal that improves performance on essay exams. Because articulation is an asset in nearly all occupations and other activities, journal writing is also valued for long-term growth.

Journal entries are tangible records of once amorphous concepts. In this way, journals aid understanding, preserve insight, and bring order to confusion. Students are empowered when they perceive how much they know and what they need to learn.

Sample Journal Prompts

What previous science courses have you taken? What did you like about them? What did you dislike about them?

What science topics are you confident that you understand?

Summarize what you learned today.

The large (completely filled) helium balloon that you saw in class today floated in air. Why doesn't the small (partially filled) helium balloon that you saw in class today also float in air?

Explain what density is in as many ways as you can.

Why does a ship float?

What happens when water boils?

Are temperature and heat the same thing? If not, how are they different?

Why do the metal parts of a bicycle's handles feel colder than the plastic grips after the bicycle has been outside during a chilly night?

Would you rather have a drink cooled with ice or with ice-cold water? Why?

Will you be burned more from water vapor at 100□ C or from water at 100□ C? Why?

How are the images formed by using a pinhole and a converging lens alike? How are they different?

Where is the image formed by a plane mirror? What evidence do you have to support your answer?

Draw a diagram showing how light bends as it goes through a prism.

What is the difference between a real and a virtual image?

How does a flashlight work?

Draw diagrams showing the ways you tried today to connect a light bulb to a battery. Explain why each circuit did or did not cause the bulb to light.

Will a battery run down sooner if it has more or fewer light bulbs connected to it in series? Why? Will a battery run down sooner if it has more or fewer light bulbs connected to it in parallel? Why?

Are static electricity and current electricity the same thing? If not, how are they different?

How well prepared do you feel for the exam being given during the next class period?

What is the most important thing you learned in this unit?

What did you like most about this course? What did you like least about this course?

Concept Maps

One of the goals of assessment is to gain insight into students' understanding of conceptual linkages. Concept maps, as first developed by D. Bob Gowin and Joseph D. Novak, are diagrams indicating perceived hierarchical relationships among concepts in an activity, an investigation, or a unit.

Each student should draw his/her own concept maps, rather than being provided with maps prepared by the instructor. An exception to this rule may be made when an instructor shows an example of how a concept map is constructed before suggesting or requiring that students construct maps on other topics. The instructor may give one word or several related words to start students on an assigned concept map. Minimum competency is shown by using all the words supplied by the instructor with all the obvious connections written by the student. More understanding is shown by a student who adds appropriate words and forms creative connections in his/her concept map.

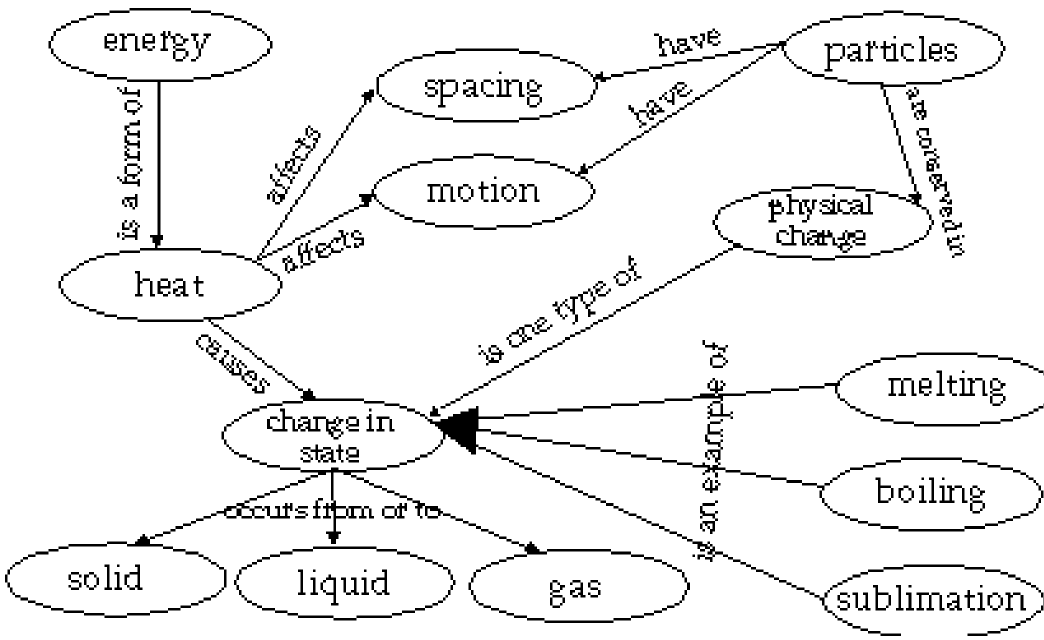
There is no one right way to draw a concept map for a particular topic. Concept maps reveal the propositions (two or more words used to represent concepts along with words connecting these concepts) held by students. Concept maps allow teachers and learners to recognize that some linkages may be inappropriate or missing, a situation that suggests the need for more learning. Creating one's own schema facilitates conceptual change.

Because the preconceptions held by any naive learner are complex, it is impossible to fully assess a learner's initial levels of understanding. However, concept maps (used in conjunction with other methods like interviews) can be useful in this difficult task. Concept maps can also show growth in understanding as a student progresses through investigations.

Sample Topics for Concept Maps

• Light • Reflection • Refraction • Image • Heat • Temperature • Energy
• Change of State • Characteristic Properties of Matter • Density • Viscosity
• Chemical Change • Electrical Circuit • Static Electricity • Current Electricity
• Electrical Resistance

SAMPLE CONCEPT MAP



Interviews

An interview is a structured conversation between the interviewer and one or more students for the purpose of establishing what the students think. A record of an interview is made with written notes, audio tape, or videotape.

An instructor should not interview students he or she is responsible for teaching. Instead, students in a colleague's class should be interviewed to discern patterns in students' thinking about the planned instruction topics for which instruction is being planned. If interviews are needed during a course for diagnostic purposes, the instructor should ask a colleague to conduct the interviews so that the instructor avoids trying to fill two incompatible roles. While teaching, the instructor guides students toward commonly accepted scientific views.

Results from previous research studies may be used to make hypotheses, before and during interviews, about what students think. However, caution must be used whenever students' responses are made to fit into a preconceived framework. Scoring or making any other judgment about students' responses is usually not done.

A planned sequence of questions should be used with impromptu follow-up questions inserted as the situation warrants because of inconsistencies or obscure points in the students' thinking. A variety of questions should be used; for example, those that ask for predictions, descriptions, or explanations. A balance of closed and open questions most quickly puts students at ease. Simple and difficult questions should be alternated to keep students talking. Questions should not allow students simply to agree with the interviewer, but should elicit richer answers. Questions should not (by design or inadvertently) lead students to the correct responses.

During an interview, students may be asked to draw pictures, diagrams, graphs, or concept maps. They may also be asked to classify pictures. Three-dimensional models or other hands-on materials may be provided for students' use. No matter what the task, students should explain their reasoning orally. Drawing, pointing, and manipulating objects all supplement and complement (but do not replace) verbal responses.

The interviewer needs to develop and maintain the students' confidence by being friendly and relaxed. Students should be told that their perspective is important to the interviewer. Waiting time must be generous enough (20 to 30 seconds long) to encourage thoughtful responses. However, embarrassing silences should be avoided. The interviewer should rephrase a question when a student is hesitant to answer. Yet, even the most skillful interviewing cannot make an articulate student out of a taciturn one. A student's right to refuse to answer must be respected with patience, empathy, and kindness.

Understanding is needed, also, when students express doubt about their own statements. Students should be given ample opportunities to justify, explain, and elaborate upon their previous answers. Interrupting a student is never appropriate. Mastery of a generalization may be checked by asking the students to apply it to several common situations.

The interviewer must listen carefully, pondering the students' responses and formulating follow-up questions to clarify points not made clear initially by the students. Students' terminology, rather than formal scientific terminology, should be used in follow-up questions. A student's response may be repeated exactly by the interviewer if necessary to confirm what was said, but a response should not be interpreted and rephrased. The interviewer should explore with sensitivity any unanticipated response and any possible misinterpretations of questions asked. If the interviewer doubts the stability or authenticity of an answer, the question that elicited that answer should be asked again later in the interview with some minor changes. As the interview progresses, the interviewer needs to remember all responses made in order to spot contradictions. Questions should be asked to lead students toward an awareness of their own inconsistencies and to give them a chance to sort out what they really believe about natural phenomena.

The interviewer should refrain from teaching during the interview. Any instructional interventions needed should occur in a different setting on a later day. During an interview, feedback to the students should be kept to a minimum so as not to cue responses to acceptable scientific thinking. The interviewer should monitor carefully his or her own body language, facial expressions, tone of voice, and oral statements that might indicate students' answers are correct or incorrect.

The strength of interviews is that they can provide a detailed assessment of a student's thinking and also can measure a student's confidence in his or her own ideas. Interviewers can distinguish between parroting of information and responding with deep meaning. Interviewers can determine whether a student lacks understanding of a concept or whether a student understands the concept but has labeled it with nonstandard terminology. Interviewers can ascertain if a student holds isolated ideas or if a student has made complex connections between ideas.

Interviews are very useful in formative evaluation to decide upon instructional activities. Interviews may be used, also, to diagnose a particular student's difficulties in learning physical science. Although interviews are time consuming for the interviewer, the amount of information gathered justifies their use.

Sample Interview Questions

How can you arrange this light bulb, battery, and wire so that the bulb glows?

Why do the bulbs burn less brightly when more bulbs are added to this circuit in series?

If you could invent a microscope to magnify this block of wood more than is now possible, what would you see looking through your invention?

In what ways could you classify these household chemicals?

Why can you see an image of yourself in a mirror?

How does a magnifying glass work?

Why does the house get colder if someone leaves the front door open on a brisk autumn day?

If two objects are at the same temperature, do they have the same amount of heat to give off to their surroundings?

Written Explanations

Writing explanations on appropriate topics is an excellent way for students to clarify, organize, and make connections between science concepts. Through this process, students practice applying to situations not previously discussed in class the models and powerful ideas developed throughout the units. Thus students recognize the fruitfulness of these models and powerful ideas.

The text of written explanations generally will not be longer than three typed pages. Explanations should be logically organized. Main ideas should be clearly identified, and useful diagrams should be carefully drawn. No inappropriate information should be included. Well-written explanations will be relatively easy to understand when compared to disorganized, vague, or inconsistent explanations. Before beginning work on an assigned explanation, students should know the criteria that will be used to evaluate their work.

Samples may be provided to students to give them detailed guidance concerning what constitutes a fine explanation. If a sample is on a topic not assigned during the course, the sample may be discussed in class prior to the students completing any explanations. After an instructor collects students' explanations on a particular topic, he/she may distribute a sample on that topic.

Explanations may be evaluated on writing mechanics, neatness, creativity, style, and substance. The amount of substance (correct details, ideas, models, and logic incorporated into both text and diagrams) should determine more than half of the score or letter grade. A rubric may be written for assigning points based on whether criteria are fully met, mostly met, slightly met, or not met at all. The most common practice is evaluation by the instructor, but a peer review system increases the number of opportunities students have to think about the material studied, to evaluate written work, and to enhance group decision-making skills.

One method includes forming committees of three students and making each committee responsible for the evaluation of three other students' anonymous papers (labeled with a student identification number assigned for that course). Students turn in three copies of their explanations, and those are distributed to committees. Each student is then responsible for reading the three explanations given to him/her, preparing to discuss these explanations, and filling out preliminary evaluation forms. Each student may be designated a chief evaluator for one other student's explanation.

During a subsequent class period, each committee meets for approximately one-half hour to discuss and score the three explanations distributed to that committee. Each member provides the group's scores and writes comments on a summary evaluation form for one of the authors read by that committee. Later, every student in the class receives his/her own explanation with summary comments and scores attached.

Each student may be required to make a response to the completed summary evaluation form concerning his/her own work. Students should decide if scoring on the form was fair and was justified by specific constructive comments. Additional points for quality summary evaluation forms may be given to chief evaluators or groups. With good reasons, any student may appeal to the instructor for a review of committee work concerning that student's written explanation.

Sample Written Explanation Tasks

A person starts an experiment with a water bath at a temperature elevated above the temperature of the room. Into the water bath is inserted a test tube containing another substance in the molten state at the same temperature as the water bath. Because the water bath is in contact with the surrounding air, its temperature decreases as time goes on. Ten minutes after inserting the test tube into the water bath, the substance in the test tube begins to freeze. Twenty minutes later, the substance is completely solidified. At this time, a burner is placed under the water bath to heat the water (which is not frozen). Draw a temperature versus time graph showing curves for both the water and the other substance. Extend the time to 90 minutes. Also, describe in words the variations in the temperatures of the water and the other substance. Explain what causes these temperature variations.

A boat sails from saltwater into freshwater. Will the boat float lower, higher, or at the same level in the fresh water as compared to the saltwater? Explain your answer, using both macroscopic and microscopic concepts. Sketch the boat in saltwater and in freshwater. Make diagrams showing particles of saltwater and of freshwater.

A sharp image from a concave curved mirror is formed on a screen located at a smaller distance from the mirror compared to the distance the object is from the mirror. Draw a diagram that shows the arrangement of the object, the mirror, and the image. Explain how the image is formed using powerful ideas from the unit about light.

A circuit is formed by two bulbs (labeled A and B) in series with each other and two more bulbs (labeled C and D) in series with each other. The two pairs of bulbs are wired in parallel with a set of three dry cells. Draw a diagram of this circuit using standard symbols. Bulbs A, B, and C are identical, but Bulb D has more resistance than the other three bulbs. Describe how the electric current is distributed around the circuit. Represent the electric current on your diagram with arrows whose length is proportional to the amount of current and whose direction matches the direction of current. Place an arrow beside each bulb. Also place an arrow beside each wire attached to the set of dry cells. How do Bulbs A and B compare in brightness? How do Bulbs A and C compare in brightness? How do Bulbs C and D compare in brightness? Explain these similarities and differences in brightness.

Questions

Assessment, whether in conventional or alternative forms, should give evidence of students' notions about phenomena studied and should provide insight into students' logic for analyzing the world around them. Distracters for multiple-choice questions should offer choices that fit frameworks often used by naive students. The answer that is counted as correct should make sense only in the context of scientifically acceptable frameworks. Likewise, free response and other types of questions should detect whether students are holding onto old ideas or moving toward the powerful ideas presented in the units studied. Questions constructed in this manner may be used for diagnostic purposes as well as for formative and summative evaluation.

Questions should ask about concepts discussed or skills developed in the units studied. Higher-order thinking should be required rather than memorization. Open book and/or open notes during testing are one method to eliminate the need for memorization. The best questions not only elicit correct answers, but also elicit reasoning for students to arrive at their own answers.

Open-ended questions have several avenues of access and more than one correct answer. They are excellent for generating higher-level thinking. Simply allowing students to supply answers, rather than identify answers, does not make questions open-ended. If nearly identical answers are the only ones counted correct, then the question is free-response (also called open-response), but not open-ended. The practical, demonstration, and free-response word problems discussed below may be open-ended.

When an instructor gives certain numbers of points for various aspects of a student's answer, the instructor is using analytical scoring techniques. This method provides specific feedback for students. Besides that, analytical scoring has more reliability than holistic scoring. However, for many open-ended questions, holistic scoring is less time-consuming and more fair. Often the total answer is more than the sum of its parts, and, therefore, the answer should be judged accordingly. Model answers can be given to students to offset the lack of feedback in holistic scoring.

For either holistic or analytical scoring, a rubric should be written. Rubrics are descriptions of standards or criteria. Usually points are associated with gradations of each standard or criteria. A rubric may be written before evaluating any responses or after looking at a representative sample. Reading all students' responses to a particular question as a set (rather than reading each student's test straight though) can improve the reliability. This procedure can increase the pace of grading in addition to improving the quality of grading. Another helpful technique is to randomly rearrange the order of students' tests before going on to reading the next question in order to minimize the effect of one student's grade on the next student's. In particular, an instructor should be cognizant of the tendency for an excellent answer to make the next answer seem worse than it normally would.

Questions may take many forms, each with its own set of advantages and disadvantages. Over reliance on one type of question should be avoided. Judicious use of several types can give more information about the knowledge and reasoning of various types of learners.

Practical laboratory questions ask students to perform for assessment purposes the manipulation of physical objects (the same as or similar to those already used during class sessions). In addition, the instructor may expect students to apply processes and concepts to new situations. In that case, the instructor may want to provide more apparatus than is necessary to answer the question. That method tests whether or not students can choose appropriate apparatus. Allowing students to request additional supplies and apparatus increases their creativity. Making diagrams and drawings should be encouraged. The instructor may want students to work together or alone for this hands-on work. Sometimes, these exercises are called performance assessment. Scoring can give points for extent of science knowledge, sophistication of laboratory procedure, and ratio of systematic to random problem-solving approaches.

Demonstration questions are another effective way to learn if students can apply concepts. Demonstrations used during tests should be based on the same concepts that students developed during class work. An instructor should seldom speak during a demonstration performed as part of a test. Upon a student's request, the demonstrations should be repeated to ensure that everyone has an adequate chance to see the phenomena. Students should be instructed to write down both observations and inferences. As with practical questions, making diagrams and drawings should be encouraged. Detailed observations with few inferences should correspond to a passing grade. More numerous and complex inferences should earn students higher grades. Demonstration questions are valuable for testing ability to communicate concepts and their interconnections.

Answering free-response word problems may be practiced with patterns already learned by applying concepts to new situations, or extending the construction of familiar concepts. Word problems may require some mathematical calculations and/or graphs. Usually students should be allowed to use calculators or computers for performing calculations and drawing graphs. As with practical and demonstration questions, making diagrams and drawings should be encouraged. Extraneous information should be included in some word problems to test students' abilities to discriminate useful from unuseful information. Data-poor problems should be used, but students need to be told to consider stating assumptions before proceeding to solve the problem. Some students may not have previously seen problems for which students are required to supply reasonable values for some quantities.

Completion questions should be written so that only one important word or phrase completes the sentence given. Deletions should be limited to the central thought of the sentence and should be placed near the end of the sentence. Even when sentences in the reading material assigned to students are paraphrased, lower-level thinking is all that is required to answer most completion questions.

A multiple-choice question consists of a stem in the form of a question or an incomplete sentence followed by several choices, one of which is correct. The other choices are called distracters or foils or decoys. All the choices should be grammatically correct and logically consistent when combined with the stem. For any question, they should be similar in length, parallel in construction, and equally precise in expression. Keyed responses (the correct choices) should be equally frequent at all response positions. If possible, a logical sequence should be followed in placement of the choices for a particular stem. One example of this is placing numerical choices in ascending order. For any multiple-choice question, the choices must be mutually exclusive and unambiguous. Avoid using "more than one of the above," "all of the above," and "none of the above" as choices for answers.

Distracters should contain commonly believed misinformation or widely used erroneous conclusions. Although the distracters must appear plausible to a student with a vague or incomplete understanding of the topic studied, those same distracters must appear obviously wrong to a student with an adequate comprehension of that topic. After a question has been used in a course, the instructor can tally the number of students choosing each option. Distracters chosen by few or no students should be subsequently replaced. The difficulty of a question can be increased by making the choices more numerically or semantically similar.

Multiple-choice questions can be improved by requesting that students give the reasons for their choices. The knowledge of a fact, application of a principle, solution of a problem, and interpretation of a situation can all be tested with multiple-choice questions.

Because true-false items must be judged unequivocally, they tend to test trivia. Sometimes students are required to correct any statement he/she marks false. This method does not increase the amount of knowledge tested because students may simply insert the word "not" into each false statement. Another limitation for true-false items is that guessing can result in a high proportion of correct answers. Scores may be calculated as the number of correct responses minus the number of incorrect responses, but this formula does not totally eliminate the effects of guessing. If true-false questions are used, a disproportionate number of either true or false statements should be avoided. Quantitative expressions should be used instead of qualitative expressions like "few," "large," and "cold." Do not use double negatives either. Compound sentences that are partly true and partly false are not appropriate true-false items. For complex sentences, the main clause should be true so that the subordinate clause determines the truth or falsity of the entire sentence.

Sample Questions

What is the volume of the larger piece of wood? (Provide students with a graduated cylinder, a balance, a ruler, a beaker of water, and graph paper. Also provide two pieces of wood of the same type. The first piece of wood should be regularly shaped—so its volume can be calculated by a formula—and small enough to fit into the graduated cylinder. The second piece of wood should be irregularly shaped and too large to fit into the graduated cylinder.)

Take a culture tube full of water. Hold it over an index card so that the culture tube covers the writing "CHOICE MATERIALS BOOK." Slowly raise the test tube approximately six inches, keeping the culture tube itself horizontal. Repeat using the card with the writing "CHECK OUT THE CODE." What do you observe? Using powerful ideas from this unit, what can you infer about the phenomena you saw? (Words with all letters symmetrical about an axis through the middle of the line of writing are written in one color. Other words are written in another color.)

What do you observe as your instructor performs today's demonstration? Using powerful ideas from the units just studied, what can you infer about the phenomena you saw? (Using four identical bottles with flat rims, fill two with hot water colored yellow and two with cold water colored blue. Invert one bottle with hot water over one bottle with cold water. Then invert the other bottle with cold water over the other bottle with hot water. Place a piece of plastic like a credit card over the mouth of the bottle before inverting it to minimize spills. When the bottles are properly aligned, remove the piece of plastic.)

What do you observe as your instructor performs today's demonstration? Using powerful ideas from the units just studied, what can you infer about the phenomena you saw? (Put a stopper into one end of a piece of glass tubing about 120 cm long with an outside diameter of about 1 cm. Fill the tube approximately half-full of blue-colored water. Being careful not to invert the tube, nearly fill the rest of it with alcohol colored red. Proceed slowly and carefully so that the water and alcohol do not mix. Put another stopper in the top end. Mark the upper level of the alcohol with a glass marker or tape on the glass tubing. During the examination period, invert the tubing several times. Allow students to notice the height of the liquids in the tubing each time you invert the tubing and return it to its original orientation.)

How much heat is given off when 15 grams of water cools from 90□C to 50□C?

What is "used up" when a dry cell no longer works to produce electricity?

What is the equilibrium temperature after 45 mL of water at 65□C is mixed with 30 mL of water at 20□C? Include a temperature/volume diagram with your answer. Assume that no heat is lost or gained from the surroundings of this water mixture.

How could you distinguish between unlabeled identical pint cartons of milk and cream without breaking the seals?

Draw a detailed sketch showing a piece of cardboard, a light bulb (with a single vertical filament), and a screen set up so the shadow of the cardboard appears on the screen. Show on your sketch how you would move only the cardboard to increase the size of the shadow. Can you increase the size of the shadow by moving only the light bulb? Why or why not?

Three U.S. coins minted with the dates of 1873 through 1964 were 90% silver and 10% copper. They were the half-dollar (mass of 12.500 g), the quarter (mass of 6.250 g), and the dime (mass of 2.500 g). On the basis of this information, how much mass do you think a silver dollar had then? These three coins with 1965 or later dates are made of a 19% to 21% silver core and two 80% silver outer layers, and all three have slightly less mass than the equivalent coins dated prior to 1965. Five-cent pieces and one-cent pieces were not changed by the Coinage Act of 1965. Nickels are made of 75% copper and 25% nickel; pennies are made of 95% copper and 5% zinc. What additional information would you need to calculate the mass of a nickel? How would you do this calculation? (Its mass is 5 g.)

On the left side of your paper, draw a detailed sketch of an arrangement of one wire, one bulb, and one dry cell that will allow the bulb to light. Label all objects. On the right side of your paper, draw a circuit diagram for the same situation. Use appropriate standard symbols. Why will your circuit allow the bulb to light?

What word completes correctly the following sentence? If resistance is constant, current would increase when there is an increase in ____________.

What words complete correctly the following sentence? The 80 calories required to change one gram of ice into one gram of water is called the _________________________ of ____________.

Where must a person be to observe a partial solar eclipse?

a) only in the umbra

b) only in the penumbra
c) only in the region of no shadow
d) in either the umbra or the penumbra

If a person is standing waist-deep in a swimming pool, what will be the appearance of that person's legs to another person standing on the grass next to the pool?

a) shorter than the actual legs
b) the same length as the actual legs
c) a few inches longer than the actual legs
d) more than a foot longer than the actual legs

Is the following sentence true or false? There is more current in the wire going into a toaster than in the wire going out of that toaster.

Is the following sentence true or false? A life jacket helps a person float because the life jacket makes him/her weigh less.

Portfolios

A portfolio is a collection of student work that records the student's efforts, progress, plans, insight, and achievement. A student should participate in the selection and organization of documents for the portfolio, following guidelines stated by the instructor (for example, particular categories of evidence required). Portfolios are rich in detail about a student's learning. What is seen as important learning is more encompassing in portfolios than in narrow forms of assessment such as objective tests. Therefore, assessment with portfolios is appropriate for all types of learners.

Instructors find portfolios useful in formative evaluation of the courses they teach and can help both instructors and students identify and meet instructional goals. Before they begin to assemble their portfolios, students should know the criteria that will be used to judge the merit of their efforts. Criteria may address the following aspects of portfolios:

- the amount of evidence included
- the level of organization used
- the quality of the pieces selected
- the variety in the learning substantiated
- the amount of growth in knowledge documented
- the connections between topics made
- the increase in skills established
- the changes in attitudes displayed
- the creativity in compiling shown, and,
- the depth of the reflection statements written

Holistic scoring is recommended for portfolios. Rubrics for scoring will vary according to the instructional goals for the course. Obviously, the scoring must be consistent and unbiased.

Portfolios may begin with a goal statement written by the instructor, whole class, or individual students. Each document put into a portfolio should be labeled with the date it was produced. For group work, all members of the group should be listed on the document. If it is not obvious what the document is, a caption should be provided.

An essential element of portfolios are the reflections written by students. Each document included in a portfolio should be accompanied by a statement giving the reasons for the selection of this document. Students should reflect upon how they produced a document and what knowledge and skills they developed while producing it. They should comment on salient characteristics of the document, aspects that changed as they produced the document, and things they would still like to modify in the document. Students may suggest logical extensions of the work they did to produce the document, possibly with a timeline for accomplishing that supplemental work.

In addition, students need to state what they learned about learning as they produced the document. They should give an appraisal of their own strengths as learners. Also, they need to articulate any changes in their own attitudes that occurred during the learning. Metacognitive and affective awareness regarding both process and product are important. Instructors may want to give students examples of good reflection statements to help students write their own. Reflection statements should be specific, thorough, accurate, and thoughtful. Support of ideas stated should be made by referring to evidence in the portfolio.

Selecting documents and writing reflection statements are valuable instruction activities besides being assessment activities. Students practice higher-order thinking like analysis, synthesis, and evaluation. Self-assessment is a valuable skill throughout one's lifetime.

A prime advantage of portfolios is that they give the students responsibility for their own learning. Portfolios motivate and empower students by making them aware of how much they have accomplished. Portfolios assist students in identifying for themselves which practices improve performance.

Evidence in portfolios may be classified into four categories. Artifacts are samples of usual work such as laboratory reports. Reproductions, like a list of books read, capture situations that are not permanent. Attestations are commendations by someone other than the student compiling the portfolio and include, letters of gratitude, prizes, and acknowledgments of individual effort in group activities. Productions, including the reflection statements, are prepared especially for the portfolio.

Inserting between five and seven documents into a portfolio usually provides enough evidence for the instructor to feel confident in making a judgment about how well a student has met the goals of the course. A student who chooses too many documents for inclusion into a portfolio does not show ability to discriminate. Students should ask themselves, "What additional knowledge, skill, or attitude will I have evidence of by including this piece into my portfolio?" If they cannot supply a concrete answer to this question, then they should omit the document.

Portfolios may be organized in a number of ways. Documents may be put in chronological order. They may be grouped by content themes. Learning goals may be the organizational schema. Another option is to order documents from strongest evidence of learning to weakest evidence or vice versa.

Portfolios may vary in their focus, also. Some are a record of best work, some are a record of a project from beginning to end, some are a record of work in progress, and some are a record of personal favorites. Whatever its focus, a portfolio should portray the student's learning as an adventure that highlights the student's successes along the way and should help the student prioritize his or her efforts on the path ahead.

Sample Items to Include in Portfolios

- Charts and graphs
  - data gathered from hands-on activities
  - data gathered from survey questionnaires
  - data taken from published sources
  - data taken from computer documents
- Drawings
  - observations of natural phenomena
  - diagrams used for solving problems
  - two-dimensional models
  - enrichment activities
- Photographs
  - three-dimensional models
  - bulletin boards
  - cooperative learning activities
- Audio tapes/videotapes
  - oral presentations
  - skill contests
  - project tasks
  - songs
- Written work
  - homework assignments
  - classroom notes
  - outlines of textbook chapters
  - essays/explanations
  - term papers

book reports
laboratory reports
extended investigations
autobiographies
concept maps
letters
poems
test answers

Group Assessment and Evaluation

Group assessment involves a teacher determining the performance level of a small group of two to six students completing a short assignment, an extended project, or a test. Groups consisting of three to four individuals seem to work best. Usually the same number of points, the same grade, or the same descriptor is earned by each member of a group.

Group assessment cannot happen when students are working individually and/or competing with one another. Interaction and communication are restricted when any student views work with others as a waste of time or believes their group effort will lower his/her own norm-referenced grade by raising others' grades. In cooperative situations, students perceive that they can reach their learning goals if, and only if, the other students in their group succeed also.

Cooperative learning involves more than students sitting at a table together and/or sharing laboratory equipment. David W. Johnson and Roger T. Johnson have determined that the following five elements are essential for a cooperative group lesson: positive interdependence, face-to-face interaction, individual accountability, small group and interpersonal skills, and processing about group effectiveness. Robert E. Slavin has formulated cooperative methods around team rewards, individual accountability, and equal opportunities for success.

In cooperative groups, students discuss material with each other, assist one another in understanding concepts, and encourage one another to work diligently. Structuring groups well ensures that no student opts out of or is excluded from class work. Students improve their abilities to articulate generalizations, question assumptions, produce convincing arguments, evaluate ideas, and tolerate ambiguity. Students increase their sensitivity to group dynamics and their respect for others' opinions. Cooperative groups are heterogeneous in verbal and mathematical abilities.

Research studies have shown that cooperative situations are better than individual and competitive situations for producing various outcomes. These include raising academic achievement, creating positive relationships between individuals (both students and faculty), fostering psychological well-being, and forming favorable attitudes toward science.

Several assessment methods work well with cooperative groups. Observations of students interacting as they work through activities can give much information about their reasoning skills, problem-solving abilities, and metacognitive strategies. Group processes may also be observed, for example, speaking unambiguously, asking appropriate questions, listening carefully, synthesizing information, identifying points of disagreement, and facilitating their resolution. Checklists and rating scales may be used to systematize observations.

Grading one activity or laboratory report per group is another useful assessment method. Each student may be required to produce his/her own report before working on the group report. An instructor may grade group reports more thoroughly than individual reports in a given amount of time because there are fewer group reports. If the level of thoroughness is not changed, an instructor will spend less time grading groups reports compared to individual reports.

A third method is oral tests. After the entire group has prepared, the instructor may choose a student at random to answer a question about the topic being studied. Other students in that group may be chosen for other questions. All members of the group pass or don't pass the oral test together.

Written tests are a fourth method of group assessment. They may be given individually with students keeping one copy of their answers and turning the other copy into the instructor. Then a small group of students goes over their answers together and agrees on one revised set of answers that is turned in for additional credit. The reverse procedure is fine, also, with the group test coming first and the individual test following. In either order, the individual test may be closed book and the group test may be open book if that combination fits the instructor's objectives for students' learning.

One potential problem with group assessment is that an ambitious and talented student may take on a very large portion of the group task and then resent the other group members who made only minor contributions but received the same amount of credit as the one who did most of the work. The students who neglected their responsibilities may develop cynicism toward a system that rewards them in spite of lack of effort. Another problematic situation occurs when a student with strong leadership skills overwhelms the rest of the group with his/her ideas even though other members of the group have more extensive science backgrounds or more developed intellectual capacities. The instructor should monitor all groups and intervene if these situations start to develop. Obviously, it is nearly impossible to monitor groups when most of the assigned work is done outside of class periods. Therefore, most group assessment should be done in class.

Each student may be required to sign a statement that he/she individually has accomplished the learning outcomes for a group task. Each may also have to attest to his/her belief that all other members of the group have successfully completed the assignment. These statements should be supplied by the instructor. Varying them periodically helps keep students from signing the statements automatically.

Students may be allowed to turn in a minority report if they cannot reach consensus within their group. When this happens, the instructor should help the group change its style of working together to avoid frequent minority reports.

Group assessment has many positive features. The intellectual discussion and disagreement that occur during group assessment stimulate meaningful learning, cognitive reasoning, divergent thinking, creativity, and long-term retention. Students have chances to get immediate feedback on their ideas. Social skills are practiced and improved during group assessments. Because working cooperatively with classmates is very satisfying to most students, the ratio of intrinsic rewards to extrinsic rewards is higher for group assessment tasks than for individual assessment tasks.

List of References for Constructing Your Course

P.W. Airasian, *Classroom Assessment* (McGraw-Hill, NY, 1994).

Assessment Alternatives in Mathematics: An Overview of Assessment Techniques that Promote Learning, edited by J.K. Stenmark (EQUALS, Lawrence Hall of Science, Berkeley, CA, 1989).

The Assessment of Hands-on Elementary Science Programs, edited by G. Hein (Center for Teaching and Learning, University of North Dakota, Grand Forks, ND, 1990).

Assessment Standards for School Mathematics: Working Draft. (National Council of Teachers of Mathematics, Reston, VA, 1993).

B. Burron, M.L. James, and A.L. Ambrosio, "The effects of cooperative learning in a physical science course for elementary/middle level pre-service teachers," *J. of Res. in Sci. Teach.* **30** (7), 697-707 (1993).

A.B. Champagne and S.T. Newell, "Directions for research and development: Alternative methods of assessing scientific literacy," *J. of Res. in Sci. Teach.* **29** (8), 841-860 (1992).

A. Collins, "Portfolios for assessing student learning in science: A new name for a familiar idea?" edited by A.B. Champagne, B.E. Lovitts, and B.J. Calinger in *This year in school science 1990: Assessment in the service of instruction* (American Association for the Advancement of Science, Washington, DC, 1990), pp. 157-166.

Curriculum and Evaluation Standards for School Mathematics (National Council of Teachers of Mathematics, Reston, VA, 1993).

D.B. Gowin and J.D. Novak, *Learning How to Learn* (Cambridge University Press, NY 1984).

M. Hamm and D. Adams, "Portfolio assessment: It's not just for artists anymore," *Sci. Teach.* **58** (5), 18-21 (1991).

D.W. Johnson and R.T. Johnson, "Encouraging student/student interaction," *Research Matters – to the Science Teacher.* (National Association for Research in Science Teaching, Manhattan, KS, 1986).

D.W. Johnson and R.T. Johnson, "Group assessment as an aid to science instruction," edited by A.B. Champagne, B.E. Lovitts, and B.J. Calinger in *This Year in School Science 1990: Assessment in the Service of Instruction* (American Association for the Advancement of Science, Washington, DC, 1990) pp. 149-156.

D.W. Johnson, R.T. Johnson, E.J. Holubec, and P. Roy, *Circles of Learning: Cooperation in the Classroom* (Association for Supervision and Curriculum Development, Alexandria, VA, 1984).

F. Lawrenz, "Authentic assessment," *Research Matters – to the Science Teacher.* (National Association for Research in Science Teaching, Manhattan, KS, 1991).

R.A. Lonning, "Effect of cooperative learning strategies on student verbal interactions and achievement during conceptual change instruction in 10th grade general science," *J. of Res. in Sci.Teach.* **30** (9), 1087-1101 (1993).

K.M. Markham and J.J. Mintzes, "The concept map as a research and evaluation tool: Further evidence of validity," *J. of Res. in Sci. Teach.* **31** (1), 91-101 (1994).

Mathematics assessment: Myths, Models, Good Questions, and Practical Suggestions, edited by J.K. Stenmark (National Council of Teachers of Mathematics, Reston, VA, 1991).

Measuring What Counts: A Conceptual Guide for Mathematics Assessment, (Mathematical Sciences Education Board, National Research Council, National Academy Press, Washington, DC, 1993).

J.D. Novak, "Concept mapping: A useful tool for science education," *J. of Res. in Sci. Teach.* **27** (10), 937-949 (1990).

Wolff-Michael Roth and A. Roychoudhury, "The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students," *J. of Res. in Sci. Teach.* **30** (5), 503-534 (1993).

R.E. Slavin, *Cooperative Learning: Student Teams* (National Education Association, Washington, DC, 1987).

J.H. Wandersee, "Concept mapping and the cartography of cognition," *J. of Res. in Sci. Teach.* **27** (10), 923-936 (1990).

Reading List for *Powerful Ideas in Physical Science*

P.W. Airasian, *Classroom Assessment* (McGraw-Hill, NY, 1994).

B. Andersson, "Pupils' conceptions of matter and its transformations (age 12–16)," in *The Proceedings of the Second Jerusalem Convention on Education*, 1–49 (1989).

B. Andersson, "Pupils' explanations of some aspects of chemical reactions," *Sci. Edu.* **70**, 549–563 (1986).

Assessment Alternatives in Mathematics: An Overview of Assessment Techniques that Promote Learning, edited by J.K. Stenmark (EQUALS, Lawrence Hall of Science, Berkeley, CA, 1989).

The Assessment of Hands-on Elementary Science Programs, edited by G. Hein (Center for Teaching and Learning, University of North Dakota, Grand Forks, ND, 1990).

Assessment Standards for School Mathematics: Working Draft. (National Council of Teachers of Mathematics, Reston, VA, 1993).

J. Barber, "Chemical reactions," in *Great Explorations in Math and Science (GEMS)*, Lawrence Hall of Science (University of California Berkeley, Berkeley, CA, 1986).

S. Bendall, F. Goldberg, and I. Galili, "Prospective elementary school teachers' prior knowledge about light," *J. Res. Sci. Teach.* **30** (9), 1169–1187 (1993).

G. Berkheimer, *Matter and Molecules Teacher's Guide: Science Book, Occasional Paper No. 121,* Institute for Research on Teaching (Michigan State University, East Lansing, MI, 1988).

C.L. Borgford and L.R. Summerlin, *Chemical Activities* (American Chemical Society, Washington, DC, 1988).

A. Brook, H. Briggs, B. Bell, and R. Driver, *Aspects of Secondary Students' Understanding of Heat*, Children's Learning in Science Project (Center for Studies in Science and Mathematics Education, Leeds, UK, 1984).

M.E. Buegler, "Discovering density," in *Great Explorations in Math and Science (GEMS)*, Lawrence Hall of Science (University of California Berkeley, Berkeley, CA, 1988).

B. Burron, M.L. James, and A.L. Ambrosio, "The effects of cooperative learning in a physical science course for elementary/middle level pre-service teachers," *J. of Res. in Sci. Teach.* **30** (7), 697-707 (1993).

A.B. Champagne and S.T. Newell, "Directions for research and development: Alternative methods of assessing scientific literacy," *J. of Res. in Sci. Teach.* **29** (8), 841-860 (1992).

Chemsource, Episode 2, videotape produced by Sourceview Videotapes (distributed by American Chemical Society, 1155 Sixteenth Street, NW, Washington, DC 20036; released 1993), :, 11 min.

Children's Ideas in Science, edited by R. Driver, E. Guesne, and A. Tiberghien (Open University Press, Philadelphia, PA, 1985).

A. Collins, "Portfolios for assessing student learning in science: A new name for a familiar idea?" edited by A.B. Champagne, B.E. Lovitts, and B.J. Calinger in *This year in school science 1990: Assessment in the service of instruction* (American Association for the Advancement of Science, Washington, DC, 1990), pp. 157-166.

C. Conery, "The reality of an image," *Phys. Teach.* **21** (9), 589 (1983).

R. Driver, "Research in physics learning: Theoretical issues and empirical studies," in *International Workshop on Research in Physics Learning: Theoretical Issues and Empirical Studies in University of Bremen*, edited by R. Duit, F. Goldberg, and H. Niedderer (Institute for Science Education [IPN] 1991), p. 403.

R. Driver and B. Bell, "Students' thinking and the learning of science: a constructivist view," *School Science Review* **67** (240), 433–456 (1986).

R. Driver and T. Russell, *An Investigation of Ideas of Heat, Temperature and Change of State of Children Aged Between 8 and 14 Years* (University of Leeds and Chelsea College, London, UK, 1982).

R. Duit, W. Jung, and von C. Rhoneck, *Aspects of Understanding Electricity*. (Institute for Science Education (IPN), University of Kiel, Kiel, Germany, 1985).

N.H. Fredette, and J.J. Clement, "Student misconceptions of an electric circuit: What do they mean?" *J. College Sci. Teach.* 280–285 (March, 1981).

D.L. Gabel, *Introductory Science Skills* (Waveland Press, Prospect Heights, IL, 1993).

D.L. Gabel and D.M. Bunce, "Research on chemistry problem solving," in *Handbook of Research in Science Teaching and Learning,* edited by D.L. Gabel (National Science Teachers Association, Washington, DC, 1994).

C. Gale and J. Layman, "The influence of microcomputer-based labs on intuitive conceptions of temperature and temperature changes," dissertation, University of Maryland, College Park, MD, 1992.

I. Galili, S. Bendall, and F. Goldberg, "The effects of prior knowledge and instruction on understanding image formation," *J. Res. Sci. Teach.* **30** (3), 271–301 (1993).

I. Galili, F. Goldberg, and S. Bendall, "Some reflections on plane mirrors and images," *Phys. Teach.* **29** (7), 471–477 (1991).

F. Goldberg, S. Bendall, and I. Galili, "Lenses, pinholes, screens and the eye," *Phys. Teach.* **29** (4), 221–224 (1991).

F. Goldberg and I. Galili, "Left-right conversions in a plane mirror," *Phys. Teach.* **31** (8), 463–466 (1993).

F. Goldberg and L.C. McDermott, "An investigation of student understanding of the real image formed by a converging lens or concave mirror," *Am. J. Phys.* **55**, 108–119 (1987).

F. Goldberg and L.C. McDermott, "Student difficulties in understanding image formation by a plane mirror," *Phys. Teach.* **24** (8), 472–480 (1986).

D.B. Gowin and J.D. Novak, *Learning How to Learn* (Cambridge University Press, NY 1984).

R.F. Gunstone, "Constructivism and metacognition: Theoretical issues and classroom studies," in *International Workshop on Research in Physics Learning: Theoretical Issues and Empirical Studies in University of Bremen,* edited by R. Duit, F. Goldberg, and H. Niedderer (Institute for Science Education [IPN] 1991), pp. 129–140.

U. Haber-Scham, J.D. Cross, G.L.Abegg, J.H. Dodge, J.A. Walters, *Introductory Physical Science* (Prentice Hall, Englewood Cliffs, NJ, 1972).

M. Hamm and D. Adams, "Portfolio assessment: It's not just for artists anymore," *Sci. Teach.* **58** (5), 18-21 (1991).

D. Hestenes, *Role of Models in Introductory Physics,* (1993).

D. Hestenes, "Toward a modeling theory of physics instruction," *Am. J. Phys.* **55** (5), 440–454 (1987).

D.W. Johnson and R.T. Johnson, "Encouraging student/student interaction," *Research Matters – to the Science Teacher.* (National Association for Research in Science Teaching, Manhattan, KS, 1986).

D.W. Johnson and R.T. Johnson, "Group assessment as an aid to science instruction," edited by A.B. Champagne, B.E. Lovitts, and B.J. Calinger in*This Year in School Science 1990: Assessment in the Service of Instruction* (American Association for the Advancement of Science, Washington, DC, 1990) pp. 149-156.

D.W. Johnson, R.T. Johnson, E.J. Holubec, and P. Roy, *Circles of Learning: Cooperation in the Classroom* (Association for Supervision and Curriculum Development, Alexandria, VA, 1984).

A.H. Johnstone, "Fashions, fads and facts in chemistry education," Paper presented at the American Chemical Society Meeting, Washington, DC, 1990.

S. Joshua and J.J. Dupin, "Taking into account student conceptions in instructional strategy: An example of physics," *Cognition and Instruction*, **4** (2), 117–135 (1987).

S. Kesidou and R. Duit, "Student's conceptions of the second law of thermodynamics—an interpretive study," *J. Res. Sci. Teach.* **30** (1), 85–106 (1993).

J.S. Krajcik, "Developing student's understanding of chemical concepts," in *The Psychology of Learning Science,* edited by S.M. Glyn, R.H. Yeany, and B.K. Britton (Lawrence Erlbaum Associates, Hillsdale, NJ, 1991) pp. 117–147.

J. Krajcik and J. Layman, "Middle school teachers' conceptions of heat and temperature: Personal and teaching knowledge," *National Association for Research in Science Teaching,* 62nd Annual Meeting, San Francisco, CA, March 30 – April 1, 1989.

F. Lawrenz, "Authentic assessment," *Research Matters – to the Science Teacher.* (National Association for Research in Science Teaching, Manhattan, KS, 1991).

R.A. Lonning, "Effect of cooperative learning strategies on student verbal interactions and achievement during conceptual change instruction in 10th grade general science," *J. of Res. in Sci.Teach.*, **30** (9), 1087-1101 (1993).

K.M. Markham and J.J. Mintzes, "The concept map as a research and evaluation tool: Further evidence of validity," *J. of Res. in Sci. Teach.* **31** (1), 91-101 (1994).

Mathematics assessment: Myths, Models, Good Questions, and Practical Suggestions, edited by J.K. Stenmark (National Council of Teachers of Mathematics, Reston, VA, 1991).

L.C. McDermott and P.S. Shaffer, "Research as a guide for curriculum development: An example from introductory electricity, Part I: Investigation of student understanding," *Am. J. Phys.* **60** (11), 994–1003 (1992).

Measuring What Counts: A Conceptual Guide for Mathematics Assessment, (Mathematical Sciences Education Board, National Research Council, National Academy Press, Washington, DC, 1993).

Modes and Conditions of Learning. An Example: The Learning of Some Aspects of the Concepts of Heat, edited by A. Tiberghien, Cognitive Development Research in Science and Mathematics (University of Leeds Printing Service, Leeds, UK, 1980).

S. Morkin, "Cabbage juice pictures," *Science and Children* **30** (2)**,** 9 (1992)**.**

S. Morris and J. D. Barnard, "Conceptually Oriented Program in Elementary Science (COPES)," (New York University, NY, 1965).

R. Needham and P. Hill, "Teaching strategies for developing understanding in science," Center for Studies in Science and Mathematics Education (The University of Leeds, UK, 1987), pp. 1–39.

J.D. Novak, "Concept mapping: A useful tool for science education,"*J. of Res. in Sci. Teach.* **27** (10), 937-949 (1990).

Operation Physics, *Heat*, (American Institute of Physics, College Park, MD, 1990).

Operation Physics, *Matter and Its Changes,* (American Institute of Physics, Washington, DC, 1989).

M.O. Pella, R.A. Green, R.L. Doran, and R. Roy, *Classroom Materials for Teaching "the particle nature of matter," Practical Paper No. 173,* Wisconsin Research and Development Center for Cognitive Learning (University of Wisconsin, Madison, WI, 1971).

M.O. Pella, R.A. Green, R.L. Doran, and R. Roy, *Teaching the Conceptual Scheme "the particle nature of matter" in the Elementary School, Technical Report No. 173,* Wisconsin Research and Development Center for Cognitive Learning (University of Wisconsin, Madison, WI, 1971).

R.W. Peterson, *Teaching Physics Safely: Some Practical Guidelines in Seven Areas of Common Concern in Physics Classrooms* (American Association of Physics Teachers, College Park, MD, 1979).

Wolff-Michael Roth and A. Roychoudhury, "The concept map as a tool for the collaborative construction of knowledge: A microanalysis of high school physics students," *J. of Res. in Sci. Teach.* **30** (5), 503-534 (1993).

B.A. Sawrey, "Concept learning versus problem solving: revisited,"*J. Chem. Edu.* **67**, 253–254 (1990).

Science Curriculum Improvement Study, (SCIS) (Rand McNally & Co., Chicago, IL, 1970).

P.H. Scott, H.M. Asoko, and R.H. Driver, "Teaching for conceptual change: A review of strategies," in *International Workshop on Research in Physics Learning: Theoretical Issues and Empirical Studies in University of Bremen,* edited by R. Duit, F. Goldberg, and H. Niedderer (Institute for Science Education [IPN] 1991), pp. 310–329.

P.S. Shaffer and L.C. McDermott, "Research as a guide for curriculum development: An example from introductory electricity, Part II: Design of instructional strategies," *Am. J. Phys.* **60** (11), 1003–1013 (1992).

D.M. Shipstone, "A study of children's understanding of electricity in simple DC circuits," *European Journal of Science Education*, **6** (2), 185–198 (1984).

D. Singer, "The location of virtual images in plane and curved mirrors," *Phys. Teach.* **17** (8), 534–535 (1979).

R.E. Slavin, *Cooperative Learning: Student Teams* (National Education Association, Washington, DC, 1987).

J.R. Taylor, "Firewalking: A lesson in physics," *Phys. Teach.* **27** (3), 166–168 (1989).

J.H. Wandersee, "Concept mapping and the cartography of cognition," *J. of Res. in Sci. Teach.* **27** (10), 923-936 (1990).

J. Wessner and L. Ukens, *Activities in Physical Science: A Nontext* (Towson State University, Towson, MD, 1993).