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Topic Overview

Chemistry is terribly interesting! I never knew that things could change so much. I mean, you could have a rock one moment and a flower the next. They always show you that on cartoons. I was thinking, obviously, that's not possible, but when I got into chemistry, I saw that things comparable to that could happen! I was just completely amazed. I'd always wanted to know the chemical aspect of that.

Allison Garner

Interviews with students during videotaping of exemplary high school chemistry teachers in their classrooms last year, revealed diverse perspectives on learning and teaching of high school chemistry.

Many students, such as Allison Garner, thought that chemistry was great. Other students had reservations and appeared to be enrolled in the class to “please their parents,” “get into college” or “become a doctor.”

There are many reasons why students enroll in chemistry and why it is taught at the high school level. Sometimes these reasons are at odds with one another. Sometimes the students only have extrinsic motives to succeed. Isn't the dream of every high school chemistry teacher to have a classroom filled with students similar in attitude to Allison who was studying chemistry because she wanted to “know the chemical aspect” of the changes in the world surrounding her?

High school teachers give many reasons for teaching chemistry. These include teaching critical thinking skills such as problem solving, helping students acquire an understanding of the nature of scientific inquiry, and enabling students to appreciate and enjoy the world around them. In reality, however, many of these most worthy goals go unaccomplished because of external pressures to cover the book or to have students score well on examinations. Would it not be better to partially achieve the aforementioned goals at the expense of “covering the book” in order to have students emerge from the introductory chemistry course as excited about chemistry as was Allison?

Teaching is a very complex human activity. Human beings are very complex organisms. What motivates one student to learn chemistry may not motivate another student. For example, research shows that males and females have different learning preferences. If the purpose of teaching high school chemistry is to help students learn chemistry content, improve their critical thinking skills, appreciate the world about them, and develop or maintain a positive attitude toward science, steps must be taken to assure that the strategies teachers use do this for every student enrolled in chemistry courses. If students do not think that chemistry is fun, and if students are not intrinsically motivated to study, they will be less likely to succeed. This negative attitude not only reduces the likelihood of their pursuing a scientific career, but may be transmitted to their children and to future generations.
This chapter is about learning and teaching high school chemistry. A brief examination of what both research and students say about these topics sets the stage for the theoretical underpinnings on how students learn. Specific instructional strategies that teachers have found effective in motivating their students, will be presented for improving classroom instruction, enhancing problem solving, and facilitating laboratory learning.

Results of a recent international study on science achievement indicate that students in the United States score lower in chemistry than students in most other industrialized countries. Does this mean that students understand less chemistry? Just how much chemistry do students understand when they enter the chemistry class and how much do they understand when they emerge? How do students feel about chemistry? How do they characterize good teaching or effective teachers? Before discussing teaching strategies, it is important to know what students are learning in the chemistry classroom, and students' perceptions of good teaching.

In the past 15 years, numerous studies on concept learning and problem solving have indicated that students enrolled in science classes understand few chemistry concepts and solve chemistry problems using algorithmic methods. These deficiencies are not apparent from students' scores on standardized tests which frequently ask questions requiring factual knowledge or solutions to problems that can be solved algorithmically with little understanding. It is when students are interviewed and asked to explain their answers that their lack of conceptual understanding becomes apparent. For example, Yarroch (1) interviewed high school chemistry students who were able to balance simple equations correctly by inspection. He found that 50% of the students who balanced equations correctly could not represent the coefficients and subscripts at the particle level. These students represented 2 NH₃ as 0000000 rather than as 000 000, or used some other incorrect representation. This is corroborated in a study using interviews by Lythcott (2) and in an analysis of carefully constructed multiple-choice test items by Friedel and Maloney (3).

Studies on children's conceptions of matter abound. A classic study by Osborne and Cosgrove (4) examined 12 to 17 year-old New Zealand students' conceptions on what happens to the chemical species of water as it boils, evaporates, and condenses. They found that while students' naive conceptions generally decreased with age, 40% of the 17 year-old students thought that the bubbles in boiling water were made of hydrogen and oxygen, 30% thought that water changed to oxygen and hydrogen when it evaporated, and 35% thought that hydrogen and oxygen combined to form condensation on the outside of a cold jar. In fact, some of the 17 year-olds even thought that the water seeped through the glass to form the condensation. Although it is difficult to believe that students in the United States could be so naive, a student in a chemistry class of a teacher who was being observed for the SourceView project asked out of the blue, “You know the water that appears on the outside of a cold glass, I have always wondered how the water got through the glass. Could you tell me?”

Conceptions that students have about relatively simple chemical concepts persist even after students have taken numerous chemistry courses. Bodner (5) reports that chemistry graduate students still have naive conceptions after an undergraduate
major in chemistry. He found that almost 20% of the graduate students thought that the bubbles in boiling water consisted of air or oxygen and that 5% indicated that they contained a mixture of hydrogen and oxygen gases. He also reports on other misconceptions held by these students on such topics as temperature and heat, and rusting of iron and weight. Several examples of students’ lack of expected conceptual knowledge are shown in the SourceView videotapes. In Episode Four, Ms. Briner asks students if it is possible to have a concentrated, weak acid? The question, which was asked after students had studied molarity and after a brief explanation of acid strength had been given, is answered “no” by a number of students. Another example is shown in Episode Five by Ms. McKibbin who asks her class what gas is being given off after she drops dry ice in cylinders of water containing indicators. Students are unsure of the answer and some indicate that it might be hydrogen, oxygen, or even ammonia.

Research on problem solving also indicates that students solve problems without understanding much chemistry. Greenhowe (6) concluded that undergraduate college students solving problems aloud frequently used an algorithmic approach, and they were unable to solve problems requiring unique solutions. Gabel, Sherwood, and Enochs (7) found not only that students could not solve transfer type problems, but students were unable to answer qualitative questions about them. For example, more students could solve molarity problems correctly using the formula, \( M = \text{moles/liter} \), than could describe how to make up two liters of a 1.0 M solution of sodium chloride in the laboratory. In another study on problem solving at the college level, Bunce and Gabel (8) interviewed students on how they went about solving chemistry problems. When asked whether they thought about the physical phenomena involved, students indicated that this was not necessary. One just found the formula or pattern that fit, that is, the “Rolodex approach” to problem solving. Additional information on these studies and many other studies on conceptual understanding and problem solving have been reviewed by Gabel (9), Krajcek (10) and Gabel and Bunce (11).

**STUDENT PERSPECTIVES ON CHEMISTRY TEACHING AND LEARNING**

Chemistry teaching involves much more than lecturing to students who dutifully take notes and answer questions. It involves more than the performance of certain teaching strategies that will be described later in this chapter. Effective teaching is an art that depends not only on the depth of the content knowledge of the teacher, his or her ability to use appropriate strategies that motivate the students to learn, but also on human characteristics such as the personality of the teacher, and their respect for students.

As part of the SourceView project, students were interviewed on a variety of topics. Some of the questions asked focused on chemistry teaching; others asked students what they liked best about chemistry. Sixty-three students were asked what made an effective or exemplary teacher. The most common response (16 students) was the teacher had a sense of humor or made the class fun. The next most common response was that the teacher made the subject matter clear (10 students). This was followed by the comment that effective teachers made the class feel relaxed and students not afraid to answer (9 students). Interestingly, only four students mentioned that understanding the subject matter was an important characteristic of a good teacher. To sort the data, student comments were categorized into two groups according to whether they were related to the subject matter knowledge and the teaching methodology (such as using demonstrations and making comparisons), or according
to whether they related to relationships between the teacher and students or personality characteristics (such as understanding, open-mindedness and enthusiasm). Students overwhelmingly cited the latter as characteristics of effective teachers. Of 146 comments made by students, 37 pertained to the content and methods whereas 109 were related to relationships and personality.

Three high school principals were also asked what they thought were important characteristics of effective teachers. It is interesting that two of three principals said that love, respect, and concern for students was the number one characteristic of an exemplary teacher. Two of three included a strong content base as another desirable characteristic, but this was ranked second and fourth. These data corroborate other research on teaching that excellent teachers not only know the subject matter well, but also have good rapport with students.

Certain aspects of chemistry are more appealing to high school students. When asked about what they liked best about chemistry, about “what turned them on,” 45 of 64 students interviewed mentioned laboratory experiments. Many explained that it was exciting or interesting to actually see things happening. Twenty-five of this group said they liked chemistry because it was related to everyday life and helped them understand things around them. Other replies repeated by three or more students were problem solving (5 replies) and that chemistry was challenging (3 replies). On the other hand, when these same students were asked what they disliked about chemistry, the responses were more varied. The most disliked part of the course was problem solving (13 replies). This was followed by memorization (12 replies), equations (7 replies), lectures (6 replies), hard work (5 replies), formulas (4 replies), laboratory experiments (4 replies), and not understanding small things such as atoms, protons, quarks, etc. (3 replies). Interestingly, six students said there was nothing they disliked about chemistry.

Although this was not a random sample of all students enrolled in the videotaped chemistry classes, but consisted of students selected by their teachers for interviews, and thus might represent more articulate students, it is interesting that the laboratory and relating chemistry to everyday life was mentioned so frequently as reasons why students liked chemistry. This also makes a statement about what was occurring in the classrooms that were videotaped. Teachers in those classrooms were selected to participate in the project because they made few conceptual errors and had good rapport with students. They were considered exemplary teachers and most had also received or were nominated for teaching awards. Apparently in teaching, they made chemistry exciting by taking time relating chemistry to everyday life and having students perform laboratory experiments. Because of the importance of the laboratory, Part Three of the Source View videotapes focuses on Laboratory Instruction. Numerous examples throughout all episodes relate chemistry to everyday life. Episode Eight, showing students in a role-playing simulation of a town meeting, is particularly effective in engaging students in a real world application.
Over the years my chemistry teaching has changed. In the beginning, I felt the coverage of all topics in the book was most important, whether the students truly understood them or not. But now, I firmly believe that if I cover just a few concepts, and they have a genuine understanding of those concepts, that provides the foundation for the further advancement of their knowledge.

Karen McKibbin

Unfortunately, all chemistry teachers have not come to the same realization about how students learn chemistry as Ms. McKibbin, one exemplary teacher featured on the SourceView videotapes. Many teachers believe that if telling is teaching, then listening is learning. They present chemistry concepts as if students’ minds are blank tablets. Lectures are delivered at a fast pace, and little time is allotted for student interaction, determining preconceptions students have about concepts, and engaging students in laboratory and other activities. Teachers using this approach should not be surprised that students neither learn nor enjoy chemistry. Today’s views of how students learn differ from those that behaviorists proposed in the mid-sixties and that have influenced how teachers were encouraged to teach for the past 25 years.

An Information Processing View

Cognitive psychologists theorize that learning takes place in several steps. In general, individuals use their senses for the input of knowledge. Some of this knowledge enters the short term or working memory and eventually is stored in long term memory until it is needed for further use.

Much knowledge that one senses, however, is never remembered. For example, a teacher does not remember what each student is wearing even moments after looking at the class. Few teachers can remember all the students’ names on the first day of class even after making an effort to do so! Certain information obtained through the senses is filtered out and other information filters through to short term or working memory. If a student is wearing an outlandish sweatshirt, or if a student has a nonconventional name, these generally aid the teacher in remembering what the student was wearing or his or her name momentarily.

Information that gets into short term memory remains there a very short period of time—about 15 seconds. In addition, many small pieces of information enter the short term memory at one time. How many people can remember their nine digit zip code the first time they hear it or read it, much less a chemical formula? Once information has entered into short term memory, it will either disappear or enter long term memory. Since one of the goals of education is to facilitate learning, it is important to understand ways information entering short term memory is transferred into long term memory. One way is through repetition. If a person repeats a zip code enough, or writes the formula for a chemical compound repeatedly, eventually it is remembered. Another way information is transferred is through association. If an individual can relate new information to be remembered with something that is already in long term memory, then it is likely to be stored and remembered. Information that is stored in long term memory is thought to be linked into networks
of different complexity. It is hypothesized that one difference between expert problem solvers and novice problem solvers is that the experts have complex networks of concepts they draw upon to solve problems. Novices, on the other hand, have limited networks with little branching. Perhaps they can retrieve a memorized formula to solve a routine problem, but since the linkages to other concepts are not present, they lack the capability of solving problems requiring additional steps, or ones never encountered. From the information processing point of view, learning is enhanced by increasing organized networks of concepts that exist in long term memory.

The Constructivist View

From the constructivist’s viewpoint, individuals create or construct their knowledge. This construction of knowledge begins at birth (or before) and continues throughout life. Hence, children enter school with a conceptual understanding of phenomena that they have acquired by observing the world around them and trying to make sense of their observations. Usually this knowledge, called “spontaneous knowledge” or “personal knowledge” by West and Pines (12), differs from that of a scientist. For example, children (and some adults also) are surprised to observe that the temperature of a piece of velvet and a piece of metal in an air-conditioned room is the same. Since the metal feels colder, the senses trick one into believing something that is incongruent with what Pines and West refer to as “scientific knowledge” or “school knowledge.” Personal knowledge is also created in other ways. For example, parents continually telling children to wear their “warm hats” may be the reason why most young children believe that the temperature inside a hat (when not being worn) is greater than the temperature outside a hat.

Unfortunately, what frequently happens in chemistry classrooms is that students do not make connections between personal knowledge and school knowledge. Moreover, if chemistry is taught to “cover the book,” students do not even make connections between various aspects of school knowledge, and have little opportunity to relate it to personal knowledge. (A salient example of this has been reported for first grade children by Brenner (13). In a study of children in a middle-class neighborhood, five year old children were used to making change using quarters and dollars to purchase confections at the the corner grocery store. In first grade they were introduced to working with pennies. They saw little connection between the two systems of money. Five cents would only buy the lemonade cup, not the contents! What grocer would have the patience to allow children to count out 50 pennies for their purchase? The children developed two systems for dealing with money, a real world system, and a school system.)

One reason why students find chemistry challenging is because chemistry is a complex subject. In an effort to describe and make predictions about the world of matter, chemists explain what occurs on the macroscopic level using atoms and molecules. Moreover, they represent these atoms and molecules using symbols and formulas. To add to the complexity is the fact that the atoms and molecules are so small and exist in such large numbers that they are difficult for students to visualize because there are no meaningful examples in everyday life. This makes understanding chemistry even more difficult because of the necessity of using mathematics to describe and relate atoms and molecules to measurable quantities of masses and volumes at the macroscopic level. It is no wonder that high school students have difficulty in making the necessary connections among the many facets of chemistry!
However, chemistry teaching frequently does little to remedy the situation, and actually may add to it. As Johnstone (14) has indicated, most chemistry instruction takes place at the symbolic level, and little time is spent in helping students relate the symbols to the chemical phenomena and to the microscopic level.

This focus on almost an exclusive symbolic representation of matter in introductory science courses may be the cause of students’ lack of understanding of basic chemical concepts as was illustrated in the studies cited earlier. A continual exposure in their high school and college courses to instruction on the symbolic and mathematical levels of chemistry will not lead students to make the connections between the science that they learn in the classroom and the world around them. How can we expect students to pursue a career in chemistry when the study of chemistry does not lead to understanding? However, if teachers are aware that this is the situation, something can be done to improve instruction. Gabel, Briner and Haines (15) have shown that when the particle nature of matter is emphasized in classroom instruction at the high school level, there is some evidence that student understanding increases on all three levels, even though the achievement levels were not as high as desirable. This emphasis on using particles to ask students to explain physical phenomena has been called using “pictures in the mind.” In the Source View videotapes, Mr. Haines uses “pictures in the mind” in Episodes Four and Sixteen when he shows students how to solve problems. In the episodes, Mr. Haines relates the physical phenomena with “pictures in the mind” with the symbolic and mathematical representations, thus helping students integrate the three ways of viewing matter.

Integrating the three ways of presenting chemistry is sometimes referred to as the SAP approach. Just as sap is an indication that a tree is alive and expected to grow in the future, only those students who understand chemistry on the three levels (Symbolic, Application or macroscopic, and Particle) have the conceptual base that is needed to be creative and to pursue a career in chemistry in their future.

A Conceptual Change Model

The goal of every chemistry teacher is to facilitate the understanding of chemistry concepts. Although some positive improvements may occur in students’ conceptual understanding by teaching chemistry on the macroscopic, microscopic, and symbolic levels simultaneously, or by rearranging the content so that more concrete concepts are introduced before more abstract ones are presented as in the National Science Teachers Association’s Scope, Sequence & Coordination Project (16), or by using an interdisciplinary approach such as that advocated by the American Association for the Advancement of Science’s 2061 Project (17), the change will not be dramatic. Substantial change in students’ understanding of science will only occur if teaching methodology and content are appropriate for students.

The use of the conceptual change model proposed by Krajcik (10), a modification of one proposed by Driver and Oldham (18), should lead to a higher level conceptual understanding of chemistry concepts than students are now experiencing in schools. The model consists of four steps that should be considered in teaching sequence. These include: (a) students describe their understanding, (b) students restructure their understanding, (c) students apply new understanding, and (d) students compare new understanding with previous understanding. The restructuring in step (b) includes student and teacher exchange to clarify understandings, student exposure to conflict situations through discrepant events, and student construction of new understanding.

8 Chemical Pedagogy (PEDA)
Some teachers are unaware that they are already using parts of this conceptual change model. A sequence in the SourceView videotapes illustrates this process quite well. In Episode Four, Ms. Briner’s major objective for the day is to lead students to understand the difference between strong and weak acids. Students have already studied concentration in the chapter on solutions earlier in the semester. Ms. Briner begins with a discussion of the previous day’s laboratory exercise in which students serially diluted a strong and a weak acid and noted the effect on pH using indicators. After students conclude that there are differences in colors and the pH’s of acids in different wells, one might think they understood that the concentration of hydrogen ion is less in the weak acid than in the strong acid when similar dilutions are made. However, there is evidence that this is not the case. Even after Ms. Briner provides a short explanation of differences between a strong acid and a weak acid in terms of percent ionization, when students are asked if it is possible to have a concentrated, weak acid, many students think that it is impossible. Even the spokesperson for the students who thought it was possible convinces himself that he was wrong! The question and discussion that ensues provides the cognitive conflict for the students in addition to making the teacher aware of the students’ thinking. The activity that follows provides students with an opportunity to make appropriate distinctions between strength and concentration and to apply their understanding to a new situation. Ms. Briner deliberately has structured her lesson to make these distinctions because from previous experience she knows that students use these words interchangeably in everyday life and are likely to have a personal view of them not congruent with the scientific view. She knows that students will not understand this difference by just telling, and that they must confront their personal views on multiple occasions in a variety of contexts for true understanding. Otherwise students may simply memorize the definitions of “strong acid” and “weak acid,” and be unable to apply them in everyday life.

An outstanding teacher is someone who makes the class feel relaxed, and makes the class participate. . . . He’ll create an atmosphere where you’re not afraid to answer, even if you are not quite sure. He is not going to scold you for being wrong. He’s not going to embarrass you in front of everyone else.

Andy Hapsekind

Classroom climate is extremely important for growth in understanding. Andy Hapsekind and other students that were interviewed for the SourceView videotapes felt that way. Students are very reluctant to reveal their personal knowledge in a tense classroom situation. The personal qualities that students mentioned in exemplary teachers creating a positive learning environment were: sense of humor, friendly, fair, patient, kind, understanding, open-minded, enthusiastic, adaptable, calm, and love of students.

During the interviews, several students indicated that they learned very well in small group settings where they felt freer to make mistakes, and were able to listen to students’ explanations of concepts. Research by Johnson, Johnson, Holubec, & Roy (19) and Slavin (20) has shown there are positive effects in achievement, retention, and critical thinking skills when students work in cooperative groups. As pointed out
by Champagne and Bunce (21), who base their statement on a tenet of cognitive psychology proposed by Ausubel (22), peer explanations may be more effective than teacher-student interactions because “the distance between two students’ understanding is far less than the distance between a student’s understanding and a teacher’s, hence communication of ideas is facilitated.” With these and other views of student learning in mind, teaching strategies that engage students in learning are discussed.

**Views on Teaching**

*When I first started teaching, I taught like a college professor. I stood at the front and I lectured, and I do very little of that now. When I’m standing in front I’m questioning. I’m discussing with my students, and I don’t stand in just the front all the time any more. I put them in groups. I make them the focus of attention. I put them in lab. I wander around. I talk with them. My teaching style is totally different now... seven years later.*

Denise Briner

Ms. Briner, an exemplary SourceView teacher, engages students in learning whether the setting is the classroom, the lecture hall or the laboratory. Effective teaching strategies engage students in learning about the elements, solving stoichiometry problems or discussing a laboratory experiment. The discussion of effective learning strategies has been divided into three major components to correspond to Parts One, Two, and Three of the SourceView videotapes. These are: Classroom Instruction, Problem Solving, and Laboratory Instruction. Division of the teaching strategies into these three categories is somewhat arbitrary because some skills used for one of the components are also applicable in others, but by following this schema, the reader can make ready reference to the videotapes.

**Effective Classroom Strategies**

As indicated in the section entitled “Views on Learning,” students will learn best when there is good rapport between teacher and students. However, even when a favorable classroom climate exists, only a minority of students are able to make sense of the science that is presented in terms of their own prior conceptions when conventional instruction such as lectures is utilized. As pointed out earlier, most students will memorize definitions in lieu of understanding concepts. Classroom strategies presented in this section can be used effectively to promote conceptual change. They can also be used ineffectively.

Common to all strategies is the appropriate pacing of instruction. If students are not allowed enough time for processing information, either when asking a question or participating in a demonstration, no matter what the content or pedagogy, learning will not take place. Effective teachers build this “thinking time” into their instruction by using such techniques as asking students to close their eyes and to think about a particular situation, or pausing sufficiently after asking a question before calling on students for a response. If students are scheduled for large group lectures, the rapid pace of delivery can be modified by stopping for two minutes after every 12 or so minutes of presentation. Rowe (23) found that if students make use of this time
by comparing notes with their near neighbors, and clarifying the material just presented with one another rather than spending the time asking the instructor questions, chemistry achievement improves. A healthy classroom climate and sufficient learning time are preconditions for effective implementation of teaching strategies discussed below.

**Questioning**

Probably the most commonly used teaching strategy at the high school level is asking students questions. When this technique is used effectively, it can aid students in concept acquisition, as well as provide feedback to the teacher about student comprehension. Four aspects about questioning need to be considered. These are: (a) What kinds of questions should be asked? (b) Why are questions asked? (c) How should questions be asked? and (d) How does the teacher respond to students’ answers to questions?

Several schemes have been developed on question types appropriate for the classroom. For example, Cunningham (24) suggests that both narrow and broad questions are appropriate for classroom use, but serve different purposes. Narrow questions provide feedback to the teacher about what an individual student understands, whereas broad questions add the dimension of requiring some original thought on the part of the student. For example, Ms. Herron (in Episode Seventeen) uses a convergent question when asking what acid is present in vinegar. In Episode Ten, when asking students to tell how the objects on their chairs relate to acids and bases, the question is broad because there are many possible answers, and students may come up with a variety of responses.

A more complex schema that has been in use for about 30 years based on Bloom's (25) *Taxonomy of Educational Objectives* was proposed by Sanders (26) who classified questions according to seven levels: memory, translation, interpretation, application, analysis, synthesis, and evaluation. No matter what schema is used to classify questions, what is most important is that unless higher level questions are asked, very little thinking is occurring on the part of students. Students reply to low level questions with one or two words, perhaps a phrase. An observer in a classroom can easily tell the level of thinking occurring by simply observing the length of student replies to questions.

It is not only the level of the question asked, however, but also the content of the question that is important. If a teacher asks a question about a discrepant event, or about something that is counter-intuitive, conceptual change is more likely to occur. For example, Ms. Briner's question in *SourceView* Episode Four, "Is it possible to have a concentrated, weak acid?" begins a discussion that lasts about ten minutes in which all students are engaged in learning. Ms. McKibbin's question in *SourceView* Episode Five,  "about what gas is being given off when dry ice is dropped into water produces a variety of responses. However, when Ms. McKibbin helps students realize that carbon dioxide is a clear, colorless gas, and the gas that they see is not clear, the questions she asks helps students resolve their cognitive conflict! Teachers ask questions for a variety of reasons. As was just illustrated, one reason for asking questions is to get students to think. Questions asked before a demonstration will help students make predictions about the outcomes. After a demonstration, students can be questioned about inferences they can make. In both cases, students' replies provide the teacher with important information on their conceptual
understanding and whether students' personal knowledge is congruent with scientific knowledge. Since each question is generally answered by only one student in the class, surveying students for answers to a given question as shown by Ms. Briner and Ms. McKibbin in the aforementioned SourceView episodes, indicates to the teacher the extentiveness of lack of congruence between personal and scientific knowledge among class members.

The methods that teachers use in asking classroom questions is also important. If a teacher calls on the student by name before asking the question, it is likely that other students in the class may not listen carefully to the question being proposed because they know they will not be required to answer. A more effective technique that gets all students involved in thinking is to ask the question, wait 3-5 seconds, and then call on a student by name to answer the question. Rowe (27) found that by including this "wait-time," students gave much longer responses than when questions were asked in rapid succession.

After a student has given a response, how should the teacher respond? Although individual teachers may have their own techniques for continuing the dialogue, one effective way to keep students involved in thinking is not tell them whether their response was correct. If the teacher then calls on other students for additional responses to the same question, comparisons can be made and class consensus can be reached. Obviously, only higher level questions can be used for this kind of discussion to ensue.

Another way to continue the class discussion is to reply to a student’s answer with another question. Questions like, “Why do you think so?” or “How did you get that?” will encourage students to expand their thinking.

Using Analogies and Models
The use of analogies and models in teaching chemistry is quite common. An analogy can be thought of as the resemblance of otherwise dissimilar things, whereas a model is a physical entity usually built to scale to resemble something else. The use of analogies helps students construct meaningful knowledge by linking an unfamiliar concept with a familiar one. The greater resemblance in features of the two concepts, the more powerful the analogy. The effective use of analogies assumes that students are familiar with the analog. In a study of problem solving using analogies, Friedel et al. (28) found that a large number of students enrolled in a beginning chemistry course were unable to make connections between problems using familiar objects such as pieces of fruit, and problems involving atoms and molecules. Hence instruction using everyday objects was unsuccessful.

On the other hand, if students become involved in making up an analogy or if they participate actively in an analogous event, they are more likely to determine similarities and dissimilarities of the analog and that which it represents. An effective use of having students represent particles in a water solution is shown by Mr. Haines in SourceView Episode Six where students (particles) move about in different sections of the classroom (volumes of water) creating different concentrations.

Care must be taken to show the limitations of a given analogy. If students perceive that the analog and concept are identical in all aspects, they may inadvertently develop a misconception about the unfamiliar concept by attributing something to it that it does not possess. The same possibility occurs in using models. One reason
why students may think that an individual atom of carbon is black may be due to the
black color of the ball-and-stick model for the carbon atom! If the inventor of the ball-
and-stick models had painted the model with four bonds green, this might have
created cognitive conflict for students showing that the color and other properties of
a large sample of atoms is not identical with the properties of a single atom!

The use of models aids students in understanding chemistry because they represent
atoms and molecules too small to be envisioned by most students in a concrete way.
Ideally, three-dimensional models represent molecules better than two-dimensional
models. Irrespective of the type of model used to represent molecules, it is important
students see the connection of the model to the microscopic structure of the
compound, to the symbols and formulas which chemists use to represent atoms and
molecules, and to physical phenomena as well. Effective uses of models are shown in
SourceView Episode Three by Mr. Lumbley who uses them in a historical context,
and in Episode Fourteen by Mr. Haines who depicts solution concentration using
magnets in beakers that have been drawn on the chalk board.

Concept Mapping

In the past several years, concept mapping, as advocated by Novak (29), has become
a useful strategy commonly used by teachers. A concept map consists of a hierarchical
arrangement of propositions, that is, concepts connected by a verb that show the
relationship between the concepts. For example, a part of a concept map on acids
and bases might contain the proposition, "acids have a sour taste." In common use,
the linking verb is frequently replaced by a line and the assumption is made that the
linkage is understood. Figure 1 shows a typical concept map for acids and bases.
Others on the same topic could be equally correct.

Studies on expert and novice problem solving behavior by Larkin (30) and Chi,
Feltovich, & Glaser (31) indicate that experts appear to have complex, elaborated
conceptual schemes in long-term memory that they draw upon in solving problems.
These appear to be lacking in novices. Since the construction of a concept map on a
given topic helps students organize concepts and the relationships among them in
a physical way on paper, this may facilitate the construction of a similar conceptual
map in students' long-term memory, and hence be a valuable tool for promoting
conceptual understanding.

Concept maps can be used in many ways and care must be taken that students do
not resort to memorizing maps. They can be constructed and used by the teacher in
planning a unit. Students can be asked to construct maps from content in a short
section of their textbook. A very creative way of using maps is illustrated by Ms.
Herron in Episode Ten in the SourceView videotapes. At the end of the unit, students
are asked to construct a map from concepts linking real world acid and base
phenomena. The creation of the map not only serves as a review for students in
helping them construct an overview of the unit, but aids Ms. Herron in identifying
those concepts about which students need additional help.
Figure 1. Concept Map for Neutralization
Collaborative Learning

Often times I’m scared to ask a question to the teacher
if I’m not quite sure of everything, but when you’re
working with your own peers, you feel better about
asking them a question, because they often times know
the answer, and they can tell you better. . . .

Philip Larson

Many students feel the same way as Philip Larson. When students work with each
other, they feel more at ease and freer to ask questions about concepts needing
clarification. This is in addition to the benefit discussed earlier of the student
receiving an answer that is more understandable because the concept development
and language used in the explanation of one student is more similar to another
student’s than to that of the teacher. Assimilation of new ideas is contingent on how
closely the new ideas are related to present knowledge.

Chemistry laboratory usually provides students with many opportunities to work
together. In the SourceView survey, working in the laboratory was what students
liked best about chemistry. However, there are many other ways that chemistry
instruction can be structured to allow for student collaboration. Even in a large
group lecture setting, students profit if the instructor stops every 12 minutes or so
and allows students to discuss the content that has been presented with one another.

A small group setting of 24-30 students provides more opportunity for students to
work in small groups. The goals to be accomplished will determine the type of
collaboration that is appropriate. If the objective of the lesson is to have students
become proficient in a skill, such as learning to balance equations, students can work
with their neighbor in appropriately designed exercises. Ms. Dillon’s use of small
groups in determining salt character shown in SourceView Episode Seven illustrates
this technique very well. The sequence of instruction is as follows: Mrs. Dillon
presents and models the thinking needed for skill acquisition at the board, students
work in small groups, Ms. Dillon circulates among students to encourage, help, and
determine difficulties, and then, summarizes and clarifies difficulties at the board.
The process is repeated several times throughout the period.

At other times, it may be beneficial to include small group work later in the class
period for a longer period of time. In Ms. Briner’s class (shown in SourceView Episode
Four) small groups of students use powdered drink mix to help clarify the difference
between “concentrated” and “strong.” In Episode Fourteen, Mr. Haines’ students use
worksheets to solve concentration problems.

Another effective way for students to work cooperatively is in the use of the jig-saw
technique. It is appropriate for student research on various aspects of a given topic.
For example, an appropriate use in a unit on acids and bases would be in the study
of acid rain. The technique consists of dividing the class into groups of three to five
students. Each student in the group studies a different aspect of the topic. These
topics are predetermined either by brainstorming, some preliminary research by the
class, from the textbook, etc. Some appropriate topics for the study of acid rain if the
class is divided into groups of five might be: causes, geographical occurrence, effect
on living things, effect on statues and buildings, and solutions to the problem. The
students do not research these topics alone, however. Students who have selected or who were assigned the same topic now meet as a group. For example, if there were 25 students in the class, and five groups of five students were formed, the student from each group responsible for "occurrence" would meet together. They would plan the approach they would take, and perhaps divide the topic further. They would continue to meet in this specialty group until they had researched the topic thoroughly, and shared their information with one another. Students would then return to their initial group where they would be responsible for teaching students what was learned about their specialty (e.g. occurrence) to other group members. In this way, each student is responsible for conveying information to his/her peers, and each student is responsible for learning about all aspects of the topic (e.g. acid rain).

Role-playing provides another opportunity for students to work together on various aspects of a topic. Students can work cooperatively in doing the necessary research that precedes their presentation, in planning and producing appropriate visuals, and in practicing and making their presentation. SourceView Episode Eight shows students working together effectively in several of Mr. Escudero's classes as they plan and present a role-playing scenario of a town meeting on a fish-kill.

Making Real World Applications

The thing I like best about chemistry class is that it helps me get a better understanding of the world around me, and I comprehend things I didn't know earlier or before I had taken the class.

Benji Lyn

After the laboratory experiments, students who were interviewed for SourceView most frequently mentioned "real world applications." It is easy to understand why this is so. There is a certain intellectual satisfaction when a person finally sees how concepts relate and everything falls into place. In terms of learning, discrete, independent networks in long term memory are being linked together to form a much larger, integrated network. This increases the students' ability to solve problems and results in a certain euphoria. Even if chemistry is taught in such a way as to link the atomic, phenomenal, and symbolic levels, unless new material is linked to the concepts already in long term memory, it will be compartmentalized into school or scientific knowledge versus personal knowledge. This, of course, results in students never making the connections between what is taught in school and the real world, and results in students who are unable to answer even the simplest questions about the world in which they live, as was illustrated by Bodner (5).

There are many ways to connect chemistry to the students' world, and almost every SourceView episode illustrates this. The role-playing of the town council meeting by Mr. Escudero's class in Episode Eight illustrates a real world application that takes three class periods. The laboratory experiment performed by Ms. Herron's class in Episode Seventeen and by Mr. Mill's class in Episode Twenty relates the value of chemistry in determining which vinegar is the best buy. Ms. Walah in Episode Two and Mr. Lumbley in Episode Three relate the properties of acids and bases to household reactions and foods. Ms. Briner uses powdered drink mix to explain solution concentration in Episode Four and Ms. Goshorn relates acid rain to car emissions and industrial pollution in Episode Nine.
Doing Demonstrations

Demonstrations also provide opportunities for students to make connections to the real world. Demonstrations that use familiar materials that act in unexpected ways provide an element of surprise and cognitive conflict to make them effective. For example, a demonstration involving changes of colors of indicators such as blueberry juice or cabbage juice in acids and bases, as shown by Ms. Walsh's class in SourceView Episode Two, is more interesting to students than the changes with litmus or phenolphthalein.

This is not to say that unfamiliar chemicals should never be used. Sometimes there is no effective alternative, and their use broadens students' familiarity with the material world. Even chemicals that the teacher might think are familiar may not be, and doing the demonstration gives the students an opportunity to understand common materials. When Ms. McKibbin in Episode Five planned the demonstration to show the effect of acids on indicators, she assumed that students knew that the gas coming from the cylinders was carbon dioxide with water vapor condensing on it. It was only by asking students about the phenomenon that she determined that this was not the case, and she seized the moment to revamp the demonstration. If she had not asked questions, and had merely told the students what was happening, very little learning would have taken place.

For an effective demonstration, presenting interesting phenomena is insufficient. The manner in which the presentation takes place determines effectiveness. Students should be involved in making observations, predictions, and inferences. Effective teachers sometimes "lead students on" by asking the right questions without revealing the outcomes. Mr. Lumley does this in Episode Three. Sometimes, it is appropriate to perform a "silent" demonstration in which students are asked to make observations while the teacher performs the demonstration silently. Mr. Haines' students in Episode Six are fascinated as he demonstrates the differences in reactivity of a concentrated and a dilute acid. In this instance, inferences about what happened occur after the demonstration has been completed.

Using Technology

Many technological tools are now available for teaching chemistry that hold promise for promoting conceptual change. These include microcomputer-based laboratory experiments (MBL), computer simulations, graphing packages, videodisks, and videotapes. A variety of these excellent instructional aids are listed in SourceBook modules and are shown being used by teachers in SourceView videotapes. The same can be said about the use of these tools in promoting conceptual change as was said about the use of demonstrations. If they are not used properly, learning will not occur. Two excellent examples occur in Episode One, a simulated lesson of poor teaching techniques, in which Ms. Walsh deliberately shows the incorrect use of two excellent instructional tools. She begins the acid-base unit with a short segment of the World of Chemistry videotape The Proton in Chemistry (32). Using this sequence at the beginning of the lesson could have provided an excellent unit introduction to stimulate student interaction about how acids relate to everyday life. Instead, however, Ms. Walsh uses it as a vocabulary-building exercise! Later in the period, she shows the Project Seraphim Periodic Table videodisk (33). Again, she deliberately misuses this excellent resource by telling students everything that they see, rather than calling on students to make the observations and offering explanations. Examples of excellent uses of a videotape and a videodisk are shown in other
SourceView episodes. Ms. Goshern shows a segment of videotape Nine that provides input for the class discussion on the effects of acid rain. Ms. Herron uses the American Chemical Society's Doing Chemistry videodisk (34) to provide input on proper laboratory techniques for titration in Episode Seventeen. Appropriate student involvement is necessary for the successful implementation of technological tools.

Assessing Student Learning

Assessing student learning throughout instruction is a requirement of good teaching. If one accepts the fundamental premise that students construct their own meaning, it is important for teachers to assess students' existing knowledge in order to plan appropriate learning activities. Sometimes students will give nonverbal cues that indicate that they do not understand a concept. Other times the teacher will become aware of students' knowledge by circulating among study groups, or by asking appropriate questions. These methods have been discussed in previous sections of this chapter.

Assessment that occurs at the end of a study unit frequently takes the form of a written test. Unfortunately, tests that accompany many high school chemistry books use a short answer or multiple choice format. In addition, many of the questions that they contain only assess whether students can memorize the content well or are able to solve problems using algorithms. Just as standardized tests drive teachers to include certain chemistry concepts in the curriculum, the content and format of tests that students take drive them to learn chemistry in a rote and algorithmic manner. If the desired outcome of chemistry education is the conceptual understanding of chemistry, more open-ended tests that require explanations are needed. These kinds of tests which require more student thinking also require more administration time, and more time to correct. Alternative ways of assessing students' understanding are also necessary. These may include laboratory practicals, and the interviewing of students. When students understand that they are responsible for their own conceptual understanding, and that they will be assessed and rewarded on that understanding, conceptual understanding will be enhanced.

Enhancing Problem Solving

When people say they can't do the math in chemistry, what they mean is, they can't take a physical situation, read that situation, visualize it, and then write down some sensible, coherent, mathematical expression that can be solved to find what they're looking for. That's what they mean, and that's a challenge.

Frank Cardulla

In this brief statement, Mr. Cardulla says it all! Problem solving in chemistry involves more than getting answers. Meaningful problem solving, that is, problem solving that involves more than recognizing and using appropriate algorithms, requires students to follow a series of steps to arrive at a reasonable answer. To help students achieve this is one of the greatest challenges of chemistry teaching.

Unfortunately, as indicated in the section on Research Perspectives on Concept
Learning and Problem Solving, most students solve problems in a very algorithmic manner, and do not relate the problem solution to any physical phenomenon. Because students are unable to make sense of the problems, it is no wonder that problem solving was mentioned most frequently by students interviewed for the *SourceView* videotapes as the thing they liked least about chemistry. The challenge for chemistry teachers is to make problem solving more meaningful so that it aids conceptual understanding rather than hinders it by adding to the memory load.

To do this, chemistry teachers need to encourage students to think rather than to rely on algorithms exclusively. Students want to know the formula! They would prefer to set up factors with units, cross out the units, and arrive at a numerical answer without relating the problem to its underlying concepts or to the real world. However, in allowing this to happen, students never realize the intellectual satisfaction of seeing how everything makes sense.

**Integrating Johnstone's Levels (14) into Problem Solving**

In the section on the Constructivist View, three levels of chemistry were discussed. These were: the phenomenological level, the atomic/molecular level, and the symbolic level. Frequently in an effort to “cover the content,” problems are solved almost entirely on the symbolic level using both chemical and mathematical symbols. This is illustrated in *SourceView* Episode Eleven. In contrast, Episode Twelve shows a conceptual approach in which Mr. Cardulla begins with a demonstration using actual solutions. Before working with problems on the symbolic level, he relates concentration to something concrete such as raisins. The raisins serve as models for atoms, ions, or molecules. Thus the three ways of referring to matter are integrated into the lesson. Mr. Haines in Episode Fourteen also relates the symbolic to the particle level using magnets to represent the particles in a microscopic volume of solution that has been enlarged sufficiently to count the particles.

Another way of getting students to connect a phenomenon to its symbolic representation is by asking them to make up a problem for the class to solve as is shown in *SourceView* Episode Thirteen. It is not surprising that students may suggest that an appropriate problem would be to find the molarity of a solution made by dissolving 100 grams of salt in 10 milliliters of water! Including additional information in problems may help students think more of the physical reality. Creating problems that include variable names rather than units may also do this. For example, if a problem reads, “How many milliliters of 0.1 M hydrochloric acid . . . .” is changed to “What volume of 0.1 M hydrochloric acid . . . .,” students must connect the variable name “volume” with the units “milliliters,” and perhaps make a better connection with reality.

**Using A Systematic Approach**

Research by Bunce et al. (35) has shown that if students use a systematic approach in solving problems they are usually more successful. Mr. Cardulla identifies the appropriate steps necessary for successful problem solving in the introductory quotation.

The first step is to “read that situation.” This appears much easier than it actually is. Cognitive psychologists would call it “problem restructuring.” It consists of decoding or translating the words given in the problem in a meaningful way. There are many barriers that may prevent the restructuring to occur in an expert-like
manner. Students may be unfamiliar with the vocabulary, or the format may contain too many variables for the limited space available in a student's short-term memory. Students' problem-solving ability generally improves when simpler words are substituted for more complex ones. Writing down what is given in a problem and what is sought generally extends students' short-term memory.

Another step recommended by Mr. Cardulla is "visualizing it," that is connecting the words in the problem with the physical phenomena that are represented. In most cases, chemistry problems can be solved by simple arithmetic. If students understand the physical situation of the problem, they can compare it to a similar problem with which they are familiar, and solve it in the same way. This makes them less dependent on setting up problems using the factor-label method in a rote manner so that the units "cancel" out. Mr. Cardulla contrasts the two methods in Episodes Eleven and Twelve.

After students have read, and visualized the situation, they should be able to write down a mathematical expression and solve the problem. This is easier said than done, and it aids students greatly in this process and in the other steps given by Mr. Cardulla if the teacher or other students model their thinking by solving problems aloud. SourceView Episodes Eleven through Fourteen show teachers solving problems aloud and Episode Thirteen shows a student in action.

When students first begin solving chemistry problems, it is frequently helpful for them to use a guide that aids them in using a systematic approach. The one used by Mr. Haines in SourceView Episode Fourteen includes the following components: what is given, what is sought, other information that must be recalled, diagram showing phenomenon and particles, planning, mathematical solution, and check. When students use this guide they approach the problem in a systematic manner and simultaneously relate the phenomenological, atomic/molecular and symbolic levels of chemistry.

**Collaborative Learning**

As indicated in the section on Classroom Climate, students achieve more in group settings than when they work alone. This is particularly true for problem solving because students need to hear other students' explanations of how they solve problems. In addition, students feel freer to make mistakes in the group setting where they won't be censured by the teacher. Students solving problems collaboratively are shown in SourceView Episode Fourteen. Other suggestions for teaching problem solving that are based on research are found in Gabel (9), Woods (36), and Gabel and Bunce (11).
The thing I like best about chemistry are the labs because I think they get across the point on the chapters, and the concepts that they're trying to explain.

Margie Greene

Chemistry teachers have always seen value in having students perform experiments, and students find them the thing that they like best about chemistry. In SourceView interviews students frequently commented about how it was the laboratory exercises helped them relate chemistry to the real world. On the other hand, the laboratory component of the chemistry course is costly, and research has shown that performing experiments doesn't necessarily improve achievement.

Types of Laboratory Exercises

Laboratory exercises or experiments can be categorized in many ways. One way to classify them is according to the amount of chemicals that are used. In the past few years, more teachers are having students perform experiments using small-scale techniques. The advantages of using small quantities of chemicals include reducing cost, saving time needed to prepare large quantities of solutions, increased safety because the chemicals are generally more confined, and less pollution of the environment in their disposal. Students can usually observe the chemical reactions just as well using small quantities, and frequently students exert more care in using them because a small error can make a big difference in the results. In addition, the experiments generally proceed faster, and there is usually time to perform several trials in one class period. Small-scale techniques are shown in SourceView for the serial dilution of an acid and a base in Episodes Sixteen, Eighteen, and Nineteen.

Another way to classify experiments is according to their purpose. Sometimes an experiment may simply be an exercise to demonstrate a laboratory technique or to illustrate a given phenomenon that leads to concept development. The serial dilution shown in SourceView Part Three is this type of exercise. It can be used effectively to illustrate changes of indicator color according to concentration. It is quite different from the titration of generic and brand name vinegars which serves not only to review the concepts and psychomotor skills needed for understanding and performing the titration, but also to help students make value judgments about which vinegar is “better.” SourceView Episodes Seventeen, Twenty, and Twenty-one show students conducting a titration experiment.

Both experiments are important in the chemistry curriculum, and both can be used to help students acquire inquiry skills. It is important that students learn to make multiple observations, realize that there are many correct answers, and determine if their observations and data are internally and externally consistent. These and other aspects of scientific inquiry are evident in SourceView Episodes Seventeen through Twenty-one. Episode Twenty-one is very effective in involving students in the scientific approach to what should be done when results go awry.

Timing of the Laboratory Experiment

One reason why students may not profit fully from a laboratory exercise is because it is placed in an inappropriate place in the curriculum. If the laboratory is not
available to the class on a daily basis, this problem may be impossible to overcome.

The purpose for conducting the laboratory experiment will determine its placement in the daily schedule. Sometimes the experiment should occur before concept development has taken place. In these instances, the concepts flow from the experiment. For example, Ms. Dillon’s students in Episode Sixteen are given only the directions for the serial dilution of the acid and base in the pre-laboratory because her post-laboratory discussion uses the information from the experiment to invent the concept “pH.” In Episode Nineteen, which portrays a post-laboratory session, Mr. Escudero illustrates this. On the other hand, it would be foolish to begin a lesson on acids and bases with a titration of generic and brand name vinegars. It is more appropriately scheduled as an application toward the end of the unit after students know the meaning of titration as is shown in Episodes Seventeen and Twenty. Otherwise, there would be so much for students to learn (beyond the capacity of short-term memory) that they would merely go through the motions of performing the experiment by following directions.

A method that includes experiments that has been found to be effective in promoting conceptual change is the learning cycle approach. This approach was initially proposed for the teaching of elementary school science by Robert Karplus and was used in the Science Curriculum Improvement Study (37). Abraham and Renner (38) adapted it for use in chemistry instruction at the high school and college levels. Instruction is composed of three phases: exploration, invention, and application. In the exploration phase, students conduct laboratory exercises that help them explore the phenomenon under consideration. For example, beginning an acid/base unit by testing a variety of foods with indicators (as shown in Episode Two) or having students taste a variety of foods (as shown in Episode Three) might constitute the exploration phase. In the invention phase, the concept is deduced from the experiments performed during the exploration. In this case, students would invent an operational definition of an acid and a base. Ms. Walsh’s students are shown doing this in Episode Two. During the final phase, students apply what they just learned to a new situation. In the titration experiment (Episodes Seventeen, Twenty, and Twenty-one), the titration of an acid with a standard base constitutes the exploration phase, a discussion of neutralization would occur in the invention phase, and the titration of vinegars or antacid tablets might constitute the application phase.

**Pre-Laboratory Discussion**

The purpose of the pre-laboratory session is to enable students to carry out the experiment in a meaningful way. It should always include a demonstration of new laboratory techniques, a reminder about safety precautions, and directions for the disposal of hazardous chemicals.

Additional information discussed will depend on the purpose of the experiment. In most instances, students will learn more if there is an element of surprise in the results. This tends to create cognitive conflict. Good examples of different types of pre-laboratory situations are shown in Source View Episodes Sixteen and Seventeen. As mentioned previously, Episode Sixteen shows the pre-laboratory for the serial dilution of an acid and a base. Its focus is on establishing proper techniques. Episode Seventeen shows the pre-laboratory session for the vinegar titration. Its purpose is to demonstrate how chemistry is useful in making a value judgment about which vinegar is “better.”
Conducting the Experiment

Peer and student-teacher interactions are important during the laboratory session. The teacher’s role is to circulate among students asking them questions, keep them on task, and ensure that safety precautions are observed. In Episode Fifteen, Ms. McKibbin shows what not to do, whereas in Episode Eighteen, she demonstrates appropriate teacher behavior.

The chemistry laboratory provides an ideal setting for peer interaction, the importance of which was discussed previously. Cooperative learning, as proposed by Johnson and Johnson (39), is an effective method providing for peer interaction while simultaneously simulating how scientists might work cooperatively in real world situations. Instead of each student doing all parts of the experiment, students work in teams of four, and submit a joint laboratory report for which they all receive the same grade. Each member of the team has a specified role. Although these may differ slightly from one teacher to the next, four common roles that are generally assigned are: the experimenter, the materials manager, the foreman, and the recorder. The materials manager gathers materials at the beginning of the laboratory session and returns them at the end. The experimenter carries out the physical part of the experiment with the help of the foreman who keeps everyone on task. The recorder records the data and is responsible for the report. SourceView Episode Sixteen shows Ms. Dillon reviewing the roles with her class. Students are assigned to groups either randomly or according to ability so that mixed ability groups result. Roles rotate by week or by experiment in order to give each student a wide range of experiences.

Cooperative learning has proven to be a successful laboratory management technique. It simulates a real life situation, results in on-task discussion by students, helps students improve their social skills, and reduces the experiments and chemicals needed by one-fourth. Because the use of cooperative groups results in fewer laboratory reports, the teacher has time to evaluate them in more detail, and thus provide better feedback to students.

Post-Laboratory Discussion

The discussion that follows the experiment determines its real value as a learning experience. This can easily be seen by contrasting the post-laboratory discussion shown in SourceView Episode Fifteen with those shown in Episodes Nineteen, Twenty and Twenty-one. In Episode Fifteen, Ms. McKibbin simulates poor teaching behaviors by rushing through the post-laboratory discussion. Students probably would have learned as much without doing the experiment by just observing her results. This is in contrast to the discussion shown in Episode Nineteen in which students compare and contrast their findings.

The discussion of laboratory results provides the teacher with an opportunity to help students understand the nature of scientific inquiry. Such things as the need to repeat experiments numerous times, the necessity of examining the data for discrepancies, the meaning of significant figures, the necessity to play sleuth, and the need to repeat parts of the experiment with variations that may provide more information, cannot be shown or learned outside the context of a real experiment. These and other facets of scientific inquiry are illustrated by Mr. Cardullis and his class in SourceView Episode Twenty-one.
An effective discussion of experimental results also leads students to link what has been learned in the laboratory to what is being learned in the classroom. Unfortunately, many students do not make this connection. The use of the Vee Diagram as suggested by Gowin (29) to synthesize laboratory results is an effective tool for helping students make the link. A typical Vee Diagram, as shown in Figure 2, is divided into two halves. On the right side, is found the same components that would be included in a conventional laboratory report. On the left side are included the concepts, principles, and theories that link the laboratory experiment with prior learning.

The effective use of a Vee Diagram is portrayed in SourceView Episodes Seventeen and Twenty. In Episode Seventeen, Ms. Herron establishes the focus question with her class during the pre-laboratory session. Mr. Mills uses the Vee diagram with his class in Episode Twenty as the basis of the post-laboratory discussion and for the students' laboratory report.

![Figure 2. Diagram for Comparison of Generic and Name Brand Vinegars Using Titration](image)

**Focus Question:** Which vinegar is better, generic or name brand?

**Conceptual**

**Methodological**

**Value Claim:** Generic vinegar is less expensive, but the name brand may have a better flavor.

**Results:**
- Generic = 0.0060 M = 0.0051 M/£
- Name Brand = 0.0050 M = 0.0062 M/£

**Calculations:**
1:1 mol ratio (from equation)
- mol Acid = mol Base
- $V_A(M_A) = V_B(M_B)$
- $M_A = \frac{V_B(M_B)}{V_A}$
- $M_A = \frac{(0.01880 \times 0.001000 \text{ mol/L}) \times 0.00000 \text{ L}}{0.00000 \text{ M}}$
- $M_A = 0.00600 \text{ M}$

**Data:**

<table>
<thead>
<tr>
<th></th>
<th>Generic</th>
<th>Name Brand</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOH(mL)</td>
<td>0.05</td>
<td>exact</td>
</tr>
<tr>
<td>Initial Vol.</td>
<td>19.85</td>
<td>20.00</td>
</tr>
<tr>
<td>Final Vol.</td>
<td>24.68</td>
<td>24.60</td>
</tr>
<tr>
<td>Volume Used</td>
<td>24.68</td>
<td>24.60</td>
</tr>
</tbody>
</table>

**Events**
- When a certain volume of NaOH is added to vinegar using phenolphthalein indicator, the solution turns pink.
- Molarity NaOH = 0.1000 M

- Generic cost: $1.30/gal.
- Name brand cost: $2.50/gal.
Teaching and learning are very complex processes. This chapter has focused primarily on some of the processes and teaching strategies related to engaging students in learning chemistry during the time students interact with one another and the teacher. Less emphasis has been placed on other very important activities that occur before and after instruction. These include such things as planning, evaluating teacher effectiveness, and the professional development of teachers.

This chapter has attempted to consolidate and synthesize information on what constitutes exemplary teaching from three perspectives: those of chemistry students, those of chemistry teachers, and those of science educator researchers. We have seen that effective teachers engage students in learning by creating a classroom atmosphere in which students want to learn, and that it is important for teachers to establish a good rapport. Students highly value teachers who have a sense of humor, and make learning fun.

This chapter has not addressed all factors that characterize competent teaching. In a detailed and excellent review of the general research base of what are called preactive, interactive and postactive teaching tasks, Reynolds (40) elaborates on many other factors. These include such things as maximizing the time spent on worthwhile activities, making appropriate transitions between activities so the lesson maintains integrity, and establishing rules and routines to establish order that are perceived to be fair. For a more extensive review of these and other factors integral to effective teaching, the summary is highly recommended.

Reynolds (40) also indicates the importance of creating lessons that enable students to relate what they already know to new information. This requires teachers not only to know the subject matter, but to also know the students in order to tailor instruction to their needs. The domain of understanding for effective chemistry teaching is very comprehensive. It includes knowledge of the liberal arts, general principles of teaching and learning, and chemistry content. The integration of these three domains is necessary for expertise in the fourth domain that is sometimes referred to as “pedagogic content knowledge.”

“Pedagogic content knowledge” refers to knowledge of specific ways of engaging students in acquiring a particular concept. In this chapter, an attempt has been made to describe some specific ways of effectively engaging students in learning. Some of these strategies will be more effective for certain concepts than others. It is only the skilled chemistry teacher who has a repertoire of strategies at his/her fingertips, that can make the judgment about the best method for presenting a particular concept to a given group of students.

In the SourceView videotapes, effective strategies to teach concepts pertaining to acids and bases to specific groups of students are presented by high school chemistry teachers. What works effectively in their situations may not work well in yours. All of this leads to the conclusion that becoming an expert teacher is a lifelong task of learning and practice. Even teachers who are recognized by their peers as excellent, are in agreement that it is important to continually expand their knowledge base in order to engage students in learning more effectively. Adopting and adapting the teaching strategies shown in the SourceView videotapes and discussed in this chapter should facilitate beginning, competent, and expert teachers in their life-long endeavor of helping students understand chemistry.
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