# Process Workshops—A New Model for Instruction

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## Motivation for Change

Until four years ago, general chemistry at Stony Brook was taught in a traditional format. Three large-class lectures were supplemented by one recitation session each week. In the recitation sessions, faculty and graduate teaching assistants answered questions and worked problems for the students. About 40 students were assigned to each recitation section. While some faculty were not satisfied with this format, it seemed to be the only reasonable response to the large number of students (1300) registering for these courses each semester. However, several factors providing strong motivation for change became evident.

Faculty increasingly perceived that traditional teaching methods had become less effective and that students were not engaged in their course work as much as in the past. They also found that more and more students had difficulty applying concepts when solving problems.

It became obvious that negative perceptions and attitudes regarding chemistry and science appearing in the press were shared by many students. This situation was documented by a national study reporting that some capable students were alienated by several aspects of traditional science courses (*1*). Other studies confirmed that many undergraduates respond poorly to the lack of human interaction and exchange of ideas in the typical lecture format common to science courses and do not see the relevance of what they are learning (*2, 3*).

Term papers written by Stony Brook chemistry majors working in an industrial internship program reported little connection between their university and internship experiences. In the university, they mostly were told what must be done, worked individually, and were held accountable as individuals. In industry, they worked as part of a team that decided what must be done, and the team was held accountable. They also saw that their success on examinations depended to a great extent on what they understood and could remember from textbook and homework assignments and lectures, whereas their success on the job depended on analyzing new situations and applying their knowledge in new contexts. Some remarked that it was unfortunate that university courses did not provide more experience in team work and applications of concepts.

These observations by our students are consistent with formal reports from industry confirming that desirable employees are quick learners, critical and creative thinkers, problem solvers, communicators, and team players (*4–6*). The general conclusion of one such survey was that industrial employers "would like chemistry-trained employees whose education included greater preparation in communication, team skills, relating applications to scientific principles, and problem solving, without sacrificing thorough preparation in basic science concepts and experimental skills" (*7*).

The opportunity to make changes in our general chemistry courses in response to the above issues was created by another problem. The recitation sessions associated with the general chemistry courses were poorly attended. Although considerable resources in terms of faculty and graduate teaching assistant time were being expended in staffing 30 to 35 recitation sessions each week, only about 10 to 20% of the students were benefiting from them. Either the traditional format of these sessions, where the instructor worked problems and answered questions, needed to be changed to make them valuable for the students, or these sessions needed to be eliminated and the staff resources used in other ways.

## The Process Workshop Classroom

In response to the above issues, we chose to develop a new model for classroom instruction. While initially this model was developed for the general chemistry recitation sessions, it is very robust. It also has been used at Stony Brook for all the class meetings of an advanced undergraduate–graduate-level course on quantum chemistry with an enrollment of 26 students. Others, who contributed their ideas to the 1997 Stony Brook General Chemistry Teaching Workshop (*8*), have implemented similar strategies in their chemistry courses. This article describes our implementation of the *process workshop* classroom in general chemistry.

A process workshop is defined as a classroom environment where students are actively engaged in learning a discipline and in developing essential skills by working in self-managed teams on activities that involve guided discovery, critical thinking, and problem solving and include reflection on learning and assessment of performance. The term *process* is used because the focus is on developing skills in key learning processes, and the term *workshop* is used because students are given tasks to complete as the active agents in the classroom. The essential skills, which we think most appropriate for a chemistry workshop, lie in the areas of information processing, critical thinking, problem solving, teamwork, communication, management, and assessment. Performance skills in these areas, just like skills in laboratory work and athletics, can be developed, strengthened, and enhanced through practice. These skills therefore need to be included explicitly in university-level courses, not only to help students be successful in these courses, but also to prepare them for the workplace and for life in general (*9*).

In a process workshop, students work in teams to acquire information and develop understanding through guided discovery. They accomplish tasks and examine models or examples, which provide all the information central to the lesson, in response to critical-thinking questions, which we call *key questions*. The key questions compel the students to process the information, to verbalize and share their perceptions and understanding with each other, and to make inferences and conclusions (i.e., to construct knowledge). They then apply this knowledge in simple exercises and to problems, which require higher-order thinking involving analysis, synthesis, transference, expert methodologies, and integration with previously learned concepts. The teams report their results to the class, assess how well they have done and how they could do better, develop strategies for improving their skills, reflect on what they have learned, and submit a written report. Each student leaves the workshop with a take-home quiz, which is produced with the computer-generated personalized assignment system (CAPA) developed at Michigan State University (*10, 11*). These quizzes test and reinforce what was learned during the workshop, promote individual accountability (an important component in a team-learning environment), and stimulate further cooperative learning beyond the workshop experience.

An instructor's guide for process workshops (*12*) and sets of workshop activities (*13, 14*) for two semesters of general chemistry are available. Generally one activity focusing on one major concept can be completed in a 55-minute period. Each activity consists of a preparation section that references a textbook to introduce the topic and associated terminology. Time then is spent in the workshop on exploring the model, answering the key questions, reporting to the class, completing the exercises and some problems, and writing a report.

A sample schedule for a 55-minute period is given in Box 1. This schedule sets a high standard for performance, which is necessary to develop skills in information processing, thinking, teamwork, communication, management, and assessment. Time must be used efficiently and effectively. Announcements and assignments consume little time if they are written on the blackboard rather than spoken. Only a short, relatively easy, one-question quiz is needed to provide individual accountability for the preworkshop homework assignment. Simultaneous reporting, which is described later, is used to present several problem solutions to the class simultaneously. The class quickly validates these solutions or challenges some, and where discussion is needed, the key issues are identified and addressed efficiently through simultaneous team discussions.

Using a process workshop to replace one recitation session or one lecture each week provides a mechanism by which lecture-based courses can evolve into a more interactive, learner-centered, process-oriented format. As lessons are developed and refined and faculty become more confident with this format, the time devoted to the workshops can increase. Following the suggestion of many students, who wanted more time for the workshops because they considered them to be valuable, we increased their length from 55 minutes to 80 minutes, which was easily implemented because Stony Brook has both of those two time periods in the schedule. Although three 55-minute lectures each week continue in the general chemistry courses, a format involving two lectures and two workshops weekly—all scheduled in 55-minute periods—has been adopted for a new developmental course, CHE 121: Concepts and Methodologies of General Chemistry. Although not everyone will agree on this point, it is not clear that lectures are needed at all to complement the workshops. In our experience, however, lectures are most effective when they are short, to-the-point, and delivered *as needed* in the workshop environment.

**Box 1. Sample Workshop Agenda**

| | |
|---|---|
| 5 min | Structure class, announcements, workshop assignment and objectives, return papers, individual quiz on preparation. |
| 20 min | Teams work key questions and exercises. Use simultaneous reporting to bring closure to key questions and exercises. |
| 25 min | Teams work selected problems. Use simultaneous reporting to bring closure to selected problems. |
| 5 min | Homework assignment, self-assessment, and preparation of written reports. |

The process workshop model represents a synthesis of several ideas being discussed in the education community. The model combines team learning, guided discovery, critical thinking, problem solving, reporting, assessment, and personalized assignments into a coherent package coupled to the use of information technology. Its goals are the development of process skills and the mastery of subject content. Its foundation, from the constructivist theory of learning, is the construction by learners of their own understanding or knowledge from information in a process that utilizes existing knowledge, preconceptions, and beliefs and previous experience (*15, 16*). The structure of the workshop includes many of the factors that promote intellectual development as defined by the Perry model (*17, 18*). The premise is that if students are actively engaged in learning and have the opportunity to exercise process skills in seven key areas, then they will grow intellectually and become better learners, thinkers, and problem solvers; and their grades on examinations and success in the real world will improve.

## Use of Learning Teams

The workshops in general chemistry have up to 40 students divided into teams of three or four to produce a *team-learning* environment that is suited for guided-discovery and problem-solving activities. Learning teams are an integral part of this model for several reasons.

The lack of community many students experience in university classes is addressed by bringing students together in teams. The development of this community is particularly important for general chemistry, since predominantly first-year students are enrolled. These students are facing a very challenging course while adapting to the demands of college. It is encouraging and comforting for them to share common experiences, concerns, and anxieties with fellow team members. They also find that they can serve as resources to help each other, and many instructors have observed that such assistance, which is offered by peers at the level of the learner's development, often is more effective than that offered by a faculty member. We have found that the collegiality initiated in learning teams often extends beyond the workshop sessions themselves; for example, students exchange addresses and telephone numbers, form informal study groups, and help each other with homework assignments. This social interaction serves to build a community of learners and provides students with the support needed for success.

The use of learning teams also engages more students in the classroom. If there are ten teams in the room, ten discussions of a single issue, or ten issues, can be discussed simultaneously. This format is more dynamic and involves more students than the traditional classroom in which one idea is presented by one person at a time. The outcome also is richer, since after a period of team discussions, only the best idea of each team is selected by the team to share with the entire class. In this format, one instructor can work effectively with a large number of students in an interactive classroom because the students participate both as learners and as teachers, and the instructor can monitor and facilitate ten discussions simultaneously.

As the team becomes involved in a lesson, the different information, perceptions, opinions, reasoning processes, learning styles, theories, and conclusions of the members at times lead to disagreement. The team format thereby gives students the opportunity to confront their misconceptions, which otherwise might go unchallenged until examination time. When managed constructively (which may require the instructor to facilitate appropriate interpersonal, social, and collaborative skills), such interaction promotes questioning, active searching for more information, and finally a restructuring of knowledge that breaks down the misconceptions. This process results in a greater mastery and retention of material than competitive and individualized modes of instruction because the students need to interact with the material and construct and defend their own understanding. In so doing, they use and develop critical-thinking and higher-level reasoning skills (*19*).

Research shows that students working in learning teams learn more, understand more, remember more, feel better about themselves and others, have more positive attitudes regarding the subject area, course, and instructors, and acquire critical thinking skills, cognitive learning strategies, and other process skills that are essential in the workplace (*19–23*). A team learning environment is particularly effective for women and nontraditional students in science because this approach addresses the inhibiting feelings of isolation and competitiveness that many report (*24–26*).

As many faculty will testify, the benefits of learning teams cannot be achieved simply by placing students in teams, giving them an assignment, and telling them to work together to complete it and teach each other in the process. Students who perceive that they can complete the assignment more efficiently on their own will do so, and others will flounder. Even if the assignment is sufficiently difficult to require cooperation and collaboration for success, students in an introductory course are unlikely to have the essential skills for the task. Five key elements and the strategies for incorporating them in the classroom have been identified as essential for team success (*19*). These elements are *positive interdependence* (one cannot succeed unless all succeed), *individual accountability* (each team member is responsible for the outcome and for understanding the material), *promotive interaction* (team members support each other and help each other learn), *collaborative skills* (behaviors that enhance cooperation are identified and promoted), and *self-assessment* (teams identify what has been done well, what needs improvement, and what has been learned).

Initially students may not work well together because they may lack the motivation to do so. They may have difficulties agreeing on methods and answers because they are not skillful in leading, collaborating, helping, and supporting each other. Also, high-achieving students may feel held back by working in a group. In anticipation of such possibilities, the concept of a learning team needs to be introduced with motivational supports from the beginning. The instructor can point out that the university is a learning community, and the two responsibilities of members in a learning community are to learn and to help others learn. Analogies can be drawn with individual sports like tennis, track, wrestling, and swimming, where team members practice together to help each other learn and develop skills for competition as individuals. The importance of developing skills in teamwork, communication, management, and assessment for the workplace needs to be stressed. With such introduction and enthusiasm by the instructor, students perceive and appreciate that the workshop is designed to provide opportunities for them to exercise and strengthen such skills as well as to learn chemistry.

Students will also value the workshop activities if specific performance skills are introduced, motivated, taught, and reinforced. For example, many students can produce the correct answer to a problem, but fewer can articulate their method of solution. To help students develop real understanding and communication skills, the focus needs to be changed from the answer to the method of solution. If the process of solving a problem and communicating the method of solution to the instructor or class is emphasized rather than the answer, then the students will appreciate that by developing solutions with others and explaining concepts and methodologies to others, they deepen their knowledge while exercising and strengthening their skills in learning, thinking, problem solving, and communicating.

Additional strategies for establishing an effective team-learning environment have been described previously (*12, 19, 27*). These strategies involve structuring the learning teams, motivating cooperative learning and process education, providing positive interdependence among the team members, requiring individual accountability from each student, encouraging promotive interactions and collaborative skills, providing closure to each session, and using assessment effectively.

## Guided Discovery and Exercises

A key aspect of a process workshop, in contrast to the lecture format, is that students, not faculty, are the active agents. Learning and retention are facilitated when a student is engaged in learning through a process of active discovery rather than by a passive transfer of information through lectures and textbooks. In the workshop activities, students discover concepts by executing a task or exploring a concept model (which is an illustration or example) that provides all the information central to the lesson. The concept model can consist of a figure, graph, table, set of written relationships, a methodology, an interactive computer simulation or animation, a brief discussion, a demonstration, a laboratory activity, or student notes from a lecture or reading assignment. Whenever possible the context should touch on students' experiences because learning theory suggests that learning requires the integration of new information with existing knowledge.

The guided discovery is carefully developed with a set of critical-thinking questions. These questions, which we call *key questions*, build on each other in complexity and sophistication. The first few address the student's preparation for class, prior knowledge, and information provided by the concept model that will be fundamental to the construction of understanding in the activity. The next few questions then help promote thought to develop relationships. The final questions require divergent thought to find relevance or to look for the boundaries in generalizing the knowledge and understanding. Students work together in teams to produce answers to these questions by thinking about what they see in the model, what they know, and what they have learned

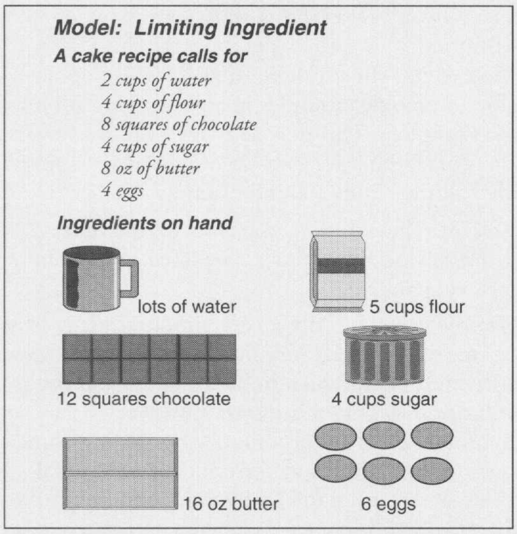


Figure 1. Model for the concept of a limiting reactant.

**Box 2. Key Questions for the Limiting Ingredient Model**

1. According to the model, how much of each ingredient is necessary to make a cake?

| water | flour | chocolate | sugar | butter | eggs |
|---|---|---|---|---|---|
| | | | | | |

2. If you follow the recipe, using only the ingredients on hand in the model, how much of each ingredient will be left over after you have baked the cake?

| water | flour | chocolate | sugar | butter | eggs |
|---|---|---|---|---|---|
| | | | | | |

3. Which ingredients on hand were in excess of what the recipe required?
4. Which ingredient on hand was consumed completely in making the cake?
5. Which ingredient limits or prevents you from making a larger cake?
6. What would be a good definition for the term *limiting ingredient*?
7. What would be a good procedure or methodology to use for identifying the limiting component in some manufacturing process? Test your methodology by applying it to the following exercises.

**Box 3. Exercises for the Limiting Ingredient Model**

1. You want to make 10 dozen standard-sized cookies as specified by a recipe that requires 16 oz of butter, 4 eggs, 3 cups of flour, and 4 cups of sugar. In taking inventory of your supplies, you find that you have 16 oz of butter, 6 eggs, and 3 cups each of flour and sugar. (a) Which ingredient will limit the number of cookies you can make? (b) How many standard-sized cookies can you make?

2. You have 100 bolts, 150 nuts, and 150 washers. You assemble a nut/bolt/washer set using the following recipe or equation.

2 washers + 1 bolt + 1 nut = 1 set

(a) How many sets can you assemble from your supply?
(b) Which is the limiting component?

3. You react 150 $H_2$ molecules with 100 $O_2$ molecules to produce $H_2O$. This reaction is described by the following recipe or reaction equation.

$$2H_2 + O_2 = 2H_2O$$

(a) How many water molecules can you produce from your supply of hydrogen and oxygen?
(b) Which is the *limiting reactant*?
(c) If you had 500 $H_2$ molecules and 500 $O_2$ molecules, how many water molecules could you produce?
(c) If you had 500 $H_2$ molecules with 1000 $O_2$ molecules, how many water molecules could you produce?
(d) If you had 1000 $H_2$ molecules and 500 $O_2$ molecules, how many water molecules could you produce?

from answering previous questions. The questions also encourage them to seek additional information from the textbook or lecture notes.

Each guided-discovery activity focuses on one concept or issue. For example, in Figure 1, the familiar idea of a limiting ingredient in a cake recipe is used as the model for the concept of a limiting reactant. Associated key questions that guide the discovery are in Box 2. In traditional classes, similar content in textbooks and lectures is used to explain and illustrate the concept of a limiting reactant, and often students are given a methodology, which then is memorized, for finding the limiting reactant. In contrast, in a process workshop, the teams are given a series of key questions pertaining to the model and they develop answers by examining the model while thinking, discussing, and constructing their own understanding. In this example, they then are asked to articulate, they are not told, the concept of a limiting ingredient and to describe a methodology for identifying the limiting component of some manufacturing process (see key questions 6 and 7 in Box 2). It is this active engagement requiring discussion, articulation, and restructuring of knowledge that is essential for developing thinking skills and true understanding.

This knowledge then is applied in exercises, which are straightforward applications requiring little or no concept synthesis or transference, as illustrated in Box 3. The purpose of the exercises is to build confidence that the concept is understood and can be applied successfully. Exercise 1, which involves a cookie recipe, is very similar to the cake-recipe concept model. Exercise 2 initiates the process of transferring knowledge to new contexts by employing a different scenario and providing information in the form of an equation (2 washers + 1 bolt + 1 nut = 1 set) that is analogous to the equation for a chemical reaction. Exercise 3 then requires application of this knowledge in finding the limiting reactant in a chemical reaction.

As part of each activity, the teams are asked to assess and reflect on what they have learned. Such reflection may be the most important step in the learning process. In this example, after completing the exercises, the following reflection task would be appropriate.

> Were your definition of a limiting ingredient and your methodology for identifying a limiting component useful in completing the Exercises? If so, explain how. If not, write below a better quality definition and a methodology that would be helpful to you in the future.

The next stage of this activity would involve problems similar to those found in many texts. These limiting-reactant problems present chemical reactions with amounts of reactants specified in mass units in order to require that students integrate their new knowledge of a limiting reactant with their previous knowledge of the mole concept and the meaning of a reaction equation. Problems also can reverse the logic a bit by asking for the amount of reactant needed to produce some amount of product. Since there are both similarities and differences in the systems used in the exercises (recipes, bolt sets, and chemical reactions), a problem could ask teams to identify and discuss these. For example, in cooking there is some flexibility in the amount of ingredients used but there is no such flexibility in bolt sets and chemical reactions. Also, in bolt sets, single components can be left; but in chemical reactions, often *molecules* must be left over, not *atoms*. Analyzing similarities and differences is an important thinking skill and reveals that the examples used in the activity utilize the similarities while ignoring some differences. This recognition strengthens a student's understanding of the concepts.

In examining this example of a guided-discovery activity, the following points are noteworthy.

- Questions and content have a real-world context taken from common experiences as well as chemistry.
- The key questions guide the exploration of the concept model to the appropriate conclusions.
- Articulation of concepts, solutions, and conclusions in discussion and writing is required.
- The strategy of organizing information in tables is demonstrated, and students are engaged by completing the tables.
- Exercises are provided to build confidence in the new knowledge before more challenging problems requiring transference, synthesis, and integration of information and concepts are encountered.
- Assessment of and reflection on learning brings the activity to closure.

## Problem Solving

Too often students simply want answers to questions and algorithmic solutions to exercises and do not realize that answers and algorithms will not help them develop the skills they need to deal with new situations or solve problems on examinations and in the real world. Furthermore, many textbook problems do not encourage students to develop or utilize a strategy or methodology for problem solving. Too often textbook problems, which are really exercises, not problems, can be solved by substituting numbers into a memorized formula. Such plug-and-chug exercises present an idealized system with all the knowns and unknowns clearly identified, use self-consistent units, and include no superfluous information. They allow the students to match the problem to textbook equations or to previously worked examples and encourage the memorization of formulas and algorithms rather than thought and the application of concepts.

Simple enhancements can turn these exercises into real problems that challenge the students and promote the development of problem-solving skills. Significant thought can be produced simply by omitting information, requiring assumptions, or including superfluous but seemingly relevant information. Problems having more than one part also promote thought. Students must identify and separate the parts, organize the information that is relevant to each part, and decide what needs to be done.

Context-rich problems also are useful in this regard. In essence, context-rich problems are short stories that present problems in the context of real-world situations or experiences where the key variables, concepts, and essential information must be identified before a solution can be attempted. They are designed to force students to analyze the problem and to identify and employ chemical concepts before turning to a mathematical equation. Such problems may not explicitly identify the unknowns and may require approximation and estimation (*28, 29*). They also develop essential process skills, appeal to the interests of students, and relate chemistry to current real-world issues, other subject areas, and employment opportunities.

We can use the content from a workshop activity on enthalpy to provide examples of an exercise, a problem, and a context problem. The exercise provides all the information, and the correct answer can be obtained in a single step, provided all the words are understood.

> EXERCISE: The enthalpy of combustion of propane is 2200 kJ/mole. How much heat is produced by burning 2.5 moles of propane?

To solve the exercise, only a very simple strategy is needed. Even if one understands very little, unit analysis can be used to justify multiplying the number of moles and the enthalpy of combustion to obtain the correct answer.

A problem can be produced by omitting some of the necessary information and introducing additional steps or parts. The statement of the problem, while it may have a real-world context, still identifies the concepts that are involved in the solution. For example,

> PROBLEM: How many grams of propane are required to heat all the water in your 50-gallon water heater from 60 °F to 140 °F? The specific heat capacity of water is 4.18 J/°C g, and the enthalpy of combustion of propane is 2200 kJ/mole.

To solve the problem, some sophistication is needed. The parts must be identified and separated, the knowns and unknowns identified for each part, and the solutions for each part obtained and combined. The problem could be enhanced even further by adding the following questions.

> QUESTIONS: Is this a large or small amount of propane? Is a large or small amount of energy stored in propane?

Since the answers to these questions are subjective, they promote considerable discussion among the team members in deciding the appropriate criteria for large and small amounts of propane and energy. This discussion needs to be reflected in the answer that the team reports. A quality answer will consist of an explanation that identifies the criteria they used. Students are made aware early in the course that one-word answers are low quality.

A realistic context problem, which we also call an extended problem, provides few if any clues about the concepts or equations needed to produce a solution.

> CONTEXT PROBLEM: You are camping at your cabin in the woods. One pound of propane remains in the tank. Will you be able to take a hot bath tonight?

Even more sophistication is needed to solve the context problem. In particular, many students have difficulty recognizing the key issues: the amount of water needed, the temperature of the water before and after heating, the energy needed to heat the water, and the enthalpy of combustion of propane. Students are reluctant to identify and make necessary assumptions and are concerned that this problem does not have a unique solution. Such context problems therefore are an important component of workshop activities because they promote discussion of what must be done and how to do it, and it is only through such encounters with the need to identify key issues and make assumptions or approximations that students will develop critical-thinking and problem-solving skills.

**Table 1. Problem-Solving Methodology and Strategies**

| Step | What to Do |
|---|---|
| 1. Define the problem. | a. Restate the problem, mention what is being sought.<br>b. Draw a sketch or diagram of the situtation. |
| 2. Identify the important issues. | a. Identify what is given (the knowns).<br>b. Identify what needs to be found (the unknowns).<br>c. Identify the constraints.<br>d. Identify the connections between the knowns and the unknowns.<br>e. Identify the chemistry concepts that are relevant. |
| 3. Evaluate the information. | a. Identify what information is relevant and what is not.<br>b. Identify additional information that is needed and where it can be obtained.<br>c. Identify and evaluate assumptions or simplifications that have been made. |
| 4. Plan a solution. | a. Identify a general approach (utilize chemistry concepts, make analogies with known problems and solutions, brainstorm, hypothesize, take risks).<br>b. Show how the unknowns can be related to the knowns and the constraints, use the connections, perhaps work backward from the target (what is being sought) to what is known.<br>c. Make valid assumptions or simplifications if necessary.<br>d. Divide into manageable pieces or subproblems if possible.<br>e. Utilize and combine chemistry concepts.<br>f. Set up a mathematical description of the problem.<br>g. Utilize chemistry concepts in equation form.<br>h. Develop as many independent equations as there are unknown variables.<br>i. Utilize dimensional analysis. |
| 5. Execute the plan. | a. Use algebra to obtain an expression with the unknown on one side of an equation and the known variables on the other side.<br>b. Use computer technology if necessary.<br>c. Substitute numerical values.<br>d. Perform mathematical operations to obtain a numerical answer.<br>e. Use dimensional analysis to obtain the units of the answer.<br>f. Combine the solutions to the subproblems. |
| 6. Validate the solution. | a. Compare the solution with the statement of the problem.<br>b. Compare the solution with experience, expectations, and real world behavior.<br>c. Is the solution complete?<br>d. Is the sign correct, expected, or reasonable?<br>e. Is the magnitude reasonable?<br>f. Are the units correct and reasonable? |
| 7. Assess your understanding of the solution. | a. Summarize the procedure.<br>b. Summarize the relevant chemistry concepts.<br>c. Identify how the concepts were used in the procedure.<br>d. Examine and compare with alternative procedures or solutions. |

In the workshops, the focus is on the quality of the problem-solving process, not on getting the answer. Students are introduced to specific problem-solving strategies and are asked to document their use. The methodology associated with a high-quality problem-solving process that can be applied in a general chemistry course is identified in Table 1. Steps 1 through 3 in this methodology serve to describe the problem as completely as possible. The features of the problem need to be summarized and related to each other in a sketch or a table. Often, restructuring a word problem in this way makes it understandable and the method of solution becomes clear. In step 4, the nature of the problem is identified. It is related to similar problems that have been solved previously and to fundamental concepts or principles, and a strategy for solving the problem is developed. This plan is implemented in step 5. Finally, in steps 6 and 7, the solution is validated and understanding is assessed. Such a methodology helps students integrate the conceptual, analytical, and procedural aspects of problem solving and become more effective and efficient problem solvers.

## Reporting

Teams share and validate their answers, solutions, and conclusions with each other to bring closure to each activity and assure quality in the work. As teams finish each part (key questions, exercises, or problems), one team member is asked to put an explanation or method of solution on the board without interrupting the class from their work. Others making slower progress then see clues about what must be done. In this way, the instructor can influence the pace of the workshop. We call this process *simultaneous reporting*.

When a few answers are on the board, a "time out" is called, and the class is asked for agreement or disagreement. To resolve the disagreements, teams can be asked to help each other or a student can provide an explanation to the entire class. It is important for the students to resolve disagreements in order to develop skills in thinking and communicating and to place the responsibility for learning, teaching, and assessment on them. If the instructor provides the information and validation, students too often will wait passively for the authoritative answer rather than seeking a resolution themselves. The instructor's role (see below) is to guide the students and assure progress in their deliberations by asking them questions.

A written report is submitted by each team to provide the results and summary of their work. The report also gives students the opportunity to reflect on what they have learned, articulate and generalize concepts, and consider what they have done well and how they can improve. In the report, students can be asked to assess the workshop activities and make two-

**Box 4. Sample Report Form**

TEAM MEMBERS (write name by responsibility):
Rotate responsibilities each week.
We verify that we all agree with and understand the solutions to these problems.

MANAGER:
Actively participates, keeps the team on task, distributes work and responsibilities, assures that all team members participate and understand

RECORDER:
Actively participates, provides documentation of work as required

SPOKESPERSON:
Actively participates, presents reports to the class

STRATEGY ANALYST:
Actively participates, identifies what the team is doing well and what needs improvement

HOMEWORK
Each team member completed the homework assignment: YES NO
Instructor's initials:

SELF-ASSESSMENT
Use the other side of page for your response.
Identify two ways your team could strengthen its performance and describe a plan for making these improvements.

REFLECTION ON LEARNING
Use the other side of page for your response.
Identify a concept from today's activity that your team has mastered, and identify one that your team understands the least.

ASSESSMENT
Provide your self-assessed grade for the session (3, 4 or 5): ___
NOTE: Instructor's validation depends on whether the self-assessed grade is reasonable. Explain the rationale for your self-assessed grade on the other side of the page.
Instructor's validation: ___
Instructor's grade: ___ Total grade: ___
May vary for different team members based on preparation, homework, and participation. See Instructor's comments on the other side of the page.

ATTACH REQUIRED PROBLEM SOLUTIONS.

**Box 5. Self-Assessment Questions and Activities**

SAMPLE REFLECTION ON LEARNING

- What was the "muddiest point" (least clear) in today's session (or in this week's lectures, in this week's reading assignment)?
- Identify the most important concepts you learned today.
- Write a "key question", which if answered would help your team understand some aspect of today's activity better. Find the answer to your question.
- Provide one example of how an equation encountered today must be manipulated or combined with another equation to solve problems or answer questions.
- Explain how concept B helps us understand Z.
- What discovery or insight about topic x did you make today?
- Explain why topic x is important.
- Write a methodology for doing M.
- What information do you need to determine x.
- What does it mean to say y?
- Summarize the academic objectives and the process skills objectives of the workshop today.

SAMPLE GROUP PROCESS

- Did everyone in your group contribute to the activity today? If so, explain how, if not, identify what individuals need to do to assure participation by all.
- Did everyone in your group understand the material covered in the activity today? If so, explain how your group assured that everyone understood, if not, identify what your group needs to do to assure that everyone in the group understands the material.
- Identify three things your group could do to work more effectively and efficiently.
- Identify one contribution made by each member of your group to today's activity.
- What constructive feedback can you give another group member on application of a skill?
- Develop a short term plan and a long term plan to strengthen your team's performance.

SAMPLE INDIVIDUAL PERFORMANCE

- Identify three ways you and other group members have modified or could modify study habits and strategies in order to improve performance on examinations.
- List two strengths and two improvements in reference to yourself in today's workshop.
- Cite two examples of how you carried out your team responsibility or role.

or three-item lists of concepts learned, strategies identified, methodologies practiced, process skills used, and questions remaining. Quality reports are motivated and rewarded by the grading policies. A sample report form is shown in Box 4.

## Assessment

Students are expected to develop essential skills by employing them in workshop activities like those described above. We believe this growth can be enhanced by having students think critically about their performance. To encourage self-assessment and peer assessment, the instructor needs to establish an environment where such assessments are safe, positive, and valued by all. In this context, it is important to make a distinction between *assessment*, which is a reflection on the quality of performance and on how improvements can be made, and *evaluation*, which is a judgment of the standard that has been reached.

Student self-assessment is important because it requires that students think critically about their involvement in the learning process. If we are trying to improve skills, we must ask students to examine and compare how others perform and to examine their own performance. Individuals need to recognize what they know and need to know, how well they can do something, and what they need to do to improve. Such assessment can be implemented very simply by asking students at various stages of an activity to identify strengths and areas for improvement in their performance along with strategies for achieving these improvements.

For these reasons, self-assessment and reflection-on-learning questions are included as part of the team's report. It is important that these questions vary weekly because the same questions will elicit the same responses with little cognitive processing. Several example questions are provided in Box 5. For the students to see value in such self-assessment, it is important for the instructor to respond to their insight by complimenting them on their perceptions, asking whether they actually implemented the improvements they identified, and rewarding improvements that have been successfully implemented.

## Role of the Instructor

Process workshops provide students with the opportunity in a course to practice together with a facilitator in order to master concepts and develop skills essential for success in the course, college, and careers. This experience complements the lectures and the textbook, which provide information, answers to questions, and solutions to problems. To help students develop skills, workshop instructors must structure classes to

**Table 2. Opportunities for Skill Development**

| Skill Area | Opportunity |
|---|---|
| Information Processing | Students are responsible for directions that have been given.<br>Students paraphrase responses and information.<br>Students search for information in notes and text in response to questions,<br>Open-notes team quizzes on lectures and reading assignments are given.<br>Team quizzes on basic chemical facts are included. |
| Thinking | Students examine models or examples in response to key questions in order to develop an understanding of concepts, which they must articulate.<br>Teams identify key issues and questions, resolve issues, produce solutions not answers, and validate their work.<br>Instructor responds to students with questions that guide them and promote thought.<br>Assignments require thinking skills to complete. |
| Problem Solving | Skill exercises develop understanding and confidence.<br>Students develop and document solutions to problems, not just answers.<br>A solutions manual is not available for the workshop assignments.<br>Context-rich problems are used with several parts and missing or extraneous data that require transference to new contexts or integration of concepts.<br>Expert strategies are suggested and modeled, and algorithms are avoided.<br>Students identify strategies for solving problems. |
| Teamwork | Students work in teams, and each member has specific responsibilities.<br>All team members are accountable for the work of the team (1 report, 1 grade).<br>All team members must understand concepts and problem solutions for success.<br>Collaborative skills and promotive interactions are discussed, assessed, and evaluated.<br>Assignments require a team effort to complete. |
| Communication | Students discuss issues and solutions within their teams.<br>Student work is validated by reports to the class through simultaneous reporting.<br>Teams and individuals respond to inquiries and defend work.<br>Disagreements are resolved through peer discussions.<br>Assignments involve writing, e.g. describe the meaning or use of a concept. Peer assessment can be used to grade writing assignments effectively and efficiently.<br>Assessment and reflection on learning reports are submitted. |
| Management | Both individuals and teams are held responsible for assignments and tardiness.<br>Team manager is held accountable for team performance. |
| Assessment | Results are reported to and validated by the class.<br>Quality responses are required in the teams' assessments of what has been done well, needed improvements, strategies for improvement, and insights they have gained.<br>Feedback to both individuals and teams. |

provide opportunities for using the skills and then serve as coaches to guide students so they benefit from these opportunities. Examples of opportunities for skill development that can be provided by the workshop environment are listed in Table 2.

Critical thinking, which is one of the most important skill areas, involves identifying key issues, asking strategic questions, developing answers to those questions, and deciding what action to take. To aid students in developing critical-thinking skills, the instructor can demonstrate the process of critical thinking in the design of the activities and in responding to questions from students.

The workshop activities use critical-thinking questions, the key questions, to guide the students' exploration of the models (e.g., see Box 2). Directed questions point the student to obvious discoveries about the model; convergent questions require the student to synthesize relationships from the discoveries. Divergent questions are open-ended and do not have unique answers. They encourage the student to generalize the concepts and consider their relevance and applicability. This approach demonstrates for the students how questions can be used to analyze new situations, aid in the construction of knowledge from information, and expedite solving problems.

In responding to questions, instructors facilitate critical thinking not by giving students direct answers to questions and solutions to problems, but by asking questions that promote thought, encourage students to use knowledge they already have acquired, and help them identify and seek necessary additional information (*30*). Such critical-thinking questions can be divergent, requiring the student to consider all possibilities; convergent, focusing on one or a few of the possibilities; or directed, pointing to the resolution of the problem or difficulty. When students discover answers on their own, retention is enhanced and understanding is developed.

An excellent example and discussion of this approach to teaching has been published (*31*). We have adapted this example for use in our instructor training program, and it provides an excellent illustration here. The situation is the following. An instructor asks a student to predict the relative boiling points of ethane and ammonia. The student responds, "Ethane has more hydrogen bonds than ammonia so its boiling point is higher." Our trainees then produce responses to this answer and subsequently classify them as *promoting, limiting,* or *inhibiting.*

Some of the results we have collected are listed in Table 3. Clearly a response of "That's not quite right. Someone else want to try?" is inhibiting. It does not encourage the student to continue thinking; it passes the job to another student. Other types of questions are encouraging but limiting. For example, "Boiling points are affected by intermolecular interactions; would you like to try again?" directly highlights the error and points the student in the right direction. Promoting responses, on the other hand, call for reflection on information, concepts, or ideas, such as asking the student to consider the factors that might affect the boiling point or asking why hydrogen bonds might affect the boiling point.

Clearly, interactions with students can either encourage or discourage thinking. Paraphrasing a student's response and

**Table 3. Responses That Promote or Inhibit Thinking**

| Response | Effect | Examples |
|---|---|---|
| Inhibiting | Closes discussion | That's not quite right. Someone else want to try? |
| | Terminates thinking | The number of bonds is not a good indicator of the boiling point. Look at the intermolecular bonding. |
| | Produces fear | |
| Limiting | Requires recall or memory | What do you mean by a hydrogen bond? |
| | Leads to the right answer | A hydrogen bond is an intermolecular force; would you like to try again? |
| | Directs thinking | Would you draw the structures and indicate where the hydrogen bonds occur and how they affect the boiling point? |
| Promoting | Calls for reflection | What factors must be considered in predicting a boiling point? |
| | Originates ideas | What happens in the process of boiling, and what kinds of interactions affect the boiling point? |
| | Examines ideas | You have said that the greater number of bonds to hydrogen in a molecule is correlated with the larger boiling point; how or why do some bonds affect the boiling point? |
| | Processes data | |
| | Creates structures | |

following with a promoting question is an effective way to encourage students to think. The technique of paraphrasing can help the student by highlighting assumptions, errors, or misconceptions while allowing students to hear what has been said and giving them time to think about what they said (*31*).

Instructors also monitor the teams and provide feedback to individuals, teams, and the class when appropriate in order to improve skills and help students identify needed improvements. Although the workshops are intended to be solely a learning experience, a grade is given each week for the team's work. The work for the semester contributes about 20% toward the final grade for the course, the balance coming from four traditional examinations. A workshop grade is necessary because we have found that many students associate the value of an assignment with its contribution toward the course grade. Also, the grading policies can be used to elicit and reward desired behaviors from the students.

The workshop grading policies, however, must reflect the objective of having a successful team-learning environment that helps all members of the team develop understanding. The grade can not focus solely on "completing the assignment" or "getting the right answer." A positive team-learning environment, where students learn from each other, can be lost if the workshop grade is based only on the quantity of lesson material completed by the team. The emphasis rather needs to be placed on the quality of the process skills exhibited by the team members in working on the lesson and on whether all members of the team understand what has been done.

If a team fails to make adequate progress, the low grade needs to be attributed, not to the meager amount of material covered, but to the lack of specific skills or other desired behaviors. In this way, the team clearly sees which skills and behaviors will prove successful. Otherwise, the team will decide that the most talented member should work the lesson as quickly as possible to accomplish more and obtain a better grade. In our experience, the two most common reasons for poor performance are inadequate advance preparation by one or more team members and the lack of participation of all members.

The focus for these workshops is not on covering material (i.e., content) but on developing process skills that will help students become better learners. Too often, "covering content" by the instructor is thought to be a synonym for "learning" by the student. The grading policies and procedure must reflect and support this focus by rewarding, proportionately to the

**Table 4. Assessment Data for CHE 131 Students, Fall 1995**

| Assessment Statement | Positive Response (%)[a] | |
|---|---|---|
| | Agree (A+B) | Do Not Disagree (A+B+C) |
| 1. The workshop questions and problems are challenging and worthwhile. | 75 | 87 |
| 2. The workshop activities help me understand and learn the course material. | 68 | 83 |
| 3. The workshop activities help me learn how to solve problems. | 66 | 84 |
| 4. I learned and understood more by working in a team than if I had worked individually. | 68 | 83 |
| 5. The self-assessment questions help members of my team identify how they can improve study and work habits. | 36 | 67 |
| 6. Working in a team has increased my confidence in studying and learning chemistry. | 54 | 77 |
| 7. Working in a team has increased my interest in chemistry. | 37 | 65 |
| 8. The procedure associated with the take-home quizzes worked smoothly. | 70 | 85 |
| 9. The take-home quiz questions are challenging and worthwhile. | 76 | 90 |
| 10. The take-home quizzes help me understand and learn the course material. | 76 | 90 |
| 11. The take-home quizzes help me keep pace with the weekly assignments. | 61 | 81 |
| 12. The take-home quizzes are valuable in preparing for the hour examinations. | 52 | 74 |
| 13. The free tutorial sessions help me understand and learn the course material. | 50 | 86 |

NOTE: About 11 weeks into the course, between the second and third hour examinations, students in the workshop sessions were asked to provide an assessment of the workshops, the take-home quizzes, the tutorial sessions, and the workshop instructor. The assessments consisted of 21 positive statements, of which 13 are shown here, and students were asked to respond on a Scantron form using a scale of A to E, where A means strongly agree and E means strongly disagree. A response of C indicated a neutral opinion or undecided position. Of 931 students registered in the class, 757 (81%) completed this assessment.

[a]The combined responses A and B indicate the percentage who agree with the assessment statement (strongly agree plus agree); combined responses A, B, and C indicate the percentage who do not disagree with the statement (strongly agree plus agree plus neutral or no opinion).

effort required, performance in each process skill area (information processing, thinking, problem solving, teamwork, communication, management, and self-assessment) and not solely rewarding the lesson material completed.

## Can This Approach Be Successful?

Our evaluation of the process workshop initiative in general chemistry courses at Stony Brook has been very encouraging. Assessment data are given in Table 4, and some written comments from students are in Box 6. Figure 2 documents the improvement in exam performance that correlated with the implementation of the workshops. This and other information supports the following conclusions.

1. Attendance at the recitation sessions improved significantly (from 10–20% to 80–90%).
2. Afternoon tutorial sessions are heavily utilized to the extent that additional sessions have been scheduled. Students are interested both in concepts associated with the personalized quizzes and in the workshop lessons.
3. The majority of students (75–90%) find the workshop questions and problems challenging, worthwhile, and helpful.
4. Significant numbers of students reported that the workshop increased their interest in chemistry (370 of 1000) and increased their confidence in studying and learning chemistry (540 of 1000).
5. The workshop instructors received A and A+ ratings from the students, revealing positive student attitudes.
6. Examinations showed significant shifts of students from lower scores to higher scores, uniformly for low- through high-achieving students. See Figure 2 and the explanation below.
7. Enrollments in the second-year organic chemistry course increased by 15%.
8. Exam grades are highly correlated with workshop and personalized quiz grades. Thus, a student can be shown that regular and persistent attention to learning and problem solving gives a clear route to success on exams.
9. Instructors report an ongoing improvement in student skills throughout the course of the semester. The graph in Figure 2, which documents that improvement in exam performance, is a difference plot, constructed by normalizing the enrollments to 1000, subtracting the number of students scoring in each 5-point interval in Fall 1993 from the number of students scoring in that interval in Fall, 1994. (Fall 1993 was used as the control group because the text and faculty instructors were the same and efforts were made to make the exams equivalent.) A positive result indicates more students scoring in that range in 1994, and a negative result indicates fewer students scoring in that range. The graphs shows that 200 of 1000 students (20%) shifted from lower to higher scores in the semester with workshops (Fall 1994).

When we began the workshop format four years ago, the faculty and graduate student instructors involved were apprehensive about the effectiveness of strategies for implementing the process model successfully in general chemistry and about the response of students to this new mode of instruction. As the first semester progressed, it became evident that the process workshop model was becoming increasingly effective and the workshop environment was more enjoyable for both instructors and students than traditional recitation and lecture sessions. The instructors were more relaxed because the students replaced them as the active agents in the classroom, and the students were encouraged by their own accomplishments and by sharing experiences with their peers. In the final evaluation the instructors said, "This is the way to teach!", and many students responded, "More time for workshops and less time for lectures!"

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**Box 6. Most Common Written Student Comments**

When we have to explain answers to each other it helps us learn the material.
We can work together and help each other understand what we don't know.
We learn skills not just solutions to some problems.
They help us recognize our strengths and weaknesses so we can improve.
Because it opens our minds to how someone else may think.
They help us develop skills to solve problems.
They help us reason and think and make us think harder.
We can get involved with other students.
You learn and understand more by working together.
Team work was stimulating and made the class a pleasure to come to.
Make the workshop longer.
More workshops each week.

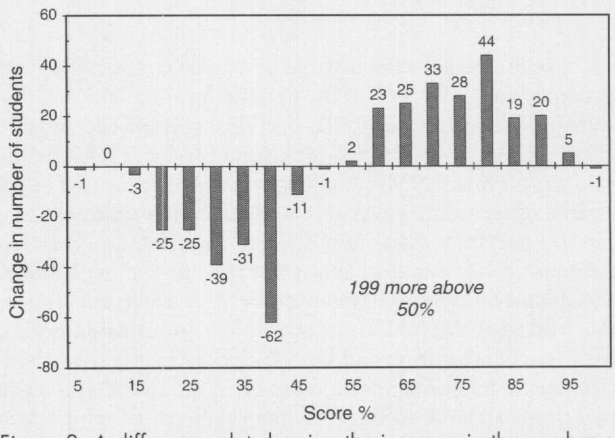


Figure 2. A difference plot showing the increase in the number of students scoring above 50% and decrease in the number scoring below 50% on all exams in the first semester with workshops compared to the previous semester with traditional recitation sessions.

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# Understanding NMR Multiplet Structure with WinDNMR

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Spectrometer technology has developed at a surprising rate over the past ten years, allowing us to perform experiments that were previously inconceivable. In addition, the speed and efficiency of computers and the sophistication of the software developed for many NMR applications have contributed to the arsenal of techniques available to the research scientist wishing to the extract maximum information from an NMR experiment. Unfortunately, many researchers who use NMR as a technique for characterization opt for the quickest experiment that will give the minimum amount of information needed to characterize a compound but which may largely ignore crucial structural information. It is too often the case that a quick two-dimensional COSY experiment will tell us which protons are coupled to each other (*1, 2*). Unfortunately, we seldom analyze the multiplets in a one- or two-dimensional spectrum, which are encoded with a wealth of structural information. The conformational dependence of a coupling constant described by the Karplus equations (*3*) can be used in tandem with molecular modeling programs to develop a detailed picture of a molecular structure (*2a*). This might be important in the way a molecule interacts with, say, living systems—for instance, in the design of efficient drug receptors.

In this paper, we wish to encourage the analysis of multiplet structure, particularly to an undergraduate audience, with the aid of a simulation program (WinDNMR) (*4*). While two- and three-spin systems are relatively easy to interpret, there are instances where the more complicated four-spin system defies the expected appearance as a result of second-order effects and accidental line overlap. For this reason we will concentrate on the potentially more complicated four-spin system as a convenient "teaching aid" and use the WinDNMR simulation program as a teaching tool capable of