PROCESS - THE MISSING ELEMENT

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Both Content and Process Are Essential

Changes in society, technology, and the world economy are occurring at increasingly faster rates. It is essential that we in higher education provide our students with opportunities to acquire the knowledge and skills that they will need to survive and be successful in this increasingly dynamic environment. Our students will need to be quick learners, critical thinkers, and problem solvers to survive. They also will need to be computer literate and skillful in communicating, teamwork, management, and assessment. A knowledge of fundamentals and concepts beyond a single discipline will be necessary. We need to provide these fundamentals, an interdisciplinary perspective, and these skills in the new curriculum.

Usually chemistry and other science courses are thought of as heavy "content courses" because the objective has been to structure knowledge and make this knowledge available to the student. This objective is very narrow. It is focused only on the very beginning of the *Knowledge Cycle* shown in Fig. 1. The common assumption has been that students on their own will be able to acquire knowledge, to apply it in solving problems and in new situations, and eventually for some, to generate new knowledge as researchers. It is important to recognize that the steps of acquiring, applying, and generating knowledge are processes that serve to link the learner and problem solver to knowledge. Because of this linkage, science education needs to be concerned equally with *content* (the structure of knowledge) and *process* (the development of skills for acquiring, applying, and generating knowledge). Since *education* is defined as the construction of knowledge, we define *process education* as the development of skills for acquiring, applying, and generating knowledge. *Process education* becomes increasingly important, in fact critical, as our knowledge base expands, as society addresses interdisciplinary and more complicated problems, and as businesses seek technological developments on shorter and shorter time scales. Under these conditions, it is those with highly developed process skills who will be the most successful.

Process skills in this context are those proficiencies that are essential for success in acquiring. applying, and generating knowledge. These skills can be classified into areas of *learning, thinking, problem solving, teamwork, communicating, management, and assessment* and seen in Fig. 1. Surveys of managers and leaders in industry generally show that desirable employees have such skills, i.e. are quick learners, critical and creative thinkers, problem solvers, communicators, team players, and self-motivated. (1,2) 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.” (3) Process skills, just like skills in laboratory work and athletics, can be developed, strengthened, and enhanced. 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.

The objectives of using the Process Model in General Chemistry Recitations are to -

- develop process skills in the areas of learning, thinking, and problem solving.
- engage students to take ownership of learning.
- increase student-student and student-instructor interactions
- improve attitudes toward chemistry and science.
- enhance learning with information technology.
- develop supporting process skills in teamwork, communication, management, and assessment that are essential for the workplace.

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A Process Model for General Chemistry Recitation Sessions

Traditionally recitation sessions associated with large-class lecture courses provide students with an opportunity to ask questions and interact with the instructor, in principle. In practice, the lecture format often is maintained in recitations with a graduate teaching assistant giving mini-lectures or working homework problems at the blackboard. This level of student involvement does not engage the students in the process of learning and is not satisfactory for students, as often documented by the poor student attendance at these sessions.

This article proposes a new model for recitation sessions in order to add process to the traditional content-oriented General Chemistry lecture course. This model has seven components or activities that support process education: c*ooperative learning, discovery learning, critical thinking, problem solving, reporting, personalized assignments, and assessment.* Within the context of this model, the recitation sessions become *workshops.* Students work in cooperative learning groups to acquire knowledge and develop understanding through guided discovery by examining models or examples and responding to critical-thinking questions. They apply this knowledge in exercises and problems, present their results to the class, and assess how well they have done and how they could do better. Students leave the workshop with a computer-generated personalized assignment that they must complete during the following week. The seven activities of the process model are related to the seven process skill areas. These activities are the tools of process education for developing process skills.

The process model also addresses some current issues in higher education. Faculty are perceiving that their teaching methods have become less effective, and that students are not engaged in learning as much as in the past It is being recognized that lecturing, which is an efficient way to present information, does not result automatically in efficient learning. (4-10) Attendance at recitation sessions often is poor even though they are intended to complement the large-class lectures and provide a more active experience. Many students miss the human interaction and exchange of ideas (11) that are absent in the lecture format and do not see the relevance of what they are learning. Consequently they develop negative perceptions of chemistry and science (12) and are lost from the science human resource pipeline early in their college careers. (13-15) Students have difficulties in applying knowledge to solving textbook, examination, and eventually to real-world problems. Many simply read about the solutions in manuals, on posted answer sheets, or watch problems being worked in recitation sessions. These students memorize algorithms for solving problems and do not understand and apply concepts. Also, students in a university setting work independently and gain little experience in teamwork and associated skills needed in the workplace. (11-14, 16) The importance and value of teamwork experiences are brought to light by comments from students participating in Stony Brook's Chemistry Industrial Internship Program. These issues are many others are addressed in the process model by utilizing cooperative learning groups and engaging the students in the learning process through a variety of strategies.

An implicit premise of this model is that if students are actively involved in learning and develop process skills, they will become better learners, thinkers, and problems solvers, and their grades on examinations and success in the real world will improve. Much research exists to document that understanding and learning requires active restructuring on the part of the learner. Restructuring involves making inferences, identifying and resolving contradictions, generalizing, integrating with previous knowledge, and posing and solving problems. (10, 17) It also is noteworthy that involvement in the classroom and student-student and student-instructor interactions have been identified as having the largest positive effect of numerous environmental factors on the academic achievement, personal development, and satisfaction of college students. (11,17) It is such restructuring and active involvement that the process model fosters.

Cooperative Learning Groups are Highly Effective

One problem faced by universities, is the large ratio of students to teachers. The university must be a *community of learners* with students learning from each other to be truly effective. In such cooperative learning environments, “individuals, working together, construct shared understandings and knowledge.” (10) The relative effectiveness of competitive, individualized, and cooperative learning formats has been compared in over 600 research reports, and the superiority of the cooperative structure has been demonstrated in many aspects. (18, 19) It has been shown that students working in cooperative-learning groups learn more, understand more, and remember more, and feel better about themselves, about the class, and about their classmates. They also have more positive attitudes regarding the subject area, course, and instructors. (18) Also in a cooperative environment, students are more likely to acquire critical thinking and problem solving skills, cognitive learning strategies, and other process skills (teamwork, communication, management, and assessment) that are essential in the workplace. (1, 3, 10, 17, 20) Further, this approach addresses the feelings of isolation and competitiveness many students report experiencing in college, especially women and other minorities in science.(16, 21) As a bonus, we have found that the collegiality initiated in cooperative-learning groups often extends beyond the workshops themselves.

The success of the cooperative learning environment should not be surprising because individuals working alone in competitive or individualized instructional modes do not have the opportunity for the intellectual challenge found in a cooperative learning group. As a cooperative learning group becomes involved in a lesson, the different information, perceptions, opinions, reasoning processes, theories, and conclusions of the members at times lead to disagreement When managed constructively with the appropriate interpersonal, social, and collaborative skills, such controversy promotes questioning, an active searching for more information, and finally a restructuring of knowledge. Compared to the competitive and individualized modes, this process results in a greater mastery and retention of material because of the more frequent use of critical thinking and higher-level reasoning. (10)

Consequently, a key feature of the process model is the use of cooperative learning groups. Each workshop has 30 to 40 students divided into groups of 3 or 4 to produce a cooperative learning environment suited for discovery learning and problem-solving activities. In each cooperative learning group, students work together to acquire knowledge, construct understanding, solve problems, and help each other learn.

The benefits of cooperative learning cannot be achieved simply by placing students in groups, 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 process skills for the task. Five key elements have been identified (10) as being essential for real collaboration and successful cooperative learning. These elements are *positive interdependence* (one cannot succeed unless all succeed), *individual accountability* (each group member is responsible for the outcome and for understanding the material), *promotive interaction* (group members support each other and help each other learn), *collaborative skills* (behaviors that enhance cooperation are identified and promoted), and *self-assessment* (groups identify what has been done well and what needs improvement). The structure of the workshop activities includes these five elements. Suggestions and strategies for incorporating these elements are described in two publications. (10, 22)

Initially students may not work well together because they lack the motivation and/or the process skills for leading, collaborating, encouraging, helping, and supporting each other. They may have difficulties identifying strategies and agreeing on methods and answers. Such skills need to be introduced, motivated, taught, and reinforced. High achieving students may feel held back by working in a group. The importance of developing process skills in teamwork, communicating, management, and assessment for the workplace needs to be stressed to such students. They need to see that the workshop is designed to provide opportunities for them to exercise and strengthen such skills. They also need to appreciate that by explaining concepts and methodologies to others and developing solutions with others they exercise and strengthen their skills in learning, thinking, and problem solving. A final point is that they are members of a "community of learners" in the university and as such have an obligation to contribute as well as the benefit of receiving.

Discovery Learning Activities Facilitate Retention

A key aspect of process education is that students rather than faculty are the active agents in the learning process. Learning and retention are facilitated when students are engaged in learning through active discovery rather than by a passive transfer of information through lectures and textbooks. In the workshop lessons, students discover concepts by exploring models or examples. A concept model is a representation that illustrates the concept. It can consist of a diagram, a table, one or more equations, a graph, a computer simulation, a set of written relationships, a hands-on activity, or a demonstration. While verbal descriptions also can be used for models, they are not particularly effective. Exploration of the model is guided by critical-thinking questions. These questions build on each other in complexity and sophistication, *vide infra*. Students produce answers to these questions by thinking about what they see in the model, what they know, and what they have learned by answering previous questions. The questions can encourage them to seek additional information from the textbook or lecture notes.

Critical Thinking is the Key to Success

Critical thinking involves identifying issues, asking strategic questions, and developing answers to those questions. A teaching methodology that involves critical thinking encourages constant improvement and develops process skills.

Critical-thinking questions are used in the workshop lessons to provide guided discovery in the students' exploration of the models. Directed questions point the student to obvious discoveries about the model, while 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 consider the relevance or applicability of the concepts and help to generalize.

Critical-thinking questions also are used by the instructor to promote the development of higher-order thinking skills. (23) Such questions model for the students how new situations can be analyzed by asking key questions. Instructors facilitate critical thinking not by giving students answers to questions and solutions to problems, but by asking questions that promote thought, that encourage students to use knowledge that they already have acquired, and that help them identify and seek necessary additional information. (24, 25) Such critical-thinking questions can be divergent, which require the student to consider all possibilities, convergent, which focus on one of the possibilities, or directed, which point directly to the resolution of the problem or difficulty. It is far better to encourage students to discover answers on their own by asking critical-thinking questions, than to provide an elegant response because retention is enhanced and understanding is developed if the answer is discovered rather than provided.

Expert Strategies are Needed for Problem Solving

In the workshop students acquire knowledge and construct understanding (Step 1 in the Knowledge Cycle) by examining the model in each lesson, integrating it with information from the textbook and lectures, and responding to critical-thinking questions. They then develop skills in applying this knowledge and understanding by working exercises and solving problems (Step 2 in the Knowledge Cycle). The exercises are straightforward applications of the concepts that were discovered through exploration of the model in response to critical-thinking questions. After the concepts can be applied to exercises successfully, they can be integrated with other concepts, generalized, and transferred to new situations. Problems furnish these higher-level applications, requiring higher-order thinking skills. (23)

Too often students simply want answers to questions and algorithmic solutions to exercises and do not realize that the answers and algorithms alone will not help them deal with new situations or solve problems in 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" can be solved by substituting numbers into a memorized formula, the so-called *plug-and-chug method*. Plug-and-chug problems present an idealized system with all the knowns and unknowns clearly identified, use self-consistent units, and include no superfluous information. Such problems 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 encourage thought and the application of concepts. It is amazing, but true, that 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 and, 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. Context-rich problems essentially are short stories that present problems in the context of real-world situations or experiences. They are designed to force students to analyze the problem and employ chemical concepts before turning to a mathematical equation. Such problems may not explicitly identify the unknowns and may require that information be estimated. Context-rich problems are designed to resemble real world problems where the key variables, concepts, and essential information must be identified before a solution can be attempted. (26, 27) Context-rich problems also serve to develop essential process skills, appeal to the interests of students, and relate chemistry to current real-world issues, other subject areas, and employment opportunities.

In the workshops students are given problems that require problem-solving strategies and methodologies and are asked to document their use. An expert methodology helps students integrate the conceptual, analytical, and procedural aspects of problem solving and become more effective and efficient problem solvers. An expert methodology incorporates such strategies as dimensional analysis, drawing a picture to represent the problem, separating the knowns and unknowns and finding a concept that connects them, identifying missing information, breaking the problem into parts or subproblems, and developing a model or representation of the problem. The focus in the activities is on the quality of the problem-solving process not on getting the answer. The use of an expert methodology in problem solving is promoted, and the quality of the problem-solving process is assessed. The methodology associated with a high quality problem-solving process applied in a General Chemistry course is identified in Fig. 4.

Reporting Builds Skills

In the workshop activity students acquire information and develop understanding by answering critical-thinking questions, working exercises, and solving problems. These tasks are accomplished by the students working together in small groups with an instructor, who facilitates the process by asking questions, providing explanations, and making analogies. To provide closure to the lesson, as groups finish an activity (questions, exercises, or problems), one group member is asked to put the answer and method-of-solution on the board. Others then see how a solution can be developed. When a few answers are on the board, a "timeout" is called, and the class is asked for agreement or disagreement. To resolve the disagreements, groups 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 the disagreements in order to develop process skills in thinking and communicating and place the responsibility for learning, teaching, and assessment on them.

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

Personalized Assignments are a Motivating Force

Students leave the workshop with additional problems to solve in the form of a personalized assignment that they must complete during the following week. These assignments are produced with the CAPA system, (28, 29) that enables an individualized assignment, which differs from all others, to be printed for each student. While a student's answer to a question is unique, the concepts and principles that must be understood are the same for all students. As a result students are encouraged to work together to discuss and understand the concepts, but each student must do individual work to obtain their correct answers. Students report their answers via the campus computer network, and a central computer tells them whether they are right or wrong and may offer on-line advice or hints. The CAPA system records the data entry and summarizes the successes and failures for the instructor. Multiple attempts to solve and report answers are allowed without penalty because this device is used as a teaching and learning tool not an evaluation tool. This approach to homework has several attractive features. It rewards diligent work and motivates students because they are assured of eventual success. It provides students with timely and accurate feedback exactly at the time they are interested in completing the assignment and enhances student-student and student-instructor interaction because students seek help. This activity features the instructor as a coach and the computer as the judge and reduces the time needed to grade and track homework assignments in large courses. These assignments promote individual accountability, self-management, and self-study and stimulate further cooperative learning beyond the workshop experience. This system was introduced at Stony Brook by Professor Roy Lacey and Dr. Brad Tooker.

Assessment is Important

Assessment and critical thinking produce an environment for constant improvement To strengthen student assessment, we ask students to assess their own and each others work in different formats. Instructors monitor the groups and provide feedback to individuals, groups, and class when appropriate in order to improve skills and help students identify needed improvements. To encourage student-assessment and self-assessment, the instructor needs to establish an environment where such assessments are safe, positive, and valued by all.

If we are trying to improve process 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, need to know, how well they can do something, and what they need to do to improve. Student self-assessment is important because it requires that students think critically about their involvement in the learning process. They need to be able to recognize when they understand a concept and can apply it to solve new problems and when they have difficulties. They need to ask critical-thinking questions while they are working: Do I have all the information? Have I identified and validated all the assumptions? Am I using an appropriate strategy? Is there a better alternative? Such assessment can be implemented very simply by asking students to identify strategies, strengths, and improvements at various stages of an activity. Self-assessment is one step in accepting responsibility for one's own learning and is essential for lifelong learning and growth.

While the workshops are intended to be solely a learning experience, grading policies are used in eliciting and rewarding desired behaviors from the students. A positive cooperative-learning environment, where students learn from each other, can be lost if the workshop grade focuses on the quantity of lesson material covered by the group. The emphasis rather needs to be placed on the quality of the process skills exhibited by the group members in working on the lesson and on whether all members of the group understand what has been done. If a group fails to make adequate progress on the lesson material, the low grade needs to be attributed, not to the meager amount of material covered, but to the lack of specific process skills or other desired behaviors. In our experience the two most common reasons for poor performance were inadequate advance preparation by one or more group members or the lack of participation of all members. In this way, the group clearly sees which skills and behaviors will prove successful. Otherwise, the group will decide that the most advanced group member should work the lesson as quickly as possible to accomplish more and obtain a better grade. The focus for these workshops is not on covering material (i.e. content) but rather is on the process skills associated with learning, thinking, problem solving, teamwork, communicating, management, and assessment The grading policy and procedure must reflect and support this focus by rewarding proportionately to the effort required not only the lesson material completed but also performance in each process area.

Instructors Play Four Simultaneous Roles

If the workshops are taught by graduate teaching assistants, it is important to upgrade the title to that of *instructor* because of the importance in teaching process skills and in doing assessment. Training sessions for instructors are scheduled the week before classes begin and each week during the semester. These sessions introduce the features of process education, the structure needed for successful cooperative learning groups, the use of critical thinking and discovery learning, and the enhancement of problem-solving abilities. The lesson material, grading, and difficulties and remedies also are discussed in these sessions. In process education, the instructor plays several roles, as a *leader, monitor/assessor, facilitator*, and *evaluator*.

As *leader*, the instructor develops and explains the lesson, defines the objectives (both academic and process skills objectives, especially in collaboration), criteria for success, expected behaviors, and establishes the organization (i.e. the goal/reward structure, the group structure, the class structure, the room structure, and the time structure).

As *monitor/assessor*, the instructor circulates through the class to monitor and assess individual team performance and to acquire information on student understanding, misconceptions, and difficulties in collaboration.

As *facilitator*, the instructor intervenes and asks timely critical-thinking questions to help groups understand how they are functioning, why they may be having difficulty, and what they need to do to improve and make progress. By combining monitoring, assessing, and facilitating, the instructor assures that all understand the assignment, that each group member is fulfilling their assigned role, mat positive verbal exchanges are occurring, and that progress is being made. Such intervention provides feedback, motivation, and reinforcement; teaches academic and collaborative skills; and guides students in the use of a problem-solving methodology.

As *evaluator*, the instructor provides closure to the lesson by asking group members to report answers, summarize the major points, and to explain the strategies, actions, and results of the group. The evaluator also provides evaluations to individuals and groups regarding performance, achievement, and effectiveness and shares general points with the class.

Can this Approach be Successful?

Others have experienced success in chemistry programs utilizing cooperative learning groups, (30, 31) and a detailed assessment of a successful three-year project teaching problem solving in physics through cooperative grouping at the University of Minnesota has been published. (26, 27) This assessment and our experience provide answers to some key questions. This assessment and our experience provide answers to some key questions. These questions and answers are summarized in Fig. 4.

The novel feature of the program described in the present article is the application of the process model to transform recitation sessions into workshops. This model uniquely incorporates seven components: cooperative learning, discovery learning, critical thinking, problem solving, reporting, personalized assignments, and assessment Our evaluation of this initiative in three General Chemistry courses at Stony Brook in 1994-95 was very encouraging. It was found that:

- attendance at the recitation sessions improved to 90% of the students.
- most students conscientiously worked the personalized assignments showing that these assignments are a tremendous motivating force.
- afternoon tutorial sessions were heavily utilized to the extent that a second session had to be scheduled on some occasions. Students were interested in concepts associated with the personalized assignment questions, again showing the motivating influence of these assignments.
- the majority of the students (over 90 % in the Spring Semester) found the assignment and workshop questions and problems challenging, worthwhile, and helpful.
- significant numbers of students reported that the workshop increased their interest in

chemistry and increased their confidence in studying and learning chemistry.

- the workshop instructors received A and A+ ratings from the students, revealing positive student attitudes.
- some examinations showed significant shifts of students from lower scores to higher scores, uniformly for low through high achieving students. Averaged over all the examinations, 200 more students of 1000 total scored above the 50% level in Fall, 1994 than in Fall, 1993.
- exam grades were highly correlated with the workshop and personalized assignment grades. Thus, a student can be shown that regular and persistent attention to learning and problem solving gives a clear route to success on examinations.
- instructors reported an improvement in student process skills throughout the course of the semester.

Initially faculty and graduate teaching assistants involved in this project 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 model was becoming increasingly effective and the workshop environment was more enjoyable for both instructors and students relative to traditional recitation and lecture sessions. The instructors were more relaxed since 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!"

After working with this new approach to teaching General Chemistry for another year, we plan other articles to share in more detail the methodology, strategies, and techniques that have been developed. Libraries of personalized assignment questions and workshop activities also are being prepared.

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PROCESS - THE MISSING ELEMENT

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Figure Captions

Fig. 1. Essential Process Skills

Fig. 2. Problem Solving Methodology and Strategies

Fig. 3. Internship Experiences

Fig. 4. Questions and Answers

Essential Process Skills

Area	Skills
Learning	Acquiring information at the lowest level of understanding (Bloom's levels 1 and 2, Ref. 23) without seeing relationships or implications; involves listening, reading, observing, searching, remembering, summarizing, questioning, inquiring, and comprehending.
Thinking	Involves the manipulation of information to develop and utilize relationships and implications by translation, analysis, synthesis, and evaluation (Bloom's levels 3-6, Ref. 23).
	Translating - rearranging information to provide a new perspective or to apply it in new situations; involves visualizing, interpreting, extrapolating, estimating, simplifying, generalizing, adapting, imagining, inferring, and predicting.
	Analyzing - resolving knowledge into components to reveral a hierarchy and connecting relationships; involves summarizing, organizing and classifying.
	Synthesizing - combining and linking concepts or knowledge to produce new concepts or new knowledge.
	Evaluating - assessing performance against criteria to reveal improvements; involves comparison with internal evidence (logical accuracy and consistency) or external criteria (comparison with other theories or information).
Problem Solving	Use of expert methodologies and strategies.
Teamwork	Involves leading, following, collaborating, resolving conflict, understanding, accommodating, cooperating, encouraging, helping, and supporting.
Communication	Involves verbalizing, writing, illustrating, discussing, explaining, listening, and describing.
Management	Involves planning, making decisions, setting goals, setting objectives, focusing, scheduling time, using resources, facilitating, and motivating.
Assessment	Involves setting criteria, comparing, contrasting, criticizing, evaluating, complimenting, and introspection.

Problem-Solving Methodology and Strategies

1. Define the problem.	a. Restate the problem, mention what is being sought. b. Draw a sketch or diagram of the situation.
2. Identify the important issues.	a. Identify what is given (the knowns). b. Identify what needs to be found (the unknowns). c. Identify the constraints. d. Identify the connections between the knowns and the unknowns. e. Identify the chemistry concepts that are relevant.
3. Evaluate the information.	a. Identify what information is relevant and what is not. b. Identify additional information that is needed and where it can be 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). 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. c. Make valid assumptions or simplifications if necessary. d. Divide into manageable pieces or subproblems if possible. e. Utilize and combine chemistry concepts. f. Set up a mathematical description of the problem. g. Utilize chemistry concepts in equation form. h. Develop as many independent equations as there are unknown variables. 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. b. Use computer technology if necessary. c. Substitute numerical values. d. Perform mathematical operations to obtain a numerical answer. e.Use dimensional analysis to obtain the units of the answer. f. Combine the solutions to the subproblems.
6. Validate the solution.	a. Compare the solution with the statement of the problem. b. Compare the solution with experience, expectations, and real world c. Is the solution complete? d. Is the sign correct, expected, or reasonable? e. Is the magnitude reasonable? f. Are the units correst and reasonable?
7. Assess your understanding of the solution.	a. Summarize the procedure. b. Summarize the relevant chemistry concepts. c. Identify how the concepts were used in the procedure. d. Examine and compare with alternative procedures or solutions.

Internship Experiences
"My experience in the internship was totally different from my experiences in courses. At the university I am supposed to work independently and am tested on what I have done or learned. In the internship I was part of a team. We met daily to discuss what
"Compared to the university, there is less tension between coworkers and that I believe is due to less pressure of competition between them."
"The internship involved teamwork and friendship. In a world where people tend to get lost in the shuffle, you are made to feel important and special about the contributions you make to the team. I remember the first day I came to work, my coworkers, alon
"Many times while working if people are too serious and quiet, someone will call a time-out which gives people a chance to relieve some of the stress."
"Our labs has the right combination of characters. Two are work-aholics, they usually guide the lab duties. One is very serious and meticulous with measurements. The two younger members of the team seem to keep the work atmosphere lighthearted. Another is
"The time I have spent has taught me how to be more of a responsible person. While in school the only person affected by a student's poor work is the student himself. In industry it is quite different. It is necessary for a group of people to depend on a

Questions and Answers

1. Are problem solutions produced by cooperative groups better than the work of the best students in the groups?	Group problem solutions were found to be significantly better than those produced by individuals. This result stems from students sharing conceptual and procedural knowledge and requesting clarification, justification, and elaboration from each other.
2. Does individual problem-solving performance improve during the course of instruction? If so, does the performance of the best students show the same improvement as that of the other students?	Individual problem-solving performance improved over time at approximately the same rate for students of high, medium, and low ability.
3. What type of problems promotes the use of an effective problem-solving methodology?	Multi-step problems, context-rich problems, and problems with missing or excess information require analysis and planning rather than an identify-and-use-a-formula (plug and chug) approach.
4. What structural and management procedures result in well-functioning cooperative groups for problem-solving?	Groups of 3 were found to be the optimal size for problem solving. A three-member group is sufficiently large to generate diverse ideas and approaches and not be dominated by one member with a strong viewpoint, and yet is sufficiently small to allow all students to contribute. Heterogeneous groups (gender, ability, ethnicity) sometimes performed better than homogeneous groups. Side-by-side seating usually isolated one member of the group, which did not occur when the students were seated facing each other, preferably around a table.
5. How can problems of dominance and conflict within a group be addressed?	The assignment of roles within a group (e.g. manager, spokesperson, recorder, strategy analyst, reflector) empowers students to take actions that they might not otherwise take. Self-assessment and discussion of the operation of the group reduces dominance and conflict. A portion of the grade is based on the quality of process skills exhibited by the group.
6. How can positive interdependence of the group members be promoted?	Goal interdependence, simply requiring that the students complete a lesson by working as a group, is not sufficient. Reward interdependence also is needed. Reward interdependence gives each student in the group the same grade for the group's work, and the grade is based not only on completing the less but also on meeting the objective that each member of the group understands the material.
7. How can individual accountability be enforced?	Each student is assigned a role or responsibility. Students assess themselves and each other. Instructors question students, who seem not to be involved, about what the group is doing. Each student can be called on to report on the group's work. Pre and post quizzes or assignments can be given.