Instructor's Guide to Process Oriented Guided Inquiry Learning

by

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Preface

Discussions and studies revealing that traditional teaching methods in higher education no longer meet students' educational needs have led to several reform initiatives. Some of these initiatives focus on changing the curriculum and course content; others seek to utilize computer-based multimedia technology for instruction; and some promote more student involvement in class and seek to engage students in learning.

Process Oriented Guided Inquiry Learning (POGIL, rhymes with *mogul*) is one manifestation of the latter. In a POGIL classroom students work in learning teams on specially designed activities that promote mastery of discipline content and the development of skills in the processes of learning, thinking, problem solving, communication, teamwork, management, and assessment. The POGIL classroom environment is appropriate for faculty who want to engage students in learning and help students develop the skills they need to be successful in courses, college, and careers. In this environment, students take on greater responsibility for their education; they learn to rely on thinking skills rather than memorization; they improve performance skills while learning subject content; and they develop positive relationships with other students and faculty.

This instructor's guide documents the need to include such performance skills in our courses and describes the educational tools and processes used in a POGIL classroom. These tools and processes include learning teams, guided inquiry activities, critical and analytical thinking, problem solving, reporting, metacognition, and individual responsibility. Strategies for the successful use of learning teams are discussed, the roles of the instructor in this learning environment are described, and implementation hints are provided along with examples of questions for student self-assessment of performance and reflection on learning. Assessment and evaluation results pointing to the success of this approach also are included.

The term *learning teams* is used rather than *cooperative or collaborative learning groups* because it better brings to mind similarities with athletic teams in which students work together to reach common goals. The term also avoids preconceptions of the meanings of *cooperative* and *collaborative*. Analogies between learning and sports (such as tennis, swimming, golf, track and field, and wrestling) can be made to introduce students to the POGIL classroom. In all these areas, participants work together in teams and help each other to develop their skills and abilities; they then compete as individuals.

This guide complements books that provide POGIL activities[1-5] that can be used at each class meeting or in sessions held once or twice each week to supplement lectures. A guided inquiry format based on the learning cycle of exploration, concept formation or invention, and application is used in these activities. Students work on the activities in teams to acquire knowledge and develop understanding. The teams examine data, models, or examples in response to critical thinking questions. They then demonstrate and apply their knowledge in exercises, and problems are used to develop problem solving skills and higher order thinking such as analysis, synthesis, transference, and evaluation.[6] This guide is intended to assist instructors in using such activities successfully in their classrooms.

POGIL can be implemented in a wide variety of ways depending on such factors as the institutional culture, class size, the nature of facilities, and instructor preferences. A few successful models include replacing essentially all lectures with POGIL sessions,[7] converting standard recitation sessions to POGIL sessions,[8] and replacing one lecture session each week with a POGIL session.[9] For example, in General Chemistry at Stony Brook, three weekly lecture periods (55 minutes) are complemented by a once-a-week POGIL recitation session (80 minutes). After these lecture and recitation sessions, students work on homework assignments individually or in study groups that they organize for themselves. Free tutorial sessions for individual students or small groups of students are provided every afternoon and some evenings to answer questions, guide students in developing an understanding of concepts, and develop problem-solving skills. The lecture sessions are being made increasingly student-centered and interactive by the use of an electronic student response system. With this response system, individuals and teams can record answers to questions which are then immediately available for feedback and discussion.

1 MOTIVATION FOR POGIL

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 need to be quick learners, critical thinkers, and problem solvers. They need to be computer literate and skillful in communication, teamwork, management, and assessment (including the ability to self assess). Knowledge of the fundamentals and concepts beyond a single discipline are necessary.[10]

Traditional teaching methods that maintain the conventional objectives of structuring and presenting information do not address these issues. Several studies[11-20] have documented that many students are having difficulty understanding and applying concepts, finding relevance, transferring skills within and across disciplines, and identifying and developing the skills they need for success in specific courses, college, and careers. Students are missing the experience of science as the exchange and evolution of ideas, and gender and ethnic issues are being ignored in the design of courses. Poor performers withdraw from learning, and even the best performers may disengage because they are not challenged. The results are low levels of learning and high levels of attrition. Both students and faculty are frustrated by the lack of achievement and community. These issues are compounded at institutions that have large numbers of diverse students in introductory courses.

To address this situation and to help students become better learners in our courses, it is essential to recognize that education has two components, *content* and *process*, and that the process component often is not given adequate attention. Science education needs to be concerned equally with both the structure of knowledge, which is the content component, and with the development of the skills for acquiring, applying, and generating knowledge, which is the process component. Process skills become increasingly important 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, those with highly developed process skills are those who will be most successful.

There are many learning process skills, and these can be classified into cognitive, social, and affective domains.[21] The most important of these skills for science education lie in seven areas: *information processing*, *critical and analytical thinking*, *problem solving*, *communication*, *teamwork*, *management*, and *assessment*. Surveys of managers and leaders in industry generally show that employees are sought who are knowledgeable and have such skills, i.e. those who are self-motivated and who are quick learners, critical and creative thinkers, problem solvers, communicators, team players.[22] The general conclusion of one such survey was "that industrial employers would like chemistry-trained employees whose education includes 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."[23] Learning process skills, just like skills in laboratory work and athletics, can be developed, strengthened, and enhanced.[24] These skills therefore need to be included explicitly in college-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.

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2 Process Oriented Guided Inquiry Learning

Process Oriented Guided Inquiry Learning (POGIL) is both a philosophy and a strategy for teaching and learning. It is a philosophy because it encompasses specific ideas about the nature of the learning process and the expected outcomes. It is a strategy because it provides a specific methodology and structure that are consistent with the way people learn and that lead to the desired outcomes.

Five key ideas about learning have emerged from current research in the cognitive sciences.[24] This research documents that people learn by:

- Constructing their own understanding based on their prior knowledge, experiences, skills, attitudes, and beliefs
- Following a learning cycle of exploration, concept formation, and application
- Connecting and visualizing concepts and multiple representations
- Discussing and interacting with others
- Reflecting on progress and assessing performance

All of these ideas are incorporated into the design of POGIL in order to help students learn both discipline content and key process skills simultaneously. POGIL is built on this research base with the idea that most students learn best when they are:

- Actively engaged and thinking in the classroom and laboratory
- Drawing conclusions by analyzing data, models, or examples and by discussing ideas
- Working together in self-managed teams to understand concepts and to solve problems
- Reflecting on what they have learned and on improving their performance
- Interacting with an instructor as a facilitator of learning

To support this research-based learning environment, POGIL uses learning teams, guided inquiry activities to develop understanding, questions to promote critical and analytical thinking, problem solving, reporting, metacognition, and individual responsibility. These seven components, which are discussed in the following sections, are the tools for developing process skills and the mastery of discipline content. Within this structure, students work together in learning teams to acquire knowledge and develop understanding through guided inquiry by examining data, models, or examples and by responding to critical-thinking questions. They apply this new knowledge in exercises and problems, present their results to the class, reflect on what they have learned, and assess how well they have done and how they could do better. To reinforce the acquired concepts and to promote individual responsibility for learning, students are required to complete additional exercises and problems outside of class, and to read relevant sections of a textbook or other resource material.

A. Learning Teams are Highly Effective

Learning environments can be competitive, individualized, or cooperative. In cooperative learning, "individuals, working together, construct shared understandings and knowledge."[25] Because the ratio of students to faculty is generally large, it seems clear that the effectiveness of a university can be enhanced if it becomes a community of learners with students collaborating and learning from each other, and in fact, the literature is replete with research on different learning environments, and the benefits of students working together have been well documented. We now know that students teaching students results in effective learning and that a cooperative environment is more effective than a competitive environment.[26-30] In addition, 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, 30]

Research has documented that relative to other situations, students working in teams learn more, understand more, and remember more; they feel better about themselves, about the class, and about their classmates. They also have more positive attitudes regarding the subject area, course, and instructors. Also, in a team environment students are more likely to acquire critical and analytical thinking skills, cognitive learning strategies, and other process skills, such as teamwork and communication skills, that are frequently considered important outcomes of undergraduate education, in addition to being essential in the workplace.[25, 30, 31] Further, this approach addresses the feelings of isolation and competitiveness many students report experiencing in college, especially women and other minorities in science.[14, 15, 32] Our experience is consistent with this research, and we have observed that the collegiality initiated in learning teams often extends beyond the workshops themselves with students exchanging telephone numbers and addresses, and organizing study groups on their own.

The success of the team learning environment should not be surprising. Individuals who work alone in competitive or individualized instructional modes do not have the opportunity for intellectual challenge found in a learning team. As a learning team becomes involved in a lesson, the different information, perceptions, opinions, reasoning processes, theories, and conclusions of the members lead to disagreement. When managed constructively with the appropriate interpersonal, social, and collaborative skills, such controversy promotes questioning, an active search 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 and more frequent use of critical thinking and higher-level reasoning.[25]

B. Guided–Inquiry Activities Develop Understanding

Many educators acknowledge that it is not possible to transmit knowledge intact from the head of the instructor to the head of the student. Also, much research exists to document that real understanding and learning requires active restructuring on the part of the learner. Restructuring involves integrating new knowledge with previous knowledge and beliefs, identifying and resolving contradictions, generalizing, making inferences, and posing and solving problems.[25, 33, 34] Thus, knowledge is personal and is constructed in the mind of the learner. This construction depends on the misconceptions, biases, prejudices, beliefs, likes, and dislikes of the learner.[35] This learning model, called *constructivism*, is one of the leading pedagogical paradigms for enhancing student learning.[36]

A POGIL learning activity engages students, promotes restructuring of information and knowledge, and helps students develop understanding by employing the learning cycle in guided inquiry activities. The learning cycle consists of three stages or phases: *exploration*, *concept invention* or *formation*, and *application*. These are described below.[37] Cognitive research tells us that the learning cycle embodies the way we learn best. It also is the way we do research; it recapitulates the simple logic of the scientific method. This sequence of exploration through application is generally more effective than other permutations of these three items.[38-41] Traditional lectures present the concepts, model how they are applied, and then provide further applications for students to work out on their own. Students are not guided in exploration or helped in developing their understanding. Problem-based learning requires students to work on large-scale applications with the objective that they will explore and develop an understanding of the concepts and fundamentals as they develop the problem solution.

In the exploration phase of the learning cycle, students are given a model to examine or a set of tasks to follow that embody what is to be learned and lead to attaining the learning objectives. A series of questions guides them through an exploration of the model or an execution of the tasks to the development and deeper understanding of a concept. The model can apply to almost any type of information to be processed: a diagram, a graph, a table of data, one or more equations, a methodology, some prose, a computer simulation, a demonstration, or any combination of these things. While verbal descriptions or explanations (mini-lectures) can also be used for models, they are not particularly effective, because no permanent record exists that can be re-examined and analyzed by the students. Case studies, field exercises, and laboratory experiments can also be used in the exploration phase. In this phase, students have the opportunity to propose, question, and test hypotheses in an attempt to explain or understand the exploration presented to them. The intent is to have the students encounter questions or complexities that they cannot resolve with their accustomed way of thinking.[33, 39]

Exploration of the model is guided by *critical-thinking questions*, also referred to as *key questions*. These questions build on each other in complexity and sophistication. Students develop answers by thinking about what they find in the model, what they already know, and what they have learned by answering previous questions. In some cases, the questions also encourage students to seek additional information from the textbook or lecture notes.

The second phase may involve either *concept invention* or *concept formation*. For activities designed with a concept invention in the second phase, the concept is not explicitly presented in the exploration phase. Effective guidance leads the exploration to conclusions and predictions based on the current understanding. Additional information and a name for the concept then can be introduced. Although instructors may be the ones to introduce the name (so that standard language is used), it is the students who discover the patterns. This phase also is called *term introduction* because after the students discover the pattern, the instructor introduces a name for it. The exploration and concept invention stages together help students develop an understanding of the concept.

Other activities are designed with a second phase that involves *concept formation*. In these activities, some representation of the concept is explicitly presented at the beginning. Questions then help students explore this representation, develop an understanding of it, and identify its relevance and significance.

Once the concept is identified and understood, it is reinforced and extended in the *application phase*. *Application* involves using the new knowledge in exercises, problems, and even research situations. *Exercises* give the learner the opportunity to build confidence in simple situations and familiar contexts. *Problems* require the learner to transfer the new knowledge to unfamiliar contexts, synthesize it with other knowledge, and use it in new and different ways to solve real-world problems. *Research questions* identify opportunities for the learner to extend learning by raising new issues, questions, or hypotheses.

C. Critical and Analytical Thinking are the Keys to Success

Critical or analytical thinking can be defined as "an investigation whose purpose is to explore a situation, phenomenon, question, or problem to arrive at a hypothesis or conclusion about it that integrates all available information and that can therefore be convincingly justified."[42] In this sense, the outcome of such thinking can be thought of as "both a tentative solution to the problem and a justifying argument."[43] Critical and analytical thinking involve identifying key issues and relationships, identifying and challenging assumptions, asking strategic questions, and developing answers to those questions. A teaching methodology that involves critical and analytical thinking encourages constant improvement and develops process skills.

Critical-thinking questions are used in POGIL activities to guide students' exploration of the models. In broad terms, there are three types of questions that are used, each with a different purpose. *Directed questions* point the student to obvious discoveries about the model. They insure that the students are able to process the information presented in the model effectively. *Convergent questions* require students to synthesize relationships from their new discoveries (and previous knowledge), and lead to the development of new concepts or deeper conceptual understanding. *Divergent questions* are open-ended and do not have unique answers. They encourage the student to generalize and to consider the relevance or applicability of the concepts.

Critical-thinking questions also are used by the instructor to promote the development of higher-order thinking skills.[6] Instructors facilitate critical thinking not by giving students answers to questions and solutions to problems, but by asking questions that promote rather than discourage thought, that encourage students to use knowledge they already have acquired, and that help them identify and seek necessary additional information.[44, 45] Such critical-thinking questions can be divergent, requiring the student to consider all possibilities; convergent, focusing on one of the possibilities; or directed, pointing directly to the resolution of the problem or difficulty. In most cases, it is far better for instructors to pose critical-thinking questions and to encourage students to discover answers on their own rather than to provide elegant responses. Better understanding is developed and retention is enhanced if answers to questions are constructed by the student rather than provided by the instructor.

By using such critical-thinking questions, both in the POGIL activities, and in lecture and discussion, instructors model for students how new and unknown situations can be analyzed and made tractable by identifying and asking key questions and then working to find the answers.

D. Problem Solving Requires Expert Strategies

In the POGIL classroom students acquire information, form concepts, and construct understanding by examining a model or executing a task. They respond to critical-thinking questions and integrate this new knowledge with information from other sources (e.g. previous activities, the textbook, and lectures). They then develop skills in applying this understanding by working exercises and solving problems. The

exercises are straightforward applications of the concepts and understandings. After the concepts can be applied to exercises successfully, they can be integrated with other concepts, generalized, and transferred to new situations. These higher-level applications, requiring higher-order thinking skills, are provided by problems. One objective of POGIL is to enhance the ability of our students to solve problems.

Woods defines a problem situation as "one that has not been encountered before; we cannot recall from memory a procedure or a solution from past experience. We have to struggle to obtain a *best* answer."[46] In *The Complete Problem Solver*, Hayes suggests that "Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem."[47] George Bodner expressed this same idea, "If you know what to do when you read a question, it's an exercise, not a problem."[48] Michael Scriven identified three classes of problems. Problems of the first kind are in-paradigm or structured problems; these are encountered in classrooms and textbooks. Problems of the second kind are new-paradigm or unstructured problems; these are encountered in the real world and require a new approach, insight, paradigm, or theory to solve. Problems of the third kind are also unstructured and are encountered in the real world but are very complex, may not have a unique solution, and may not be solvable with the information available. Scriven proposes this third category because he sees such problems as presenting different cognitive and pedagogical challenges than the other two.[49]

In courses, problems for students can be produced from exercises simply by omitting information, requiring assumptions, or by including superfluous but seemingly relevant information. Problems can also be produced by combining exercises to form questions that have more than one part, because the process for arriving at a solution becomes more complex. Students must identify and separate the parts, organize the information that is relevant to each part, and decide what needs to be done. The difficulty of a problem depends on the clarity of the problem statement or situation, the complexity of the issues, the familiarity of the context, the presence of clues that identify the relevant concepts, the number and nature of the knowledge items involved, and the complexity and nature of the equations needed.

Students are challenged most by context-rich problems.[50, 51] Context-rich problems are essentially short stories that present problems in disciplinary or real-world contexts. They are designed to force students to analyze the problem statement and employ concepts before turning to a mathematical equation. Such problems may not explicitly identify the unknowns and may require that information be estimated. The key variables, concepts, and essential information must be identified before a solution can be attempted. Such problems serve to develop essential process skills, appeal to the interests of students, and relate concepts to current real-world issues, other subject areas, and employment opportunities.

Many students simply want answers and algorithmic solutions and do not realize that the answers and algorithms alone will not help them deal with new situations or solve problems on examinations and in the real world. Furthermore, many textbook "problems" are not really problems and do not encourage students to develop essential skills for problem solving. Too often, the questions posed in textbooks are exercises that can be solved by substituting numbers into a memorized formula, the so-called plug-and-chug method. Plug-and-chug exercises present an idealized situation with all the knowns and unknowns clearly identified, use self-consistent units, and include no superfluous information. Such questions allow the students to match the situation to textbook equations or to previously worked examples. These questions encourage memorization of formulas and algorithms, and use of pattern recognition rather than nurturing thinking skills and the application of concepts.

Students typically find problems very challenging because they come to our courses with expectations that produce certain behaviors.[52] We have observed several behaviors that limit student success in problem solving. It appears that many students have the following thoughts when given a problem. "If I am being asked this question, I must know the answer. If I am supposed to know the answer, then it shouldn't take very long, and I shouldn't have to think about it. I only need to find the right equation, plug in the numbers, and calculate the result. Drawing a picture or diagram to represent the problem would be a waste of time, and it would look silly to develop a plan or outline a solution on paper. I should be able to do everything in my head."

This approach has several fallacies and, as we know, is not very successful as a result. For example, evidence indicates that working memory can handle about five or six pieces of information and operations, and students do not realize that paper or other means must be used to expand their working memory in order to address complex issues successfully.[35] Also, students do not recognize and appreciate that diagrams or other analysis on paper would help them visualize the problem, identify the issues that need to be addressed, and keep track of their progress. Simply asking a student to draw a diagram to represent what the problem is asking often leads the student to a solution.

Early thinking about facilitating problem solving focused on heuristics. Heuristics are simple rules or procedures that are presumed to help people find solutions and answers. The most well-known set is provided by George Polya in his book, *How to Solve It*.[53] Some of the many variations and elaborations that have been compiled and discussed since are listed as references.[54-58] A set of heuristics expanded from a variety of sources is given in Table 1.

Discussions in textbooks that advise students on how to solve problems are often based on heuristics. For example, a textbook may suggest that students define and visualize the problem, identify the information that is given and needed, identify a process to solve the problem, manipulate the equations, substitute and do the calculations, and validate the solution. Students generally do not find these methodologies to be very helpful and are often reluctant to use them. Such methodologies are not very helpful because students do not know what to do at each step. If the methodology is brief (e.g. understand the problem, develop a plan, execute the plan, look back),[53] it is too general to be helpful, if the methodology provides much detail (e.g., see Table 1), it is too complex to comprehend and implement, and it still is not clear what should be done at each step in specific situations.

If the use of heuristics is to be helpful to students, it needs to be taught explicitly. Even when this is done, the results are mixed. Reif, Larkin, and Brackett reported that "We further taught students a simple strategy for problem solving. Our results indicate that students can indeed be taught such general cognitive skills and that they can transfer these skills to areas outside of physics."[56] Although in another study, no significant differences were detected in achievement between control students and treatment students who had been taught an explicit problem-solving approach.[55] A meta-analysis concluded that "strategies based on Polya's heuristics or variations thereof appear to facilitate students' ability to solve routine problems even though there is some evidence that students may be doing so using algorithms."[59]

Conclusions from Novice–Expert Comparisons

It therefore appears that something more than such heuristics is needed in order to improve problem-solving skills. Reif suggested that an effective strategy must identify the cognitive mechanisms that a student uses in problem solving before instruction and those that are needed to produce good problem-solving performance. This understanding of cognitive mechanisms then is used in the instructional design.[60] This insight led to comparisons of problem solving by novices and experts. This novice-expert research on problem solving produced the following conclusions.

1. ***The organization of knowledge in long-term memory is important***

   The content knowledge of discipline experts is organized around key concepts in ways that reflect a deep understanding of the subject matter. The knowledge that novices have stored in long-term memory is not organized. It appears to be stored as isolated pieces. Experts conditionalize their knowledge (see below), organize it around concepts, and connect the pieces strongly together by recognizing features and patterns that are not noticed by novices. These knowledge structures, *schemata* or *chunks* as they are called, contain content knowledge (facts, principles, concepts, theories, relationships, and equations), characteristics that facilitate connecting a problem to the appropriate schema, and procedures and strategies for solving problems. The schemata not only make it possible to quickly identify and retrieve knowledge from long-term memory as it is needed, but they also aid in transferring the knowledge and using it in new contexts.[61-64]

   Experts do not have to search through everything they know in order to solve problems; rather their schemata include specifications of the contexts in which they are useful.[65, 66] In the language of cognitive science, such knowledge is *conditionalized*. "Knowledge must be conditionalized in order to be retrieved when it is needed."[24] (p.49) Often experts facilitate this retrieval by asking critical-thinking questions to help them determine the relevant concepts and decide what needs to be done. Novices, on the other hand, experience difficulty in identifying and retrieving the knowledge needed to solve a problem because their knowledge is not conditionalized; items are stored as independent.

2. ***Novices rely on and are limited by their working memory***

   Working memory is limited to five to nine slots. Experts expand their working memory by using paper notes and diagrams and by chunking bits of information into larger pieces.[35, 67] This chunking increases the amount of information that can be held in working memory since one chunk takes only one slot. Since novices are reluctant to use paper notes and diagrams and have not developed schemata, they run out of space in working memory; they are unable to keep track of all the relevant information and the connections between what they know and what they need to find.

3. ***Experts have good strategies for analyzing problems and planning solutions***

   When given a problem in chemistry or physics, experts think about the concepts involved, why they are relevant, and how they can be applied. Novices tend to look at the surface features of the problem; they think in terms of information that they have memorized or equations that they have been given; and they rely on matching the new problem to what they have seen before. Novices are likely to start by plugging numbers into an equation, while experts are likely to begin by restating the problem in their own words, drawing diagrams to represent the problem, and developing a plan based on qualitative ideas.[61, 63, 68-72]

Table 1 **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. 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 obtained. c. Identify and evaluate assumptions or simplifications that have been made.
3. 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 concepts that are relevant. e. Identify the connections between the knowns and the unknowns.
4. Plan a solution.	a. Identify a qualitative approach (utilize 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 sub-problems if possible. e. Set up a mathematical description of the problem. f. Utilize concepts in equation form. g. Develop as many independent equations as there are unknown variables. h. 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 behavior. c. Is the solution complete? d. Is the sign correct, expected, or reasonable? e. Is the magnitude reasonable? f. Are the units correct and reasonable? g. Can the assumptions be removed to produce a better result?
7. Assess your understanding of the solution.	a. Summarize the procedure. b. Summarize the relevant concepts. c. Identify how the concepts were used in the procedure. d. Examine and compare with alternative procedures or solutions. e. Generalize the solution, the process, and alternatives for use in other contexts.

4. ***Metacognition is an important component in the problem-solving process***

Experts continually reflect on what they are doing and why they are doing it. They look for inconsistencies and other ways to validate their results, and they are flexible in their approach to new situations. "The ability to monitor one's approach to problem solving —to be metacognitive—is an important aspect of the expert's competence."[24] (p.50)

5. ***The ability to transfer knowledge to new contexts is essential***

The ability to transfer knowledge to new contexts is the key to being able to solve Scriven's problems of the second and third kind (unstructured and very complex).[49] Experts have this ability, and novices need to develop it. "Many approaches to instruction look equivalent when the only measure of learning is memory for information that was specifically presented [facts, algorithms, and previously solved exercises and problems, which therefore are no longer problems]. Instructional differences become more apparent when evaluated from the perspective of how well learning transfers to new problems and settings."[24] (p.77)

Successful problem solvers have a mastery of the discipline content (content knowledge), they have an effective problem-solving process (process or procedural knowledge), and they have this knowledge organized hierarchically in schemata that connect concepts and related facts to each other in ways that facilitate quick retrieval and use in solving problems. They are also able to recognize when different pieces of this knowledge are needed in diverse contexts and are able to quickly retrieve and use it (transfer skills). Intelligence, memory, and the use of specific strategies do not separate the expert from the novice in successful problem solving. Rather, "experts have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information…. This, in turn, affects their abilities to remember, reason, and solve problems."[24] (p. 31)

In other words, experts are successful problem solvers because they recognize patterns of information in the problem, patterns that make connections to conceptual schemata stored in long-term memory. It is the ability to make these connections that enable experts to successfully use heuristics like those in Table 1. The items in Table 1 describe the types of things experts do as they work to make connections between their conceptual schemata and the problem at hand in order to produce a solution to the problem.

From this perspective of novice-expert research, it appears that in order to improve student problem solving skills, we need to help them strengthen their content knowledge, instruct them in the use of an effective problem-solving methodology, and most importantly, assist them in developing knowledge schemata and transfer skills. Clearly, it is not adequate simply to give students problems to do and state in the course syllabus; "To be successful you need to use conceptual understanding to solve the assigned problems."

"Common teaching practices usually pay far too little attention to issues of knowledge organization. Thus material usually is presented sequentially, chapter by chapter or lecture by lecture, so that students themselves must somehow try to integrate all this accumulating knowledge into a coherent organization facilitating flexible knowledge use. The task of creating such an effective organization is a substantially difficult undertaking which most students are ill prepared to carry out without outside assistance. Furthermore, arguments or problem solutions, presented in books or classrooms, are usually exhibited in the form of linear sequences of steps. Such a presentation may be impeccable from a purely logical point of view. However, unlike a more hierarchical organization, it is *not* well designed to help students remember or apply such knowledge."[60]

Implications for Instruction

In contrast to the traditional classroom, the POGIL structure is well-suited for growing the ability of students to solve problems. Learning teams have been shown to be beneficial in helping students increase their ability to solve problems.[50, 51] POGIL activities are organized around key concepts and their applications so the development of a hierarchical knowledge structure is supported; and the activities are designed to help students develop an understanding of the concepts, which is essential. Below are described additional strategies that address each of the above five issues identified as important in the novice-expert research.

1. ***Organizing knowledge in long-term memory***

   Discipline or content knowledge needs to be stored in long-term memory in structures or schemata that make its use in problem solving quick and easy. It needs to be organized in a hierarchy with a small number of basic concepts at the top and detailed applications at the bottom. Different knowledge items need to be associated with each other, and they need to be connected to some recognition switch that triggers their use. We need to help students build such structures in developing their problem solving skills because such a structure makes it easier to remember the material, recognize when it is needed, and retrieve it quickly.

   Pattern recognition should be an important component of this instruction because it triggers access to knowledge that is relevant to a task.[24] (p.48) Students therefore should be asked to compare and contrast problems in different contexts; to identify patterns in representations of concepts, problems, and their solutions; and to classify problems in terms of the concepts, principles, and procedures needed to solve them. In addition, students need to understand why those concepts, principles, and procedures are relevant. There is some evidence that such problem categorization can be successful, even when the focus on conceptual understanding and the application of concepts is not emphasized.[73] Unfortunately many texts combine, classify, and label end-of-the chapter problems by type, and provide worked examples for each type, so students need not conduct such an analysis.

   To further nurture problem-solving skills, students can be asked to identify the relevant issues and concepts, explain why they are relevant, and plan solutions. Brainstorming sessions can be used to highlight new ideas and approaches. Such activities complement the focus on accuracy and numerical results that are part of science courses. "Instruction that focuses solely on accuracy does not necessarily help students develop fluency."[24] (p.49)

   Jumping too quickly from topic to topic does not provide adequate time for students to develop a deep understanding of the material, and "curricula that emphasize breadth of knowledge may prevent effective organization of knowledge because there is not enough time to learn anything in depth [and make connections among the different items]."[24] (p.49) POGIL activities that extend across multiple concepts and those with diverse applications of same concept can be used to address these issues. Also, a section called *Making Connections* can be included in each POGIL activity.

2. ***Overcoming the limitations of working memory***

   Helping students to chunk their knowledge and develop knowledge schemata, as just described, will help students to expand the information that can be used in working memory. Students also need to be encouraged and taught explicitly to make notes on paper, and to draw diagrams when analyzing problems, and planning and implementing solutions. Van Heuvelen lists three reasons why students do not draw diagrams:[74] they have not been taught how to draw diagrams and represent information, concepts, and principles with symbols; they do not understand the concepts and principles that they need to include in the diagram; and the understanding that they bring with them is in conflict with what they are being taught, and this dissonance confuses them.

3. ***Analyzing problems and planning solutions***

   It is generally helpful to use an explicit problem-solving methodology (e.g. some appropriately selected subset of items in Table 1) but students must be instructed in how to use the methodology. The instruction needs to focus on the analysis of the problem and on planning a solution, not on the steps taken in a procedure that leads to the correct answer. It needs to help students integrate the conceptual, analytical, and procedural aspects of problem solving.

   If a solution is presented or if the problem solving process is modeled by the instructor, then in order for students to benefit, they need to analyze the process and identify for themselves what was done, how it was done, and why it was done. They need to compare and contrast the expert's approach with their own. Again the focus needs to be on the process, not the steps in the solution, or the answer to the problem. Strategies used in solving problems should be documented by identifying the concepts, principles, and procedures that are needed and by specifying why they are needed.

4. ***Benefiting from metacognition***

   The use of an expert strategy in problem solving can be promoted, and the quality of the problem-solving process itself can be improved through metacognition. Learning teams can assess the approaches used by other teams to identify their strengths, areas for improvement, and insights regarding problem-solving. This feedback is then shared to grow everyone's understanding of problem solving and how it can be applied to very rich problems. The goal is that, when students attempt to solve a problem, they will think explicitly about what they are doing, and note what is (and is not) necessary and effective. This analysis can then be compared and contrasted with the approach used by the instructor (an expert strategy).

5. ***Transferring knowledge for use in new contexts***

   Team and class discussion can be used to help students identify situations in which their new knowledge is useful, and often the last critical-thinking question in a POGIL activity will ask students to identify the relevance or usefulness of what they have learned. Diverse problems illustrating how the concept is used in different situations can be assigned, and students working in teams can analyze these problems and explicitly identify when, where, why, and how to use their knowledge.

   Many textbooks work against this objective. End-of-the chapter problems are often grouped and identified by topic or concept, and students never have to think about which concepts need to be applied and why they need to be used. Students often have trouble on exams because the questions usually appear randomly and are not identified by type. If this is the case, students have not developed the skills in inquiry and in identifying key issues to the level that they need in order to be successful on exams, in future courses, or in the real world.

Developing Essential Transfer Skills

Research has shown that the following items affect the ability of students to transfer what they have learned to new situations.

1. ***Initial learning is essential***

   "Without an adequate level of initial learning, transfer cannot be expected."[24] (p.53) In other words, you can't transfer what you don't know and don't understand. The material needs to be mastered, and understanding developed. "Attempts to cover too many topics too quickly may hinder learning and subsequent transfer because students (a) learn only isolated sets of facts that are not organized and connected or (b) are introduced to organizing principles that they cannot grasp because they lack enough specific knowledge to make them meaningful."[24] (p.58)

   Students need to be motivated to spend the time necessary for mastery-level learning. While extrinsic rewards (good grades and concomitant career advancement) and punishments (poor grades and poor prospects for career advancement) affect behavior, intrinsic rewards are generally more successful. Such intrinsic rewards include the success of meeting a challenge that is not too easy to be boring or too difficult to be frustrating, opportunities to share knowledge and results of work with others, recognition that what is being learned is relevant and useful, and opportunities to use new knowledge to help others.[24] (pp. 61,77)

2. ***Multiple contexts are important***

   "A single context is less likely to support transfer than the use of multiple contexts. With multiple contexts and examples and problems that demonstrate wide application, students are more likely to abstract and generalize the relevant features of concepts and to develop a flexible representation of knowledge that facilitates transfer."[24] (p.62)

   To help students in this learning process, instructors can ask them to compare and contrast different contexts, to consider how a solution plan changes as parts of a problem change, or to create a solution that applies to a whole class of related problems, not just to a single problem. Instructors might also ask students to think about areas of relevance and applicability as they learn new concepts.

3. ***Opportunities for transfer need to be revisited over time***

   The ability to transfer knowledge generally increases with time after an initial learning experience. "It is important to view transfer as a dynamic process that requires learners to actively [and continually] choose and evaluate strategies, consider resources [and past experiences], and receive feedback."[24] (p.66) Students need the opportunity to use their knowledge repeatedly in a variety of contexts over an extended time interval.

   When students are learning a new concept that is connected to previously learned concepts, instructors should ask them to identify what they need to do in order to transfer from the previous learning experience to the current one. In fact, identifying what can be transferred from a previous leaning experience to the current one should be part of a POGIL activity, as appropriate. Transfer can be promoted using a simple critical-thinking question such as, "Can you think of something that we did last week that might be useful here?"

4. ***Metacognition increases transfer***

   Frequent feedback from the instructor is critical, and "students need to monitor their own learning and actively evaluate their strategies and their current levels of understanding." Group discussions of objectives, strategies for achieving them in different contexts, and reflection on how those strategies can be improved have been shown to improve transfer.[24] (pp. 67,78)

Problem-Solving Instruction in Action

Several successful research-based instructional strategies for improving problem-solving skills have evolved from this novice-expert research. These strategies emphasize the importance of restating the problem in terms that the problem solver can understand, planning a solution qualitatively before turning to formulas and mathematics, and using metacognition along the way. Below are some examples:

Van Heuvelen[74] developed *active learning problem sheets* for physics instruction[75] based on the following approach. A problem usually is posed in words. Students are asked to, and are shown how to, construct several different representations of the problem. Students restate the problem in their own words, identifying the information they have been given and what they need to find. They construct qualitative representations as appropriate; examples might include a sketch of the physical situation, a diagram to represent the problem, or a sketch of a graph showing how variables are related. From these qualitative representations, they identify mathematical equations that represent the features of the problem. Finally they solve the problem quantitatively.

Reif[60, 76] suggested a five stage approach that has been formalized as the Minnesota Physics Problem-Solving Strategy.[77] In ***Stage 1***, students are asked to develop an understanding of the problem by describing it in their own words and in terms of diagrams or other symbolic representations. They identify what known, what is to be found, and what additional information is needed. In ***Stage 2***, they use this qualitative understanding to produce a description in terms of the concepts, principles, diagrams, symbols, and equations of physics. After the problem has been described, a solution is planned or constructed in ***Stage 3***. This planning usually breaks the problem into sub-problems, outlines the procedures, and produces the equations that need to be solved. This stage is the most difficult one, but three approaches are helpful: means-ends analysis, working backwards, and successive refinements. In *means-ends analysis*, successive sub-goals are identified that take one closer and closer to the end result. *Working backwards* is similar to means-ends analysis except one starts from what one wants to find and tries to connect it to information that is given. In making *successive refinements*, one constructs and solves a similar but simpler problem and then introduces the additional complexities that are part of the real problem. In ***Stage 4***, the plan is implemented and calculations performed, and in ***Stage 5*** the result is validated.

One approach with reported success in computer science seems to have promise for application in other disciplines because it strongly emphasizes the connection between concepts and their use in solving problems. When students were trained in a five step self-explanation and self-regulation methodology (metacognition), they made fewer errors and were deemed to be more successful in solving problems.[78] After encountering material in text or lecture (and guided inquiry could be included too), these students were asked to (1) identify the important concepts in the material, (2) elaborate on and identify the connections between these concepts, (3) examine an example problem and identify the steps needed to solve the problem, (4) identify the reason for and meaning of each step, and (5) relate the concepts presented in the initial material to the steps in the example problem.

E. Reporting Builds Skills and Solidifies Concepts

There are a variety of student-centered techniques to provide closure to an activity or section of an activity. Involving the students in the process increases motivation and performance and provides them with opportunities to develop communication and thinking skills. Individual presenters or spokespersons from different teams can be called upon to share their teams' responses to one or more of the questions, or spokespersons can be exchanged between teams. They then present and explain their answers to the teams they are visiting and resolve any disagreements before returning to their original teams.

An approach known as *simultaneous reporting* is particularly efficient. In this case, the presenters from a few teams are asked to put on the board their teams' answers to questions, solutions to exercises, or plans for solving a problem. When information is on the board, a time-out is called, and the class is asked for agreement or disagreement on each item in turn. To resolve disagreements, the person who put the information on the board can provide an explanation to the entire class, or teams can be asked to help each other. It is important for the students themselves to resolve the disagreements in order to develop process skills in thinking and communicating and to place the responsibility for learning, teaching, and assessment on them. This method of closure is called *simultaneous reporting* because several answers are reported to the class and validated simultaneously rather than serially.

A written report is submitted by each team at the end of the POGIL session. These reports can contain one or more of the following items as appropriate: the team's answers to the critical-thinking questions that were addressed during that session, a summary of the important concepts that they developed from the activity, the team's solutions to some or all of the problems that they worked. The report gives students the opportunity to assess their performance and reflect on what they have learned. This assessment and reflection process is described in the next section.

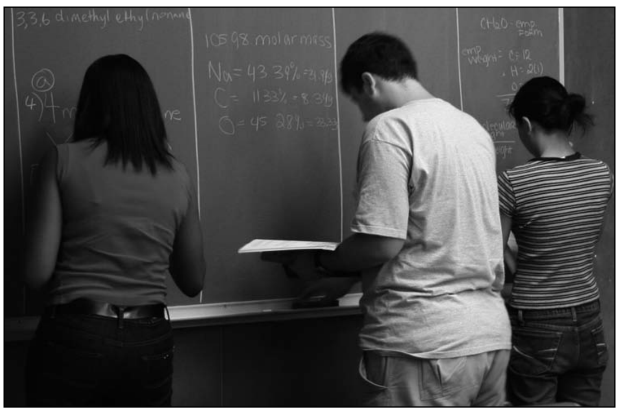
F. Metacognition is Important

Metacognition means literally, thinking about thinking. It includes self-management, self-regulation, self-assessment, and reflection on learning. Metacognition is used in POGIL to help students realize that they are in charge of their own learning and that they need to monitor it (self-management and self-regulation), that they need to think about their performance and how it can be improved (self-assessment), and that they need to reflect on what they have learned and what they don't yet understand (reflection on learning).

Metacognition produces an environment for continual improvement. Students can be asked to assess their own work and that of each other; 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. In order to encourage self-assessment, peer assessment, and support assessment by the instructor, an atmosphere must be established in which such assessments are safe, positive, and valued by all.

To establish a learning environment where assessment is valued and appreciated, a distinction must be made between assessment and evaluation. *Assessment* is the process of measuring a performance, work product, or skill; giving feedback to document strengths and growth; and providing directives for improving future performance. *Evaluation* is the process of making a judgment or determination concerning the quality of a performance, work product, or use of skills against a set of standards.[79] Assessments are nonjudgmental and are designed and intended to be helpful in producing improvement. Evaluations, on the other hand, are judgmental, and are designed and intended to document the level of achievement that has been attained. Feedback provided during daily learning experiences should be given in the form of assessments, while course examinations provide the evaluation. In athletics, coaches give players assessments throughout the week during practices and scrimmages; the big game on Saturday is an evaluation. In order to establish the value and use of assessment, the instructor must model self-assessment, must request assessments of his or her own performance from students, and must act on those assessments.

If one of the goals is for students to improve their process skills, they must be asked to examine their own performance as well as that of others and make comparisons. Individuals need to recognize what they know, what they need to know, how well they can do something, and what they need to do to improve. Student metacognition is important because it requires students to 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.



The written report that is submitted by each team at the end of the workshop session gives students the opportunity to reflect on what they have learned, to articulate and generalize concepts and strategies, and to consider what they have done well and how they can improve. In the report, students can be asked to assess their performance in the workshop activities and to make two- or three-item lists of concepts learned, strategies identified, methodologies practiced, process skills used, and questions remaining. It is important to use a variety of specific and substantive questions in motivating this self-assessment, e.g. where could unit analysis be used to solve a problem, was unit analysis used, where could a diagram have been drawn to help solve a problem, which tasks could be done in parallel by individuals and which should be done sequentially by the entire team so all understand the activity. Other examples are given in Appendix B. It also is essential that instructors insist on high quality substantive responses to these questions, provide feedback to the students on the quality of their responses, and show students that they recognize when their students' self-assessment have produced improvements in their performance.

G. Individual Responsibility is a Motivating Force

Applying newly gained knowledge is essential for solidifying understanding, increasing retention, and documenting relevance, which is why the third phase of the learning cycle is *concept application*. In addition, students need to test their own comprehension and work to develop their own skills. For these reasons, it is essential that students be held individually responsible for the learning that takes place in the POGIL classroom.

There are a variety of ways to ensure individual responsibility. For example, examinations are usually given on an individual basis, but it is preferable to provide students with more frequent feedback on their own understanding by using assessment opportunities. One method for doing this is to give a brief (one or two question) quiz on the previous session's material at the beginning of every POGIL session. Another possibility is to require students to hand in answers to some number of homework questions on a regular basis for grading, and with the advent of computerized homework-generating systems, the possibility exists of providing each student with a personalized assignment.

One example of the use of a personalized assignment is provided by the implementation at Stony Brook. Students leave the weekly POGIL session for General Chemistry with additional problems to solve in the form of a personalized assignment, which they access over the internet. These assignments are produced with the CAPA system[80, 81] that enables an assignment that 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 correct answers.

Students report their answers during the week 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 (assessment) not an evaluation tool.

This approach to homework has several attractive features. Each student identifies the assignment as his or her responsibility because it has his or her name on it. Diligent work is rewarded and students are motivated because they are assured of eventual success. It provides students with timely and accurate feedback exactly at the time at which they are interested in completing the assignment. Student-student and student-instructor interactions are enhanced because students seek help. Faculty are perceived as supportive helpers, and the computer appears to be the judge and authority figure. Time needed to grade and track homework assignments in large courses is greatly reduced. Within the context of POGIL, these assignments promote individual responsibility and accountability, self-management and self-regulation, and stimulate further cooperative learning beyond the classroom experience.

H. Grade Points May be Necessary

Although the POGIL lessons and out-of-class assignments are intended to be learning experiences, in some cases they must count in the course grade in order for students to take these activities seriously. Grade points are essentially the currency that students use to place value on course requirements. For some students, there is not adequate motivation to do an assignment simply because it will help them on a future exam. Because institutional cultures and student populations vary from place to place, you will need to ascertain the extent to which grade points are appropriate for various aspects of your POGIL implementation.

Grading policies are also used to elicit and reward desired behaviors from the students. A positive team-learning environment, in which students learn from each other, can be lost if the session grade focuses on the quantity of lesson material covered by the team. The emphasis needs rather 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 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 which produced that outcome. Two common reasons for poor performance by learning teams are inadequate advance preparation by one or more team members and the lack of participation of all members of the team.

By identifying the lack of specific skills or behaviors, the team clearly sees which skills and behaviors are necessary for success and which need to be improved. 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. The focus for these workshops is not on covering material (i.e., content) but is rather on the process skills associated with learning, thinking, problem solving, teamwork, communication, management, and assessment. The grading policy and procedure must reflect and support this focus by rewarding performance in each process area as well as mastery of the lesson material.

The grading is based on objectives and criteria that have been clearly stated to the students at the beginning of the session. Usually, the general objective is to complete or make satisfactory progress on the lesson so that each member of the team understands the material. The criteria relate to the success in meeting this objective, to the quality of written and oral reports presented by the group, and to the quality of process skills exhibited by the group during the workshop. While some general criteria pertaining to these items can carry over from session to session, others should focus on specific issues as needed. These specific criteria should be stated very explicitly at the beginning of each session by writing them on the board or by providing a handout with the agenda for the session. Criteria might include, for example, quick resolution of disagreements within a team, insightful discussion within a team of how to solve a problem, sharing answers to two or more questions with the entire class, helping one other team when called upon, or 100% scores by all team members on the end-of-session quiz.

Assessment and evaluation by the instructor occur during the class session and relatively little additional time is needed for grading. Grading can be simplified, made time-economical for the instructor, and be incorporated with self-assessment by using the following scheme. Each team assesses itself using the criteria provided by the instructor at the beginning of the session; each team awards itself a grade of 3, 4, or 5, and provides a rationale for that assessment. If the instructor agrees, that score is doubled. The instructor also provides an independent evaluation both of individuals and of the team for an additional 3, 4, or 5 points awarded to individuals. Consequently a realistic student score of 3 will become at a minimum, 9 (3+3+3); an unrealistic student score of 5 will be limited to 8 (5+0+3); and an excellent performance will receive 15 (5+5+5). This scheme thereby promotes realistic self-assessment by the students. It also encourages all students in a team to be engaged and participate since the instructor's points may differ for different team members. The instructor's points can include credit for homework, pre-session and post-session quizzes, and display of specific process skills and other desired behaviors. To avoid conflict, the instructor should monitor the self-assessment process and intervene when necessary before the session ends to ensure that each team's self-assessment is realistic.

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3 STRATEGIES FOR SUCCESSFUL LEARNING TEAMS

The benefits of learning teams cannot be achieved by simply telling students to form teams and giving them an assignment; requiring them to work together, teaching each other in the process, to complete it and. 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 collaboration for success, students in an introductory course are unlikely to have the essential skills for the task. Following the recommendations of Johnson, Johnson, and Smith [25], we have identified the seven elements discussed below as being essential for real collaboration and successful team learning. Guidelines also are discussed in the book by Millis and Cottell.[82]

A. Structure the Teams

The composition of a team determines its dynamics and effectiveness. The instructor needs to control the structure of the teams as a means to ensure that all teams in a workshop are reasonably effective.

Teams of three or four students work well for guided inquiry and problem-solving activities. In larger teams not all members stay engaged, and smaller teams lack the diversity of perspective and skills that produces a rich exchange of ideas.

Initially teams can be formed randomly. After getting to know the students, e.g. after the first or second class meeting, instructors can reform the teams to include a high-achieving student, a low-achieving student, and two others to provide diversity in gender and ethnicity. Diversity within each team is reported to be desirable because the perspectives and talents of the members will differ.[25]

Students within a team usually bond together very quickly. To ensure that changes will be accepted readily by the students, dates should be scheduled at the beginning of the term at which the teams will be reconstituted, e.g. after each hour examination. If the teams are functioning well, there may be no need to reorganize as scheduled. On the other hand, if one or more teams are dysfunctional, the reorganization can eliminate the problems with no obvious stigma to anyone.

Some instructors have found that they can change the teams at any time without any apparent problems or difficulties. Others work successfully with a combination of *affinity teams*, in which students work with whomever they choose, and *project teams*, which are assigned by the instructor for specific projects; but control over the team structure is an important tool to use in addressing difficulties that may arise.

B. Motivate Process

The importance of process skills in courses, in addition to content, needs to be introduced and motivated. Some instructors spend a few minutes at the outset of the course to explain the POGIL methodology and the reasons for it. Alternatively at the first session, teams can be asked to identify skills needed for course work or for those desired by employers. For example, for the first team activity, instructors might ask students to play the following role: “Your team is the employment committee of a start-up biotechnology company. You are planning to hire several new scientists in the coming months. Identify eight characteristics that you will be seeking in the applicants.” Instructors might then ask each team to report one of their characteristics and make a list on the board. “Knowledge or knowledgeable” will be only one of the characteristics. Other likely characteristics will be “team player,” “self-starter,” “problem-solver,” “creative thinker,” “verbal,” “intelligent,” and “assertive.” This situation can be used as an opportunity to point out that knowledge of discipline content is only one of the important things to acquire at the university and in this course, and that equally important are skills essential for the workplace and for life-long learning. These skills lie in the areas of information processing, thinking, problem solving, teamwork, communication, management, and assessment. The instructor should explain to students that the format of the POGIL class is designed to help exercise, strengthen, and develop these important and essential skills.

C. Motivate Learning Teams and Collaborative Skills

Since not all students may be familiar with the concept of learning teams and collaborative learning, these ideas may need to be introduced and motivated. Instructors need to point out that the university is a learning community, and that the two responsibilities of members in a learning community are to learn and to help others learn. Instructors may highlight the team structure found in the workplace and draw analogies with individualized sports such as tennis, track, and wrestling in which team members practice together to help each other learn and develop skills for competition as individuals.

An instructor might explain to the class that during these class sessions they will work together to acquire information and apply it in solving problems. One might point out that research has shown that students working in learning teams learn more, understand more, and remember more than those who work in individualized or competitive environments. In addition, these students acquire critical-thinking skills, problem-solving and learning strategies, and other process skills that are essential in the workplace, e.g. in the areas of teamwork, communicating, management, and assessment. Furthermore, a strong correlation between participation and grade in the POGIL sessions and performance on examinations has been documented.[29]

The desirability of *collaborative skills* and *promotive interactions* needs to be introduced, motivated, taught, and reinforced. Initially students may not work well together because they lack the motivation and/or process skills for leading, collaborating, encouraging, helping, and supporting each other. They may have difficulties identifying learning and problem-solving strategies and agreeing on methods and answers.

The importance of specific skills and actions may need to be explicitly discussed with the students in the areas of teamwork (leadership, cooperation, and conflict management), communicating (discussing, listening, and explaining), and management (decision making and use of resources), e.g. bringing their text, coming on time, encouraging each other, and listening and thinking about each other's perspectives. The team can identify and record particular skills that were used or needed to be used during a session. Bonus points can be awarded when members of a team use a particular skill. One can also pick a "skill-for-the-day" and ask students to identify for the instructor and for the class when they need and use that skill, e.g., when someone exhibits leadership, helps with time management, or finds something relevant that others overlooked.

Promotive interactions are positive, encouraging, and supportive interactions that occur between team members, and also between the instructor and the students. Promotive interactions found in cooperative learning and absent in competitive and individualized learning result in a number of important positive outcomes in the areas of learning, interpersonal relationships, and psychological health.[25, 26] Students can be asked to identify promotive interactions that occur in each session. The instructor can model promotive interactions by complimenting students and teams, shaking hands with insightful students, and by giving a *Marvelous and Magnificent Award* (packages of M&M candies) to the entire class.

High-achieving students may feel held back by working in a group, but not if the assignments are sufficiently challenging to require collaboration for success. The importance of developing process skills for life and for the workplace in teamwork, communication, management, and assessment can be stressed to such students. They need to realize that the POGIL session is designed to provide opportunities for them to exercise and strengthen such skills. They also should 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. In some cases, we tell students that we have found that the difference between a student who receives an A and one who receives an A^{-} or B+ is that the former has a better understanding of the material and is able to explain concepts to others and help others develop problem solutions.

D. Promote Positive Interdependence

The students in a learning team must depend on each other such that one cannot succeed unless all succeed. They need common specific objectives or tasks to accomplish, and they must depend upon each other to complete the task (*goal interdependence*). Further, they must share equally in the reward for success (*reward interdependence*).

In the context of the POGIL classroom, students are given an assignment to complete at each meeting. The team works together to complete the assignment. All members must participate fully and agree on strategies and answers since only one set of answers can be submitted from a team. The objective is for each member of the team to understand and be able to explain what has been done. Students are told that they have two responsibilities: to learn the assigned material and to ensure that all members of the team learn the material. At the end of the workshop period, each team submits one report of what they have done, and (in those implementations in which the quality of the report and the group performance is graded each time) each member of the team receives the same grade.

Tasks should be distributed among team members and complementary roles can be assigned to promote interdependence and involvement by everyone. These roles rotate weekly. We have found that the roles of manager, spokesperson, recorder, and strategy analyst work well, but roles can be invented to meet any needs that arise. Several examples are given in the literature. [7, 25, 83]

> The *manager* actively participates, keeps the team focused on the task, distributes work and responsibilities, resolves disputes, and ensures that all members participate and understand.
>
> The *spokesperson* (or *presenter*) actively participates and presents reports and discussion to the class.
>
> The *recorder* actively participates, keeps a record of the assignment and what the team has done, and prepares a report in consultation with the others.
>
> The *strategy analyst* (or *reflector*) actively participates, identifies strategies and methods for problem solving, identifies what the team is doing well and what needs improvement in consultation with the others, and prepares a report in consultation with the others. A sample Strategy Analyst's report is provided in Appendix F.

To further promote positive interdependence, individual weekly quiz grades can be averaged to obtain a grade for the team, but it is generally not wise to combine exam grades of team members, although bonus points might be given based on team performance. For example, if all team members score above 80% on an exam, each receives 10 bonus points; if three of four team members score above 80%, those three receive 10 bonus points; and if two of four score above 80% those two receive 5 bonus points.

E. Require Individual Accountability

After working together in a team, individuals should be better prepared to complete similar tasks by themselves. After all, it is individuals who take the examinations and seek jobs. Clearly all members of the team must participate, learn from the activity, and be held accountable for understanding the material and for developing their process skills, as mentioned previously in Section 2G.

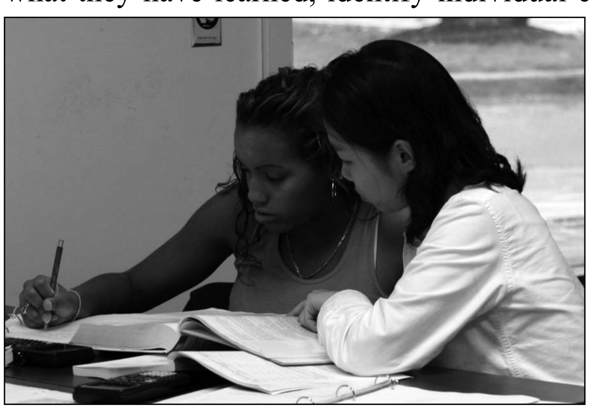
Each student needs to be monitored and assessed frequently by the instructor, and the results reported back to the individual and the team. Group discussions of team dynamics and the participation of the members also can be helpful. Individual accountability can be promoted by keeping the teams small, by rotating the roles of the team members, by asking a disengaged student questions about their team's progress, by having teams report to each other, by giving a very short (e.g. one question) quiz at the end of a session or at the beginning of the next one, and by giving homework, take-home quizzes, and traditional examinations.

F. Provide Closure

In a POGIL classroom students acquire information and develop understanding by examining models, answering critical-thinking questions, working exercises, and solving problems. These tasks are accomplished by the students working together in small teams with an instructor, who facilitates the process. The students need to leave the classroom session with a feeling of success and accomplishment. Time needs to be allocated for closure and reflection on what has been learned as described previously in Section 2E.

G. Use Metacognition

As discussed in Section 2F, teams need to discuss group dynamics and process how well they are working together in achieving goals and maintaining effective working relationships. They need to reflect on what they have learned, identify individual contributions, evaluate the quality of the results, determine which actions were helpful and which were not, and identify what to continue and what to change. The quality of self-assessment is greatest and has the most impact if each strategy analyst makes a verbal report to the class during a session rather than by submitting a written report only to the instructor at the end. Examples of questions and requests that promote reflection on learning and self-assessment of performance are given in Appendix A and Appendix B.



In many cases, grading policies need to consider and reward achievement in teamwork and other process skills as much as they do with content. The grade the team receives should reflect mastery of content by *all* members and should reflect the level of process skills exhibited, especially collaborative skills, i.e. helping each other. Because many students pay attention to how the objectives are reflected in the grading policies, you need to reinforce your stated objectives, which reflect the importance of teamwork and other process skills, in your grading policies. For example, at the beginning of each class identify two or three content objectives and two or three process objectives, then have the teams self-assess their performance and provide a self-assigned grade based upon those criteria.

4 A New Paradigm for the Teacher

In a POGIL classroom, a teacher is not the expert provider of knowledge, but rather guides students in the process of learning, in developing skills, and in developing their own understanding. In this sense, the instructor acts as a *coach* and has four roles to play: leader, monitor/assessor, facilitator, and evaluator. Some hints for the instructor in carrying out these roles are given in Appendix C.

A. Instructors Play Four Simultaneous Roles

As *leader*, the instructor creates the learning environment by developing and explaining the lesson, by determining the objectives (both the content objectives and the process skills objectives), by defining the expected behaviors and criteria for success, and by establishing the organization (i.e. the goal/reward structure, the team structure, the class structure, the room structure, and the time structure).[84] An example of a POGIL session is described in Appendix D, and a sample class schedule is provided in Appendix E.

As *monitor/assessor*, the instructor circulates through the class to monitor and assess individual and team performance and to acquire information on student understanding, misconceptions, and difficulties in collaboration. The instructor uses this information as a *facilitator* to improve performance.

As *facilitator*, the instructor intervenes and asks timely critical-thinking questions to help teams understand why they may be having difficulty and what they need to do to improve and make progress. Facilitators should intervene with respect to students' processes rather than content-related issues. The questions posed by the instructor help identify why the team is having difficulty. The first questions should be open-ended and general, then more directed and specific as needed. For example, an instructor might ask: Where are you stuck? What progress have you made? What do you find confusing? What are you asked to find in the problem? How is what you need to find connected to the information that you are given? What did you learn previously that is relevant here? (At the directed level, actually point to the previous information.) Can you draw a diagram to represent what the problem is asking? (And after the diagram is drawn.) Now can you solve the problem?

Always try to interact with the teams in ways that encourage deeper thought. For example, if a student responds that methane has a higher boiling point than ammonia because it has more hydrogen bonds, one approach is for the facilitator to paraphrase the response and ask for additional insight: "You have said that the greater number of bonds to hydrogen within a molecule is correlated with a higher boiling point. What do you see as the role of bonds to hydrogen in determining the boiling point?"[44]

For difficulties in math and logic, a facilitator might establish analogous situations that the team can reason through, then have the team identify connections with the original chemistry context. For example, students may have difficulty identifying the number of different chlorine molecules that can form from chlorine-35 and chlorine-37 isotopes, but they instantaneously know that four outfits can be produced with a red and a blue tee-shirt and black and tan slacks.

At the end of the intervention, ask the team to reflect on the process by asking, What was the source of the difficulty? How did you resolve it? How can you avoid it in future similar situations? What generalizations can you make to help you in new situations?

By combining monitoring, assessing, and facilitating, the instructor ensures that all participants understand the assignment, that each team member is fulfilling the assigned role, that 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 learning process.[85]

As *evaluator*, the instructor provides closure to the lesson by asking team members to report answers, summarize the major points, and to explain the strategies, actions, and results of the team. Evaluations are given to individuals and teams regarding performance, achievement, and effectiveness, and general points are shared with the class.

B. Planning and Preparing Lessons

As of the publication of this instructors guide, POGIL materials for high school chemistry, general chemistry, organic chemistry, and physical chemistry have been developed and classroom-tested, and are available for widespread use. Information about these and newly developed materials is available from the POGIL website (www.pogil.org).

Many instructors are interested in developing their own materials, particularly for those subject areas for which activities are not available. Both the POGIL project and Pacific Crest (www.pcrest.com) regularly hold workshops introducing instructors to the methodology of activity design and development and to many useful techniques for classroom facilitation. Information about upcoming workshops is available from the POGIL and Pacific Crest websites.

One approach to designing activities is presented here. We call this design the *Learning- Research Process* because it not only represents not only how people learn but also how research is done. The seven steps in the Learning–Research Process are outlined in Table 2. The heart of the design, the three-stage learning cycle of exploration, concept invention or formation, and application is embedded in the middle. In addition to these three stages, this design explicitly takes into account that learners need to be motivated to spend the time necessary for learning complex subjects, that they need to build the new knowledge on what they already know, and that they need to reflect on what they have done.[24] Similar formulations are known as the 5E and 7E learning cycle and instructional models.[86, 87] A detailed methodology for producing activities is given elsewhere.[88]

The sequence of steps need not always be the same as the sequence shown in Table 2. For example, in some lessons it may be desirable for the students first to explore and develop understanding in order to discover what it is that they are learning, then to identify why they are learning it and what they knew about it in the first place; then they expand on this experience later through readings and resource material.

There are a variety of ways to implement POGIL activities in the classroom. One approach involves using the POGIL activity as an *introduction* to the content. Following the POGIL session, the students are expected to read the relevant sections of the textbook, and work the exercises and problems.[9]

Alternatively at Stony Brook, two formats for implementing POGIL lessons have been used with nearly equal success. One focuses class time on problem solving. Students develop an understanding of the concepts by exploring the model, by responding to the critical thinking questions, and by working exercises as homework prior to the classroom session. They use the textbook as a resource in this task. Time in the classroom is used to bring closure to this homework assignment by using the technique of simultaneous reporting (Section 2E.). The teams then work problems and extended problems together and discuss solutions and their connections to the concepts.

In the other format, students are told not to look at the assignment until they come to the POGIL session. During the session, the teams develop an understanding of the material together by answering the key questions and working the exercises. They work problems as homework, which is brought to closure through simultaneous reporting in the following meeting.

C. TA Training

In many cases POGIL workshops are conducted by graduate teaching assistants, who must be given appropriate information in order to perform well. It also is important to upgrade their title to that of *Graduate Student Instructor* (GSI) because they have a primary role in facilitating learning, teaching process skills, and conducting assessment.

At Stony Brook, all graduate students are given demographic and background information about Stony Brook's undergraduate population and an introduction to such topics as learning theory, effective pedagogical approaches and strategies for teaching in different settings, gender and diversity issues, and responding to student problems.

Chemistry graduate students who will be implementing POGIL participate in three three-hour sessions the week before classes begin. These sessions motivate Process Oriented Guided Inquiry Learning, present an overview and specific features pertaining to the application at Stony Brook, and describe the content of the first lesson. They also participate in weekly two-hour meetings during the course of the semester. These meetings focus on three important areas: (1) philosophy and pedagogy, (2) subject material, and (3) administrative details, including grading policies and practices. Successes, improvements, difficulties and remedies, and the lesson for the coming week are discussed.

The initial meetings address the structure needed for successful learning teams, the features of process-oriented education, the development of problem-solving skills, and the utilization of critical-thinking and guide-inquiry learning approaches to teaching. These ideas are then reinforced during the subsequent weekly meetings. A lecture format is not used in these training sessions. Instead, participants work in teams to consider issues using critical thinking, modeling, role playing, and metacognition. The training sessions are thereby modeled after the POGIL classroom environment.

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5 Can This Approach Be Successful?

Determining whether or not the POGIL approach is successful depends on the goals that an instructor has for the students in his or her class and on how success is defined; these of course may differ for different instructors.

When the POGIL approach first was instituted at Stony Brook in Fall 1994 by replacing traditional recitations with POGIL workshops, faculty and graduate teaching assistants involved in the project were apprehensive about the effectiveness of the pedagogy and the feasibility of the strategies for implementing it. This general chemistry course had two sections, each meeting three times a week for lecture (500 students) with recitation sessions (36 students) meeting once a week. As the first semester progressed, however, it became evident that POGIL was becoming increasingly effective, and the POGIL environment was more enjoyable for both instructors and students compared 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!"* The end-of-the semester course assessment[8] revealed that:

- Most students (85%) conscientiously attended the POGIL sessions and worked the computer-based homework assignments
- The majority of the students (about 90%) found the POGIL activities 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
- Instructors (graduate teaching assistants) received A and A^+ ratings from the students, revealing positive student attitudes
- 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, one can demonstrate to a student 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

Another study[7] compared the course grades for students in General Chemistry at Franklin and Marshall College before and after the implementation of the POGIL instructional methodology. The studied sections were taught by three instructors; the "before" approach was an interactive lecture and the "after" approach was POGIL. All of the sections were small, with roughly 24 students in each section. The data that appear in the table below are for a combination of first semester and second semester grades:

	Years	n	A	B	C	D, F, W
Before	1990-4	485	19%	33%	26%	22%
After	1994-8	420	24%	40%	26%	10%

The previous table shows that with POGIL the number of students who receive a D or F or who withdraw from the course decreases. This pattern is a relatively common result of implementing the POGIL approach. For example, at a regional small liberal arts college, similar results were obtained by comparing the course grades for Organic Chemistry I for two groups of students taking the course during the same semester with different instructors using different approaches. Both classes were small, about 20 students, and they were randomly distributed between the two sections. One was taught by a very experienced instructor using an interactive lecture approach, and the other was taught by a different instructor using POGIL. Both classes were given the same mid-term and final exams, and both were co-written and co-graded by the two instructors. The grade distributions for the courses are shown below:

	A	B	C	D, F, W
Lecture	20%	20%	27%	33%
POGIL	29%	35%	24%	12%

A similar "experiment" was also done for Organic Chemistry I at a large, public university with a significant minority population. In this case, the only exam that was given in common was the final exam. It was a multiple choice exam, written solely by the "lecture" instructor. Historically, at this institution, the withdrawal rate for this course had been about 38%. Students who withdrew did not take the final exam. The distributions of performances on the final exam are given below:

	n	A	B	C	D	F	W
Lecture	109	12%	19%	16%	1%	5%	47%
POGIL	75	9%	32%	31%	15%	1%	12%

Another example involves the performance on the 1993 ACS General Chemistry exam, given as a final exam for General Chemistry II at a small regional liberal arts college. This exam had been given every year for ten years, beginning in 1994, with the same instructor each year. Class sizes averaged about 40 students. Between 1994 and 2003, the average result was 55.5% correct with a high of 65.2% and a low of 47% (which happened to be in 2003). For the 2003-4 academic year, this instructor employed the POGIL approach (after attending a POGIL three-day workshop in June, 2003). The average for 2004 was 68.5%, higher than any previous class, and 13% higher than the average.

One other type of study has been reported in the literature.[9] In this case, student performance in a first semester general chemistry course at a large public university was investigated. The two groups of students had the same lecture instructor, and they took the same mid-term and final exams. The difference between them was that in the "control" group, students were given the standard fifty-minute lecture three times each week, whereas in the POGIL group, the instructor compressed the content from those three lectures into two, and for the third hour each week, the students met in small groups of about ten with a *peer leader* who served as the facilitator for a POGIL session. This experience is described as *Peer-Led Guided Inquiry* (PLGI) since it combines elements of both Peer-Led Team Learning and POGIL. The PLGI students outperformed the "control" group on every exam, including the final. For the four exams given during the term, the gap in average performance grew as the semester proceeded, with the difference on the fourth exam being greater than 10%.

Table 2 **The Learning–Research Process**

Steps in the Learning-Research Process	7E Equivalent	Component of the Activity
1. Identify a need to learn	Engage	An issue that excites and interests is presented. An answer to the question Why? is given. Learning objectives and success criteria are defined.
2. Connect to prior understandings	Elicit	A question or issue is raised, and student explanations or predictions are sought. Prerequisite material is identified.
3. Explore	Explore	A model or task is provided, and resource material is identified. Students explore the model or task in response to critical-thinking questions.
4. Concept invention, introduction, and formation	Explain	Critical-thinking questions lead to the identification of concepts, and understanding is developed.
5. Practice applying knowledge		Skill exercises involve straightforward application of the knowledge.
6. Apply knowledge in new contexts	Elaborate & Extend	Problems and extended problems require synthesis and transference of concepts.
7. Reflect on the process	Evaluate	Problem solutions and answers to questions are validated and integrated with concepts. Learning and performance are assessed.

Several common and important outcomes are observed in all of these studies:

- Student attrition is lower for POGIL for than traditional courses
- Student mastery of content generally exceeds that for traditional instruction
- Students generally prefer the POGIL approach over traditional methods
- Students generally have more positive attitudes about the course and the instructors
- Student learning skills appear to improve over the semester

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7 Appendices

A. Reflection on Learning

B. Self-Assessment

C. Hints for the Instructor

D. Structure of a POGIL Session

E. Sample Class Schedule

F. Sample Strategy Analyst's Report

A REFECTION ON LEARNING

Summarize the academic objectives of today's session. Identify the content you were supposed to learn and how well you mastered it.

What was the "muddiest" or least clear point in today's session? In this week's lectures? In this week's reading assignment?

What was the most useful thing you learned during this session?

What questions remain uppermost in your mind as we end this session?

Identify the three most important concepts you learned today.

List five concepts that you found important today and explain what they mean to you.

List five things that you learned about _____________ today.

In no more than three sentences, summarize what was learned about _____________.

Why is the concept of _____________ important in _____________?

Identify a concept from today's activity that you have mastered. Identify one that you understand the least.

Write a "key question" which, if answered, would help your team better understand some aspect of today's activity. Find the answer to that question.

In your own words, summarize the meaning of _____________ (or the relationship between _____________ and _____________, or how _____________ can be applied).

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 the concept of _____________ helps us understand _____________.

What discovery or insight about topic _____________ did you make today?

Identify and illustrate how topic _____________ can be used.

Explain why and how concept _____________ is useful in solving problem _____________.

Explain why topic _____________ is important.

Show how you can do _____________.

Write a methodology for doing _____________.

What information do you need to determine _____________.

How can you recognize _____________?

What does it mean to say _____________?

How can you identify _____________?

Identify a memory aid for _____________.

Identify an everyday example or analogy for _____________.

B Self-Assessment

Summarize the process objectives of the today's session, i.e. identify what you learned to do today and assess how well you learned to do it.

List two strengths (and why they are strengths) and two improvements (and how they can be implemented) in reference to your (or your team's) performance in today's session.

Cite two examples of how you carried out your team role today.

What insight have you gained as a result of your team's performance today?

What did you do to prepare for today's class? How might you prepare better next time?

What was your plan for improving performance today compared to the last session, and why was your plan successful or not successful?

Identify three ways in which you and other team members have modified or might modify study habits and strategies in order to improve performance on examinations.

Identify three good study habits and three poor study habits, and identify the advantages and disadvantages of each.

Did everyone in your team contribute to the activity today? If so, explain how. If not, identify what individuals need to do to ensure participation by all in the next session.

Did everyone in your team understand the material covered in the activity today? If so, explain how your team ensured that everyone understood. If not, identify what your team needs to do to ensure that everyone in the team understands the material in the next session.

Midway through a session have a designated team member report and identify team strengths, needed improvements, and insights or discoveries about the subject matter or about team dynamics.

For each member of your team, identify a strength (and why it is a strength) and an improvement (and how it can be implemented) that helps your team understand the subject material (or apply concepts in solving problems, or meet some other specific workshop objectives).

Identify three things that your team might do to work more effectively and efficiently.

Identify two areas of needed improvement and develop a plan to strengthen your team's performance.

Which team member contributed the most? What can be done to better equalize the contributions from each team member?

What problems do your team members have in working together? What might your team do to eliminate these problems?

Use the team strength indicator form on the following page.

How Strong Is Your Team?

For each item, score your team's performance as:
1 = not very good
2 = needs significant improvement
3 = needs some improvement
4 = adequate
5 = stellar

Write a justification for your score and provide a plan for improving your team's performance.

Item	Score	Justification	Plan
Everyone came prepared.			
Everyone participated fully.			
We encouraged and helped each other.			
Everyone asked questions when they didn't understand.			
Everyone gave clear explanations to each other.			
Everyone contributed ideas.			
We listened to each other.			
Each person contributed to our success; no one dominated.			
Everyone understood the material.			
We completed the assigned work.			
Total			

C HINTS FOR THE INSTRUCTOR

For each lesson or series of lessons, you will need to:

- Select the lesson material
- Determine the composition of the groups (three or four diverse students)
- Structure the room (face-to-face grouping)
- Select/prepare instructional materials (promote interdependence and individual accountability, and develop skills)
- Assign and define roles (manager, recorder, spokesperson, strategy analyst)
- Communicate content objectives (learn specified concepts and apply them in solving selected problems)
- Communicate the process objectives (exhibit the specified behaviors: e.g. active participating, checking, encouraging)
- Communicate the procedures to be followed
- Define the criteria for success (correctly answer questions and solve problems in a way that insures that all team members understand)
- Define the goal/reward structure (one set of answers, everyone agrees and understands, one grade for the team)
- Identify the structure for individual accountability (individual reporting and grade component including preparation)

Things will go smoothly if you remember to:

- Monitor teams closely, but be friendly, courteous, and helpful
- Communicate in an exciting manner
- Understand and empathize with the students
- Promote individuality and creativity
- Introduce and orient the students to the course, the format, and the material
- Be positive about the course, text, instructors, format, the university, chemistry, etc.
- Answer team questions only; individual questions should be handled by the team
- Respond to students in ways that encourage thinking; for example, if a student gives an incorrect answer to a question, paraphrase the answer and ask a question that will encourage the student to think more deeply about the answer

Things will go smoothly if you remember to:

- Ask questions like *What are you doing? Why are you doing it?* and *How will it help you?*
- Ask a student to repeat instructions to ensure that all have heard and understood
- Require a moderate, not high, workload from the students
- Be realistic in assessing what students have learned and can learn
- Be sensitive to students’ needs and special situations
- Give students specific tasks to finish within a predetermined time limit
- Assign a role or responsibility to each team member and structure tasks so they can be divided according to these roles
- Ensure that the work is perceived as being worthwhile
- Allow students to experience success
- Learn students’ names and use them; help them learn each others’ names
- Ask questions that aid students
- Ask pairs or teams of students to respond to a question
- Acknowledge responses warmly, especially those from infrequent contributors
- Say something positive about a response even if it is incomplete or inaccurate
- Turn questions back to the team; ask others to discuss them
- Ask teams to generate ideas using brain-storming sessions (critical analysis is not part of brainstorming)
- ask individuals to present each team’s ideas
- If you don’t know something, say *I don’t know, but I’ll find out,* or ask the class for an opinion
- Be willing to learn from the students
- Criticize ideas, not people
- Generate a feeling of closure by sending students out of class happy, feeling that they have accomplished something

D Structure of a POGIL Session

This section provides a sample script for the first session. Instructors have generally found it to be a very helpful guide and have adapted it in many ways to match their situations, needs, priorities, and teaching styles. A POGIL session is called a *workshop*.

The First Session: Introduction to the Workshop Sessions

Welcome students back to school. Establish rapport with the class: Ask how many are 1st, 2nd, 3rd, or 4th year students. Ask how many are chemistry majors, biology majors, etc. Gather any other information that can easily be collected from the large group.

Introduce yourself: state the section number, your name, your office location, your office hours, and the hours during which free tutorials are available. List materials needed for workshop: text, lecture notes, activity book, calculator, pen/pencil, and paper.

Introduce the course structure. Emphasize that the purpose of the lectures and text is to provide information and model how to apply concepts in solving problems, and that the homework and workshops help develop essential skills in information processing, critical and analytical thinking, and problem solving. Explain that staff office hours and free tutorial sessions are provided for individual help. Stress the importance of planning and developing solutions to the homework problems rather than reading solutions or obtaining solutions from others. Have each of student draw up a chemistry study schedule providing 8 to 12 hours of study time and naming a study partner with whom they will complete and summarize lecture notes, discuss concepts and their use in solving problems, and compare homework solutions, and answers. Ask them to turn this schedule in to you the following week.

Introduction to Learning Teams

This introduction is important in getting students to be committed to this approach and motivated to make it successful.

Ask rhetorical motivational questions, such as, “How many of you would like to receive an A or B in the course?” “How many of you would like to learn twice as much in the time you spend studying?” “How many of you would like to acquire essential skills that are sought by employers?”

Explain that research has shown that students who work together learn more, understand more, remember more, and acquire skills essential in the workplace. Explain that because of this, the format of learning teams will be used in the workshop sessions. Point out that there has been a very strong correlation between performance on the workshop lessons and take-home quizzes and examination grades. Encourage students to organize study groups on their own to fill in and summarize lecture notes, and to compare homework and take-home quiz answers and methods.

If you want to organize N students into teams of 4, you will need $N/4 = n$ teams. Have the students count off in four sequences of 1 through n, then have all the 1’s, 2’s, etc take seats grouped next to each other. Explain that the teams may be reconstituted later, e.g. next week or after the first hour examination. With teams larger than four, you will have *workers* and *loafers*. Teams of 2 and 3 members are better than a team of 5.

Explain the responsibilities of team members: Each member must learn the material, and each helps others in the team to learn the material. Each carries out definite assigned roles in the functioning of the team. An individual’s success in the workshop is based upon the success of that person’s team.

Designate and assign roles to team members as *manager*, *spokesperson*, *recorder*, and *strategy analyst*. Define the roles and explain the purposes of each.

manager — actively participates, keeps the team on task, distributes work and assigns responsibilities, resolves disputes, and ensures that all members participate and understand.

spokesperson — actively participates, represents views and conclusions held by the majority, presents required oral reports and discussions to the class.

recorder — actively participates; keeps a record of instructions and what the team has done, and prepares the final written report and other documentation in consultation with the others.

strategy analyst — actively participates, identifies and keeps a log of problem-solving strategies and methods, identifies and keeps a log of what the team is doing well; what needs improvement, and insights and discoveries regarding course content and individual and team performance.

For teams smaller than four, the roles of spokesperson and strategy analyst or spokesperson and recorder can be combined. Rotate these roles each week. You will need to monitor the rotation to insure that it actually occurs. If students need your prompting to rotate roles, emphasize the purpose behind using roles. Encourage rotation by asking team members to consider whether they strengthen their skills by carrying out the responsibility of a role or by avoiding it. While the strategy analyst may consult with other members of the team, we have observed that the quality of the strengths, improvements, and insights or discoveries is higher if the strategy analyst reports on his or her observations alone.

Ask the teams to consider what they want to accomplish in college. Give them one minute to formulate a response. Develop a list by asking for one item from each team. Often one gets "*Have fun*, *Meet friends*, *Get a good job*." Mention other possibilities and point out how those might easily lead to the outcomes they have mentioned.

Now ask a more focused question: "Your team is the Employment Committee of a start-up biotechnology company, which is planning to double the number of employees over the next year. What are eight characteristics that your committee will use to screen the applicants?" Give the teams two minutes to formulate a response. Develop a list by asking for one item from each team.

Discuss the result. Point out that surveys have shown that companies want people who are quick learners, critical and creative thinkers, problem solvers, communicators, and team players who are self-motivated and knowledgeable. Point out that *knowledge of subject matter* is only one component. Emphasize that teamwork skills are especially important in the workplace. Point out that the course is structured to provide opportunities to exercise, strengthen, and develop such skills. Mention that this structure is an integral part of the course since both knowledge of subject material and the skills to learn it and use it are to be acquired by the student. These skills can be classified into seven categories: learning, thinking, problem solving, teamwork, communicating, management, and assessment. They are called *process skills* because they are essential in the processes of acquiring (learning), applying (problem solving), and generating (research) knowledge.

Define Specific Objectives

While the following are general statements, you should modify them for each lesson to suit the content of that lesson and to fit your learning objectives for both content and process.

The content objective is to complete the workshop activity correctly and to understand the concepts and their application in solving exercises and problems. Team members work together to obtain a team consensus on answers and methods of solution.

The process objective is to have all members of the team participating constructively, understanding the material, and demonstrating and developing skills in the areas of learning, thinking, problem solving, teamwork, communication, management, and assessment.

Preparation

If you want students to come to the workshop with some preliminary preparation, you need to stress the importance of this preliminary work. Two strategies providing such motivation are given below. In each case, poor performance must affect their grade in some way, and good performance must be rewarded.

Assign and require three to five homework problems to be turned in at the beginning of the workshop. Grade one of these at random.

Give a one question quiz (closed book, completed by individuals, not teams) at the beginning of the workshop. Invent a very basic and simple question relevant to the workshop or use one of the simple questions from the workshop lesson. Give zeros to those who come late and miss the quiz. Students need to be encouraged to come on time.

Reward/Grading

Discuss the grading policy. Workshops should count as 10% to 20% of the final grade, split between preparation, the workshop activity and report, and the take-home quiz. The criteria for success are completing the take-home quiz correctly and meeting both the content and process objectives of the workshop, i.e. correctly completing the workshop activities with all members of the team understanding the concepts and methods of solution for exercises and problems while exhibiting essential process skills.

One report is due from each team at end of each workshop session. Since all members of the team must understand and agree on answers and methods of solution, they all receive the same grade for that report. If one is absent from a workshop session, that person will receive a grade of zero for that session. One grade will be dropped from the final tally to accommodate absences.

Explain how you will grade the workshops. Explain the importance of team and individual self-assessment skills and the development of expert strategies for problem solving. Require that the team's report include: summarizing what was done, identifying appropriate problem-solving strategies, describing the use of process skills, specifying one or two performance items that were done well, and explaining how the performance could be improved.

Closure

As the teams finish working, ask the spokesperson of a team to put the answer and method of solution for one of the problems on the board. When a few answers are on the board, ask the class for agreement and disagreement on each in turn. To resolve the disagreements, ask teams to help each other or ask the spokesperson to provide an explanation. Get students to do the explaining, avoid giving mini-lectures yourself. Allow five minutes or so near the end of the session for the teams to finalize the reports. You can hand out the take-home quizzes during this time.

Experience Speaks

Some instructors have found that:

- they could successfully motivate and reward preparation for the workshop by giving a one or two question quiz at the beginning of the session or by assigning three to five homework problems and grading one of them.
- students appreciated spending 20-30 minutes during class to review prior to an examination. The review should not be a mini-lecture by the instructor. Instead, instructors should give the class a sample exam to be worked on in teams and use simultaneous reporting to provide closure.
- students appreciate a review of the lecture material. However, instructors should require that students formulate and ask specific, thoughtful questions about the material (as a team) and have the other teams develop answers to those questions.
- students appreciate and respond to the instructor's encouragement and enthusiasm for and enjoyment of chemistry. It helps to frequently say things like, *This is great! This is fun! This is useful! This is really interesting!*
- students appreciate being told and reminded of what is expected of them, and they often need to have things repeated.

Summary

- Explain that the workshop sessions use a team learning format because research has shown that students working in teams learn more, understand more, remember more, feel better about themselves and others, and acquire skills essential in the workplace.
- Mention that surveys have shown that companies want people who are quick learners, critical and creative thinkers, problem solvers, communicators, and team players who are self-motivated and knowledgeable. Students need to develop skills in these areas as well as learn subject material.
- Emphasize the dual responsibility of team members in meeting the academic goal: to learn the material and to ensure that others in the team learn the material.
- Emphasize the dual responsibility of team members in meeting the process skills goal: to develop process skills and help others develop process skills.
- Explain that the grading structure for the workshops reflects individual performance in the context of a learning team. Workshop activities count for about 16% of the final grade, including the take-home quiz.
- If questioned, explain that team efforts and team rewards are an intrinsic part of most aspects of our society and economy and that the university is a community of learners in which people teach and learn together.
- Explain explicitly the team roles: manager, spokesperson, recorder, strategy analyst. Identification of a *spokesperson* is intended to make the presentations go faster and be of higher quality since this one student has time to prepare and think about being called-on, but this role dilutes *individual accountability*, since only one student needs to be prepared to make a presentation to the class. On the other hand, you can ask any student at any time to tell you what the group is doing and to explain the results as you make your facilitation rounds from group-to-group.

E SAMPLE CLASS SCHEDULE

5 minutes	individual quiz on homework assignment
5 minutes	structure class, announcements, workshop assignment and objectives, return papers
15 minutes	teams work on Workshop Assignment, Part One (Model Exploration and Exercises)
5 minutes	use simultaneous reporting to bring closure to Workshop Assignment, Part One
15 minutes	teams work on Workshop Assignment, Part Two (Exercises and Problems)
5 minutes	use simultaneous reporting to bring closure to Workshop Assignment, Part Two
5 minutes	announcement of homework due at the next workshop, preparation of final written reports from strategy analysts and recorders
55 minutes	***Total***

F Sample Strategy Analyst's Report

Strategy Analyst's Report

Team Members *(write name by role)* *Rotate roles each week.*

We verify that we all understand and agree with the solutions to these problems.

Manager: ______________________________

actively participates, keeps the team on task, distributes work and responsibilities, ensures that all team members participate and understand

Recorder: ______________________________

actively participates, keeps log of work and other documentation in consultation with team

Spokesperson: ______________________________

actively participates, presents reports to the class

Strategy Analyst: ______________________________

actively participates, identifies and keeps notes of problem-solving strategies, use of process skills, what the team is doing well, and what needs improvement, gives verbal report, prepares written report in consultation with the team

Homework

Each team member completed the homework assignment: ***YES*** ***NO***

Instructor's initials:_________________

Reflection on Learning *(Instructor inserts question, see Appendix A for examples.)*

Use the other side of this page for your response.

Self-Assessment *(Instructor inserts question, see Appendix B for examples.)*

Use the other side of this page for your response.

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.

Instructor's validation: ________

Instructor's grade: ________ Total grade: ________

May vary for different team members based on preparation, homework, and participation.

Instructor's comments:

Attach Recorder's Report of your team's work.