PROCESS ORIENTED GUIDED INQUIRY LEARNING

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There are several recurrent themes percolating through modern chemical education. Among these are:

A student-centered active classroom promotes learning.

Students learn best by analyzing data and developing concepts by themselves.

Instructors facilitate the learning process by interacting with groups of students in class.

In this paper, we describe an innovative instructional approach involving these themes and principles. Process Oriented Guided Inquiry Learning (POGIL) is a learning environment where students are actively engaged in mastering a discipline and in developing essential skills by working in self-managed teams on guided inquiry activities.

Despite many reports on the effectiveness of non-traditional approaches to science instruction, the lecture model remains the preferred form of classroom presentation. Lecturing is based on a series of assumptions about the cognitive capabilities of students and their learning strategies. This methodology assumes that all students need the same information, presented orally and at the same pace, without dialogue with the presenter, and in an impersonal way. Although lecturing is an efficient way to present information, it does not result automatically in efficient learning.[1-7] Horowitz has shown that after about 10 minutes of a typical lecture, 50% of the class is lost.[8] Bodner, in numerous presentations, has suggested that there are three situations in which the lecture is the most effective approach for the introduction of new material: 1) when only factual information, no conceptual understanding, is involved; 2) when there is no textbook available; 3) preaching.[9] In general, none of these apply in the context of undergraduate chemistry education.

In a lecture format, many students miss the exchange of ideas and interpersonal interaction[10] and often miss the relevance of what they are learning. Consequently they develop negative perceptions of chemistry and science[11] and are lost from the science human resource pipeline early in their college careers.[10-14] Students remaining in science often have difficulties in applying knowledge to solving textbook, examination, and (eventually) real-world problems. Many simply read the solutions in manuals and on posted answer sheets, or watch problems being worked in recitation sessions. These students memorize algorithms but do not understand and apply concepts. The stark absolutes presented by many texts and lecturers can leave students with the sense that science is an uncreative tabulation of immutable truths, with no room for student thought or participation. Also, many college and university students, particularly those attending commuter campuses or community colleges, work independently most of the time and gain little experience in teamwork and associated skills needed in the workplace. [10-13;15]

These and other concerns associated with the lecture method have prompted the initiation of a new philosophical and pedagogical approach to instruction. Recent developments in cognitive learning theory and classroom research results suggest that students generally experience improved learning when they are actively engaged and when they are given the opportunity to construct their own knowledge.[16;17] These approaches counter the widespread misapprehension that effective teaching must be instructor-centered, involving the transfer of content directly from the expert (professor) to the novice (student).[18]

In the Constructivist Model, learning takes place when the learner is actively engaged in the process of integrating new knowledge with that previously held in memory. Newer approaches to teaching, more aligned with this model, center on the learner as the focus of the learning experience.[18-21] Such student-centered approaches to learning are based on the premises that students will learn better when: they are actively engaged and thinking in class; they construct knowledge and draw conclusions by analyzing data and discussing ideas; they learn how to work together to understand concepts and solve problems; and the instructor serves as a facilitator to assist students in the learning process.

Student-centered learning environments are particularly effective if the focus of student work is a discovery exercise based on the learning cycle model. A learning cycle recapitulates the simple logic of the scientific method. As described by Lawson,[16] a learning cycle has three critical parts: (1) an Exploration phase in which a pattern of regularity in the environment or data is sought, (2) a Concept Invention phase in which a concept is developed from the pattern and a term introduced to refer to the concept, and (3) an Application phase in which the concept is applied in new situations.[17;21] A learning cycle exercise exposes students to the joys of figuring concepts out for themselves, imparts a sense of ownership and participation, and provides valuable epistemological insight into the nature of scientific inquiry. The combination of active student engagement with the learning cycle paradigm results in a student-centered guided-inquiry model.

At its best, this approach utilizes small group discussion as the medium for construction and restructuring of knowledge in the minds of the learners. Key cognitive steps in this process include making inferences, identifying misconceptions, resolving contradictions, generalizing, integrating with previous knowledge, and posing and solving problems.[7;23] All these are natural elements of small group discussion. Active involvement in the classroom, including student-student and student-instructor interactions, has been identified as having the largest positive effect of numerous environmental factors on the academic achievement, personal development, and satisfaction of college students.[10;12;23] Over 600 research reports compare competitive, individualized, and cooperative learning structures. Comprehensive reviews and analysis of this research have been published showing the effectiveness of cooperative learning.[24-26] Learning teams and cooperative learning strategies have also been shown to be particularly effective in facilitating the success of women and other underrepresented groups.[15;27]

Any steps taken toward a student-centered classroom will improve the learning environment. The studies of Mazur on Peer Instruction[28] and those from the New Traditions project on ConcepTests[29] have shown that in large classes, even minimal supplementation of lectures with short interactive exercises has a positive effect on student learning, and that the more time devoted to student-engaged activities, the greater this impact. In addition, at many institutions where large lecture sections are a current necessity, recitation sections provide an ideal venue for implementation of a more student-centered approach.

The General Chemistry course at Stony Brook University (SB), combines the traditional lecture with process-oriented workshops that employ both text-based and web-based materials to engage students in the learning process. The focus is on developing important process skills in the area of information processing, critical thinking, problem solving, teamwork, communication, management, and assessment. The pedagogy being used in Physical Chemistry at SB is a hybrid of a presentation/lecture model and the guided-inquiry model. Students read a text for background information. They then are asked to work in learning teams and apply this knowledge in exercises, problems, and team activities. Time in class is used to address the difficulties these learning teams encounter. Mini-lectures in response to *we-need-to-know situations* are a key component of this format.

While the SB implementation is a blend of traditional and student centered approaches, the model developed at F&M[30;31] by J. Farrell, R. Moog, and J. Spencer represents more of a departure from traditional instruction. In the F&M model, there are virtually no lectures, and a guided-inquiry group-learning model is used almost exclusively in classes of about 24 students. Students are assigned roles within groups and use guided inquiry activities to develop and learn concepts. The instructor serves as a facilitator. Some aspects of this approach can be applied in large classrooms by including ConcepTests and short student discussions into lectures. An initial study at a large state university indicates that full implementation of the F&M model in a larger classroom is also very effective. In a 184-student study at this university, the lecture section lost nearly half of its students before the final exam, while the group learning section of nearly 80 students experienced only 12% attrition.

At the heart of the guided inquiry component of POGIL is a carefully developed set of critical-thinking questions. These questions build on each other in complexity and sophistication, leading student groups toward discovery of a chemical concept. Typically, the first few questions build on students prior knowledge and direct attention to the information provided in the concept model. A concept model can consist of a figure, graph, table, set of written relationships, a methodology, an interactive computer simulation, a brief discussion, a demonstration, or a laboratory activity. It is analogous to the data a researcher would collect in a true discovery situation, yet streamlined and focused to facilitate the learning process. The next few questions help promote thought to develop relationships and find patterns in the data toward development of a concept. The final questions require divergent thought to find relevance or to look for the boundaries in generalizing students new knowledge and understanding. Students work in teams to answer these questions by thinking about what they see in the model, what they know, and what they have learned by answering previous questions.

Over the past several years, we have assessed the effectiveness of our approach at many different institutions. Several common, and important, outcomes are observed in all of these assessments of POGIL implementations: more students successfully complete the courses; student mastery of content is at least as high as for traditional instructional methods; and students generally prefer the approach over traditional methods. Given the wide range of students, institutions, and implementations represented in these studies, this is strong evidence for the general effectiveness of the approach.

Controlled student assessment data collected in guided inquiry organic courses at two liberal arts colleges and a state university show that students retain as much (or more) factual and conceptual knowledge as lecture-trained students. Assessment data also indicate that the POGIL method has a particularly high positive effect on learning for the bottom half of each class leading to a large reduction in attrition.

At F&M, a study compared the performance of over 400 General Chemistry students taught using the POGIL approach over a four year period to a similar number taught in previous years using a traditional approach by the same instructors.[31] The W, D, F rate decreased from 21.9% (traditional) to 9.6% (POGIL). The percentage of students earning an A or B rose from 52% to 64%. In the Physical Chemistry course at F&M, a comparison of five years of classes before and four years after introduction of POGIL showed an increase of average grade from 2.88 to 3.25 for the same instructor.

Many similar conclusions have resulted from extensive evaluation studies[32] of POGIL workshops in General Chemistry courses at SB.

Attendance at the recitation sessions improved significantly (from 10 - 20% to 80 - 90%).

Most students (75 - 90%) find the workshops challenging, worthwhile, and helpful.

Examinations showed significant shifts of students from lower scores to higher scores, uniformly for low through high achieving students. The shift for the examination total produced 20% more students scoring above the 50% level.

Enrollments in the second year organic course increased by 15%.

Instructors reported ongoing improvement in student skills throughout the semester in reading and understanding the text, applying concepts in solving problems, working together as a team, oral and written communication, and reflecting on what they have learned and their performance as a team and as individuals.

The POGIL project has recently received support form the National Science Foundation (DUE-0231120) for national dissemination of this methodology and accompanying materials. For further information on project activities, contact pogil@pogil.org or http://www.pogil.org.

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