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The Effect of Process Oriented Guided Inquiry Learning on Student Achievement in a One Semester General, Organic, and Biochemistry Course.

Lafayette Eaton
St. John Fisher College

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Dedication

For Kristina, Paige, & Madelin

Acknowledgments

I would like to thank my wife Kris for her support in this endeavor. I often have in jest suggested that she be given an honorary degree in this field since she proof read every paper including this one that I submitted to the program. Without her support this project never would have been completed

I would also like to thank Paige and Madelin who put up with me working long and often unusual hours.

I would like to acknowledge Michael Garoutte of Missouri Southern State University, who's very well written activities were generously provided for use in the classroom.

Finally, I would like to thank Rick Moog of Franklin & Marshall College and Andrei Straumanis College of Charleston. Their support was provided through a well organized and well run workshop on using guided inquiry, and cooperative learning activities in the classroom. The information gained at this workshop help immensely with the implementation of these programs in my classroom.

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The Effect of Process Oriented Guided Inquiry Learning on Student Achievement in a One Semester General, Organic, and Biochemistry Course.

In 1975 J. Dudley Herron published an article titled *Piaget for chemists: Explaining what "good" students cannot understand.* This paper was among the first linking student learning in chemistry to cognitive research in psychology. Teachers began to think about why students were not learning chemistry and began to search for something that translated Piagetian constructivist theory in to pedagogy for teaching chemistry. Thus began the decades long debate regarding how students learn chemistry.

There are many examples in the literature indicating that students do not learn chemistry effectively through passive rote instruction; that student misconceptions regarding the nature of the physical world are hard to replace with more accepted concepts (Andersson, 1986; Bodner, 1991; Furio Mas, Perez, & Harris, 1987; Mulford & Robinson, 2002; Nurrenbern & Pickering, 1987); and that student achievement increases in cooperative versus competitive learning environments (Johnson & Johnson, 1990; Johnson, Johnson, & Smith, 1991; Qin, Johnson, & Johnson, 1995; Slavin, 1983). Process Oriented Guided Inquiry Learning (POGIL) a pedagogical method of instruction which incorporates the learning cycle, cooperative learning, and guided inquiry that was developed in an attempt to address the mounting evidenced regarding student achievement in chemistry and teaching methods. However, the question remains does POGIL increase student achievement in chemistry?

The literature contains a limited number of studies related to the POGIL method (Farrell, Moog, & Spencer, 1999; Tien, Roth, & Kampmeier, 2002). The Farrell et al. and Tien et al. studies indicated that POGIL has a positive effect on student achievement in chemistry. This author, encouraged by these studies, began to use the POGIL method in an introductory chemistry course. However, this author did not see the gains indicated by the Farrell et al. and Tien et al. studies. Farrell et al. and Tien et al. students were science majors as opposed to the students in this author's classroom who were non-science majors.

This study was designed to ascertain whether POGIL increases student achievement in introductory chemistry courses. Student achievement was measured quantitatively based on student performance on instructor created exams. Students in the control group were given instruction using the traditional lecture method for one semester. Students in the treatment groups were given instruction using POGIL for one semester. The achievement of the students was expected to increase when POGIL was used as the method of instruction. These results would be inline with cognitive theory, which indicates that people learn by constructing knowledge.

Literature Review

Process Oriented Guided Inquiry Learning (POGIL) is a new teaching method based on cooperative learning, constructivism, and the learning cycle. A review of the literature on these topics is presented.

Cooperative Learning

Cooperative learning is not a new pedagogical method of instruction. In fact, cooperative learning enjoyed widespread popularity in U.S. education during the latter part of the 19th century. The main proponent of cooperative learning at the time was Colonel Francis Parker who was superintendent of the public schools in Quincy, Massachusetts. Parker became well known for his ability to promote a classroom environment of cooperative learning. At the height of his program the schools in Quincy received on average 30,000 observers a year (Johnson, Johnson, & Smith, 1991).

After Parker, John Dewey continued to support the progressive idea of cooperative learning which continued to spread through American schools in the earlier part of the 20th century. During the middle part of the 20th century cooperative learning lost favor in response to a movement to increase interpersonal competition in the classroom. However, during the last 20-30 years cooperative learning as has taken on a second life as a valid pedagogical method of instruction. (Johnson et al, 1991)

Basic Components of Cooperative Learning

What is cooperative learning? What does it look like in the classroom? Johnson et al. (1991) suggest that there are five key components that must be present in order for something to be labeled as cooperative learning. These components are: positive interdependence, face-to-face interaction, individual accountability, interpersonal skills, and group processing. In positive interdependence students must feel like they are in this together. Students see the importance not only of learning the objectives themselves but insuring that all members of the group attain the objectives. Positive interdependence can be promoted in several ways. One common method is rewards given for successful group work. For example, if each student in a group reaches a minimum score on an assessment the entire group receives bonus points. Another method of fostering positive interdependence is to limit the resources available to students so that they must all work together or no one will complete the task. Positive interdependence can also be achieved by assigning specific roles for each member of the group, thus giving each member specific tasks that complement each other. Cooperative learning also must include face-to-face interaction. Students must be given time in which to interact with each other in the process of completing the task. Individual accountability is another key component of cooperative learning. Each individual is responsible for and assessed for their understanding of the material. Cooperative learning must have enhancing interpersonal skills as a component. Students should be given a chance to work on group skills such as trust, communication, and conflict resolution. Students need to receive direction and feedback to improve their interpersonal skills. Finally, cooperative learning includes group processing skills. Students are given time to reflect on the process of learning in their group. They must look at the dynamics of their group and determine what processes worked well and which did not.

Meta-Analysis

Many of the best studies in the literature regarding cooperative learning are meta-analyses. Meta-analysis is a quantitative review of the literature as it pertains to a specific topic in education research. Bowen (2000) suggests that there are four elements required for an informative meta-analysis: identifying the independent and dependent variable, identifying quantitative research studies, tabulating the data, and determining the effect size. Effect size will be used extensively in this review to indicate the significance of the studies evaluated. Therefore, a short description of how effect size is determined and its meaning will be discussed. In general, although there are variations, effect size is the difference between the mean of the treatment group and the mean of the control group divided by the standard deviation of the of the control group (see Equation 1)

$$\text{Effect Size} = \frac{Mean(Treatment) - Mean(Control)}{S\tan dardDeviation(Control)} \qquad (1)$$

The effect size compares the performance of students in one group with the performance of students in another group, usually the control vs. treatment groups. An effect size of 0.00 indicates that the students in the two groups are performing at the same level. An effect size of say 0.8 indicates that students in one group that are performing at the 50th percentile are performing at approximately the 80th percentile in the second group. The effect size, therefore, is a method of comparing student groups across a broad spectrum of studies using the mean and standard deviation of the samples (see Table 1) (Bowen, 2001).

Table 1

Effect Sizes and Percentile Changes between Treatment and Control Groups

Effect Size	Percentile Change[a]
0.00	50
0.20	58
0.40	66
0.60	73
0.80	79
1.00	84
1.20	88
1.40	92
1.60	95
1.80	96

[a]A student performing at the 50th percentile of the treatment group is performing at this percentile of the control group. Note: From "A Quantitative Literature Review of Cooperative Learning Effects on High School and College Chemistry Achievement," by C. W. Bowen, 2000, Journal of Chemical Education, 77, p. 117. Copyright 2000 by the American Chemical Society.

This method of calculating effect size has it limitations. Published studies are used almost exclusively. This limits the pool of data to studies that show some effect either positive or negative as studies that show no change are puhlished less frequently (Bowen, 2001).

Cooperative Learning and Achievement

Literally hundreds of studies on the effects of cooperative learning and achievement have been performed in the last 100 years. Johnson et al. (1991) reviewed the results of a meta-analysis of over 375 studies. The effect size when all studies were included in the analysis showed that cooperative learning versus competitive learning resulted in an effect size of 0.67 and cooperative learning versus individualistic learning resulted in an effect size of 0.64. The effect size was similar for college age students with 0.59 and 0.62 respectively.

This meta-analysis was so broad that not all the studies used were conducted with care. When only high quality studies were considered the effect size was 0.88 and 0.61 respectively (Johnson et al., 1991). High quality studies as defined by Johnson & Johnson (1990) are those in which: students were randomly assigned to groups (control vs. treatment), the control conditions were well defined, teacher and curriculum effects were controlled, and where the success of the implementation of both the treatment and control group were confirmed. The results of the Johnson et al. review of the meta-analysis results become striking when only studies involving critical thinking competencies are included. The effect sizes of these studies are 0.93 and 0.97 respectively. In the Johnson et al. review it was determined that the following were positively effected by cooperative learning: achievement, critical thinking, high order thinking, attitude toward subject, interpersonal relationship skills, social support skills, retention, and self esteem.

Slavin (1983) conducted his own meta-analysis limited to 41 studies that met the following criteria: treatment group consisted of elementary or secondary students, the

Cooperative Learning and Achievement in Chemistry

Although the literature indicates that cooperative learning has a positive influence on learning in general and SMET courses specifically, what does the literature reveal regarding cooperative learning and achievement in chemistry? Bowen (2000) has completed the most extensive meta-analysis specifically designed to look at cooperative learning and achievement in chemistry. Bowen located 15 studies in the literature that used cooperative learning to deliver content in high school or college chemistry courses. The average effect size was 0.37 indicating a positive effect on achievement. Although it is clear that the positive effect size is smaller than that seen for learning in general and SMET courses it is positive. Of the 15 studies used in the analysis 11 showed a positive effect size. In addition to this analysis several other papers in the literature were reviewed. The studies reviewed used cooperative learning either in or outside of the classroom (Hagen, 2000; Shibley & Zimmaro, 2002; Tien, Roth, & Kampmeier, 2002; Towns, Kreke, & Fields, 2000; Carpenter & McMillan, 2003).

Several of these studies were qualitative in nature (Carpenter & McMillan, 2003; Towns et al. 2000). The quantitative studies showed either no statistically significant improvement in achievement (Shibley & Zimmaro, 2002) or a significant improvement in achievement (Hagen, 2000; Tien et al., 2002). None of the studies reviewed showed a negative impact on achievement. One study in particular was representative of those studies showing a positive influence on achievement in chemistry when cooperative learning was used (Tien et al., 2002). This study was completed at the Rochester Institute of Technology a small private college in a sophomore organic chemistry course. This study evaluated effectiveness of cooperative learning in achievement, retention, and error. Based on this idea educators become focused on how best to transmit this knowledge (Bodner, 1986).

Educational research continued to try and find more effective methods of transmitting ideas (Bodner, 1986). This led to many curriculums breaking concepts into skills from easy to more difficult. The teacher then presented these skills clearly in an orderly manner. This presentation was followed by practice sessions, activities, and feedback. Students had a passive role that required external motivation through reinforcement (Fosnot, 1996). Several cliché's have cropped up describing the ideas of behaviorism such as: 'students are a blank slate' or 'students are a black box'. Each of these clichés has the same premise. The student arrives in class with out any preconceived ideas regarding the topics to be discussed and the teacher will fill this emptiness with the 'truth' (Bodner).

Although the traditional behaviorist theory of learning has lost favor in the past 10 to 15 years it still affects the way many courses are taught, how classrooms are built, and how student are assessed. Many classrooms are designed to place the instructor at the center of the classroom. Course material is delivered by breaking concepts into parts which become skills to be mastered. For many students the only form of assessment is an exam after instruction in which there is an answer key with the 'correct' answer. Behaviorism/traditional education models hold that there is only one truth and therefore all knowledge can be judged as either true or false (Bodner, Klobuchar, & Geelan, 2001).

Constructivism

Constructivist learning theory has been developed based mostly on the work of Jean Piaget. The basic premise behind constructivism is that knowledge is constructed in the mind of the learner by the learner. This construction is a continual process in which the knowledge is continually tested. Knowledge is only valid if it works in the situation in which it occurs (Bodner, 1986; Bodner et al., 2001; Fosnot, 1996; Herron, 1996). Bodner suggests that Piaget indicated that learners construct knowledge as they try to organize their experiences in terms of existing schemas. Piaget argued that the cognitive state of the learner was in equilibrium.

This equilibrium is a dynamic process between assimilation and accommodation. Assimilation is the organization of an experience into one's own mental structure. This assimilation is an attempt to make external data fit an existing schema (understanding) of the world. Disequilibrium occurs when the learner is unable to assimilate the new experience into any of the existing schema possessed by that learner. This leads to an accommodation in which the learner changes an existing schema until it fits with the new experience. The processes of assimilation and accommodation are initiated by a discrepant event, an experience that comes in to direct conflict with an existing idea of how something should work (Bodner, 1986; Bodner et al., 2001; Fosnot, 1996; Herron, 1996).

Piaget indicated that there are three common ways in which learners make an accommodation following a discrepant event: (1) They ignore the event in order to preserve equilibrium; (2) They waver, holding more than one schema to explain an experience based on the context in which the problem arises; or (3) they construct a new schema that better explains the discrepant event (Fosnot, 1996). These theories have been used in recent years to change pedagogy to develop teaching and learning experiences that foster changing the preexisting understanding (Bodner et al., 2001). This pedagogy is based on student disequilibrium.

The embracing of constructivism by some chemical educators has been met with some criticism. According to Bodner et al. (2001) there are three major objections to the constructivist model of learning and they are: constructivist fail to recognize that a 'real' world exists; constructivism limits the ability of the instructor to suggest that a student is wrong and instead students simply have alternate concepts; and constructivists by concentrating on the process of learning ignore teaching. Bodner et al. suggests that these criticisms lie mostly in a misunderstanding of constructivism and/or a view that radical constructivism suggested by Piaget and other should be used verbatim in the classroom. The controversy over the use of the constructivist model and how much and when to use it is best summoned up by Herron "The major influence that research in psychology and education has had on my teaching is the portion of the time I spend telling students what I think versus the portion I spend asking them what they think" (source unknown).

Constructivism and Chemical Education

The implication of constructivism and the chemistry classroom is the shifting role of the teacher and student. The teacher moves from the center of attention in the front of the classroom to an observer and facilitator. The student role also changes from a passive role to one in which the learner is the center of instruction. The instructor becomes adept at questioning both the correct and incorrect answers of students creating a dialogue in which the instructor probes the students' reasoning behind a response. This dialogue focuses on the process by which the student arrived at the answer, does not allow students to use ideas or equation without fully explaining their meaning, and requires the students to reflect on their understanding of the topic (Bonder, 1986; Bunce 2001).

Bodner (1986) argues that science is a constructivist activity. Scientific research, like learning, is built on the preexisting constructs that are challenged when new data does not fit properly into an existing scientific theory. This conflict requires that scientists resolve the conflicts between existing theories by modifying the current theory or constructing a new one as in the case of accommodation by the learner when presented with an experience that does not fit an existing schema. Bodner quotes Kelly (1955) who goes even further in suggesting the goals of scientists and the goals of each of us in our everyday lives is the same

> …to think about individuals in terms of their scientists-like aspects by arguing that 'It is customary to say that the scientist's ultimate aim is to predict and control.' …each of us shares the scientist's goal to predict and control the course of daily events. In doing so we develop theories, test hypotheses, and weigh experimental evidence about the sequence of events that mark our lives. (Bodner, p. 14)

Learning Cycle

The learning cycle incorporates the theory of constructivism into a teaching method that can be used in the classroom. Atkins and Karplus (1962) first purposed the idea of the learning cycle calling their method guided discovery. It was intended to mimic the way scientist acquired data, invented new concepts, and applied them in nature (Lawson, 2002). This guided discovery method did not have distinct order or steps.

This idea transformed into a formal teaching model presented by Karplus and Their in 1967.

Karplus and Their (1967) purposed that teaching science was a three step cycle: exploration, invention, and discovery. The learning cycle has gone through much iteration and there are now many different versions of the learning cycle which are all very similar. Lawson (1989) purposed a change to the terms used for the learning cycle to: exploration, term introduction, and concept application.

During the exploration phase of the learning cycle the students are introduced to new phenomenon by exploring new material and collecting data. The students are given minimal guidance during this phase of the learning cycle. The exploration should be designed to raise question or create a discrepant event. The outcome of the exploration phase should be the recognition of a pattern in the data (Herron, 1996; Lawson, 2002).

Following the exploration phase is the term introduction phase. This phase of the learning cycle establishes the vocabulary of the phenomenon and the pattern discovered by the students. This can be done using several methods: lecture, reading, discussion, or videos. The key is to get the students to begin to use the correct terms to describe what they see. This phase should always follow the exploration phase.

The third and final phase of the learning cycle is known as the concept application. Students are asked to apply the new concepts and the terms associated with them to new situations. This phase is an important step in getting students to internalize the concept. The students are able to see the utility of the concept as it is used to solve more and different problems (Herron, 1996; Lawson 2002).

Process Oriented Guided Inquiry Learning (POGIL)

In the spring of 1980 Marlene Kolz and William Snyder (1983) after having become dissatisfied with the results of the lecture format in regards to learning chemistry attempted a new teaching method. Kolz & Snyder had become aware of the tendency of students to follow a cycle during lecture period. The students would start the period very attentive this would be followed quickly by a long period of inattentiveness and the period would end with the students return to attention. They were interested in breaking this cycle of 'spurt-sag-spurt'. Kolz & Snyder selected a method which was purposed by Derek Rountree (1974). Rountree purposed giving the students worksheets and stopping the lecture to have the student's complete problems on the worksheet. Kolz & Snyder suggested that the use of the worksheet would produce several outcomes. They felt that it would break the 'spurt-sag-spurt 'cycle, but in addition it would allow the students to try out their understanding of the concepts. It would also allow the instructor to gain valuable feedback as to how well the students were assimilating the material. Kolz & Synder found moderate success with this method. Ostercamp (1992) also purposes a similar method of using worksheets in an interactive manner for organic chemistry in 1992. Upon review the literature these two papers stands out as probably the first teaching methods that had the look and feel of POGIL. The POGIL teaching method really began to take hold following a meeting at the State University of New York Stony Brook in 1997. This meeting was dedicated to improving the teaching/learning process in General Chemistry. One of the main goals of the meeting was to address the issue of the student-centered model of instruction as well as creating a network of like minded chemical educators to move forward using cognitive research to create teaching methods for the chemistry classroom (Hanson & Wolfskill, 1998).

Process Oriented Guided Inquiry Learning (POGIL) A New Model for Teaching Chemistry

Process Oriented Guided Inquiry Learning (POGIL) is a student centered teaching strategy developed for the science classroom and more specifically the chemistry classroom. Supported by grants from the National Science Foundation, POGIL's creation has been driven by cognitive research indicating that people learn by constructing knowledge from experience. The POGIL classroom is centered on two guiding principles; guided inquiry activities and cooperative learning (Farrell, Moog, & Spencer, 1999; Hanson & Wolfskill, 2000; Spencer, 1999). The guided inquiry activities are designed based on the learning cycle.

There are several versions of the learning cycle and the one used to create POGIL activities is a 3 part cycle incorporating exploration, concept invention, and application Most activities begin with a model that is either a graphic or tabulated data. The exploration phase of the learning cycle begins with the model and the first guided questions. These initial questions require the students to simply look at the model. The concept invention phase begins with guided questions that stimulate the students to look for patterns or trends in the data. These guided questions also begin to attach concepts and vocabulary to the trends the students have discovered. Finally, the students are asked to apply the new concept in the final questions on the activity. These guided inquiry activities are completed in a cooperative learning environment (Hanson & Wolfskill, 2000; Spencer, 1999). The groups are composed of between 3 and 5 students with 4 being the optimal number. Each student in the group is given a role to fulfill during the course of the day. The roles are manager, presenter, recorder, and reflector. The manager's responsibilities are administrative and include: ensuring all group members are fulfilling their roles; keeping the group on task; keeping track of time; making sure all group members understand each concept; and communicating with the instructor. The presenter's tasks include: giving oral reports regarding the solutions to problems; and/or writing solutions to problems on the board. The recorders' responsibilities include: recording the names and roles of each group member; writing the answers to the day's questions; and recording any additional information requested by the instructor. Finally, the reflector's tasks include: observing the group dynamics with respect to the learning process; recording these reflections; and possibly presenting the reflections to the class. These roles are rotated on a daily basis and group membership is rotated every 2 to 4 weeks (Farrell et al.,1999; Hanson & Wolfskill).

Another key aspect of POGIL is that it focuses on the process not just the product. Students are required to go beyond the answer and explain their strategies for solving the problems and they are required to explain them using the terms and concepts put forth in the activities. Finally, POGIL requires that students report their understanding of the concepts and process in both written and oral commentary. This act of reflection gives the students valuable practice in metacognition (Farrell et al., 1999; Hanson & Wolfskill, 2000; Spencer, 1999).

Process Oriented Guided Inquiry Learning and Chemistry Education

The literature includes some quantitative studies of the affects of group problem solving and POGIL specifically in the chemistry classroom. Williamson & Rowe (2002) conducted a study of group problem solving versus lecture. The objectives of the Williamson & Rowe study were to determine if students who participate in a group problem solving method learned the content at least as effectively as in traditional lecture and would group problem solving affect the withdrawal rate of students. The students in the study were junior level quantitative analysis students. There were two sections of the course being offered. The treatment section was given problems or more properly named exercises on an overhead to solve in cooperative learning groups. The control section was given a traditional lecture over the same topics. The results of the Williamson & Rowe study indicated that the treatment section had better scores on exams, quizzes, and the course. However, the difference proved to be statically insignificant with $p < 0.05$. Although no improvement was indicated the data suggest that no harm was done (Williamson & Rowe).

A study of a method more similar to POGIL conducted by Lewis & Lewis (2005) showed statistically significant achievement gains by students using Peer Led Guided Inquiry. Peer Led Guided Inquiry (PLGI) was developed based on the model of POGIL provided by Farrell et al. (1999). The major difference being that the facilitator is a student who has previously completed the course versus an instructor. The Lewis & Lewis study consisted of two section of General Chemistry. The treatment section met for two lecture session and one PLGI session per week. The control section met for three lectures per week. The same topics were covered in both sections and students were randomly assigned to each section. The results of the Lewis & Lewis study indicated that the performance on the exams was higher in the treatment group and the difference was significant at the $p = 0.05$ level. The study also showed that as the semester progressed the difference in the performance of the control section versus the treatment section increased with the treatment section increasingly outperforming the control section.

Farrell et al. (1999) documented one small study conducted specifically on POGIL's affect on student achievement. In the Farrell et al. study the objective was to determine if the use of POGIL affected the withdrawal, D, and F (WDF) rates of students in General Chemistry. The control group was the General Chemistry courses from 1990-1994 taught at Franklin and Marshall College. These courses were all instructed using the traditional lecture method. The treatment group was the chemistry courses from 1994-1997 that were taught using the POGIL method. The results indicate that the WDF rates decreases after using the POGIL method. The WDF rates prior to POGIL were 21.9%. This rate dropped to 9.6% when POGIL was used. The literature further indicates that student achievement is not adversely affected by the use of POGIL or POGIL like methods and these methods appears to have a significantly positive effect on achievement in some cases (Banerjee, 1997; Bradely, Ulrich, Jones & Jones, 2002; Gutwill-Wise, 2001; Hoke & Robbins, 2005; Miller, 1993; Oliver-Hoyo, Allen, Hunt, Hutson, & Pitts, 2004).

Method

The participants in this study were students enrolled in CHEM 120 an introductory chemistry course offered at St. John Fisher College located in Rochester New York. The course is described in the college bulletin as a one-semester course for nursing majors and students seeking and introduction to chemistry. Topics from general chemistry, organic chemistry, and biochemistry are covered, with emphasis on applications for health professionals

Participants

The participants in this study were students enrolled in CHEM 120 during the spring semesters of 2004 (control group), 2005 (treatment group), and 2006 (treatment group) who completed the exams on the topics of general and organic chemistry. During the spring 2004 semester 33 students completed all relevant exams. This sample included 29 female and 4 male students and 31 nursing majors and 2 students with other majors. The spring 2005 sample included 39 students of which 35 were female and 4 were male. This sample contained 33 nursing majors and 6 students with other majors. The spring 2006 sample contained 47 students of which 45 were female and 2 were male. This sample contained 43 nursing majors and 4 students with other majors.

Materials

The materials used for this study included 3 in class exams. The exams were different enough that a straight comparison of exams across all three sections would not have had much meaning. Therefore, the mean of the exam scores was used to compare the control and treatment groups since the totality of the topics was very similar. The exam structure included each of the following components: multiple choice questions, problems, and essay questions. The questions were a combination of traditional questions requiring the use of algorithms and conceptual questions that probed student understanding of the concepts. The appendix contains representative sample question from each exam administered to the control group and to each treatment group. The three in class exams assessed student understanding of the following topics: atomic structure, periodic table, nuclear chemistry, chemical bonding, naming compounds, writing formulas, types of matter, mole concept, mass conservation, solutions, acid and base chemistry, oxidation and reduction, organic functional groups, properties of organic compounds, and reactions of organic compounds. Exams one and two were taken in class with out any resources. The control group took exam three online with the option of using the textbook and Internet as resources. Exam 3 was considered an individual assessment, but was not proctored. This increased the chance that some students may have taken part in academic dishonesty. The textbook used for the control group was Essentials of General, Organic, and Biological Chemistry written by H. Stephen Stoker (2003). The treatment groups took exam 3 in class with the option of using the textbook as a resource. The textbook used for the spring 2005 treatment group was Chemistry: An Introduction to General, Organic, & Biological Chemistry written by Karen Timberlake (2003). The textbook used for the spring 2006 treatment group was Chemistry: An Introduction to General, Organic, & Biological Chemistry written by Karen Timberlake (2006). In addition to the textbook an unpublished set of POGIL activities written by Michael Garoutte (2004) were used in the treatment groups' classrooms. Student scores on the College Board Standard Achievement Test (SAT) were used as a measure of student prior knowledge and general state of preparation for college.

Data Collection

Three instructor made exams were used to collected data on the achievement of students in both the control group and the treatment groups. The mean of each individual exam was averaged to obtain a mean for all three exams for each student. A one way analysis of variance was used to determine if any changes in the mean between groups was statistically significant. The SAT scores for those students enrolled in the Chem 120 during the spring semester 2004, 2005, and 2006 were collected and compiled.

Procedure

The control group in this experiment was composed of the students who had enrolled in CHEM 120 during the spring 2004 semester. The treatment group consisted of students who had enrolled in either the spring 2005 or spring 2006 semester. The students were assigned to these group randomly based on their progress in the nursing program and their choice on enrollment in the course. The treatment group was instructed using the Process Oriented Guided Inquiry Learning (POGIL) teaching method. Students in the treatment groups worked in cooperative learning groups to complete activities designed using the learning cycle. Direct instruction was minimal. The control group was instructed using the direct instruction method commonly referred to as lecture. The topics covered in both the treatment and control groups were the same with minor differences. Achievement differences were measured using a one way analysis of variance to determine if any changes in the mean scores between the control group and the treatment groups were statistically significant. Success would constitute a significant ($p \leq .05$) increase in the mean exam scores in the treatment groups. To determine if any differences or lack there of measured by the in class exams was effected by student prior knowledge and preparation, student SAT scores were compared across all three groups using a one way analysis of variance.

Results

The mean exam scores of the students in the both treatment groups (70.2 & 73.9) were lower than the mean exam score of the students in the control group (74.5) (see Table 2). However, a one way analysis of variance (ANOVA) indicates that implementation of Process Oriented Guided Inquiry Learning (POGIL) had no statistically significant effect on student achievement in General, Organic, and Biochemistry as measured by in class exam scores, $F(2, 210.3) = 1.18$, $p > .05$ (the alpha level was maintained at .05 for this an all subsequent analysis).

Table 2

Analysis of Variance for Exam Scores

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Exam Scores 2004	33	2456.875	74.45076	81.72455
Exam Scores 2005	39	2735.988	70.15354	259.411
Exam Scores 2006	47	3473.643	73.90729	179.0388

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	420.6055	2	210.3028	1.17802	0.311544
Within Groups	20708.59	116	178.5223		
Total	21129.19	118			

Although there is not a significant difference in achievement among students in the control group and the treatment groups the level of student prior knowledge and preparedness as measured by SAT scores were statistically significant, $F(2, 40446) = 3.90$, $p = .02$ (see Table 3). The mean SAT scores for both treatment groups (2005 & 2006) were higher than those of the control group (2004). To determine if the difference was statistically significant between both the control group and each individual treatment group two additional ANOVA were compiled comparing the control group to the first treatment group (see Table 4) and comparing the control group to the second treatment group (see Table 5). The difference between the SAT scores of the control group (2004) and the first treatment group (2005) was statistically significant, $F(1, 80488) = 6.77$, $p = .01$. The difference in the SAT scores of the control group (2004) and the second treatment group (2005) was statistically insignificant, $F(1, 30310) = 3.11$, $p = .08$. This suggests that the students in the first treatment group (2005) should have out performed the control group (2004) based on prior knowledge and level of preparation as measured by SAT scores. Not only did the students in the first treatment group (2005) not meet the expectation of achieving at a higher level than the control group (2004) based on SAT scores they achieved at a lower level (2005 mean 70.2, 2004 mean 74.5 see Table 1) although this difference is statistically insignificant.

Table 3

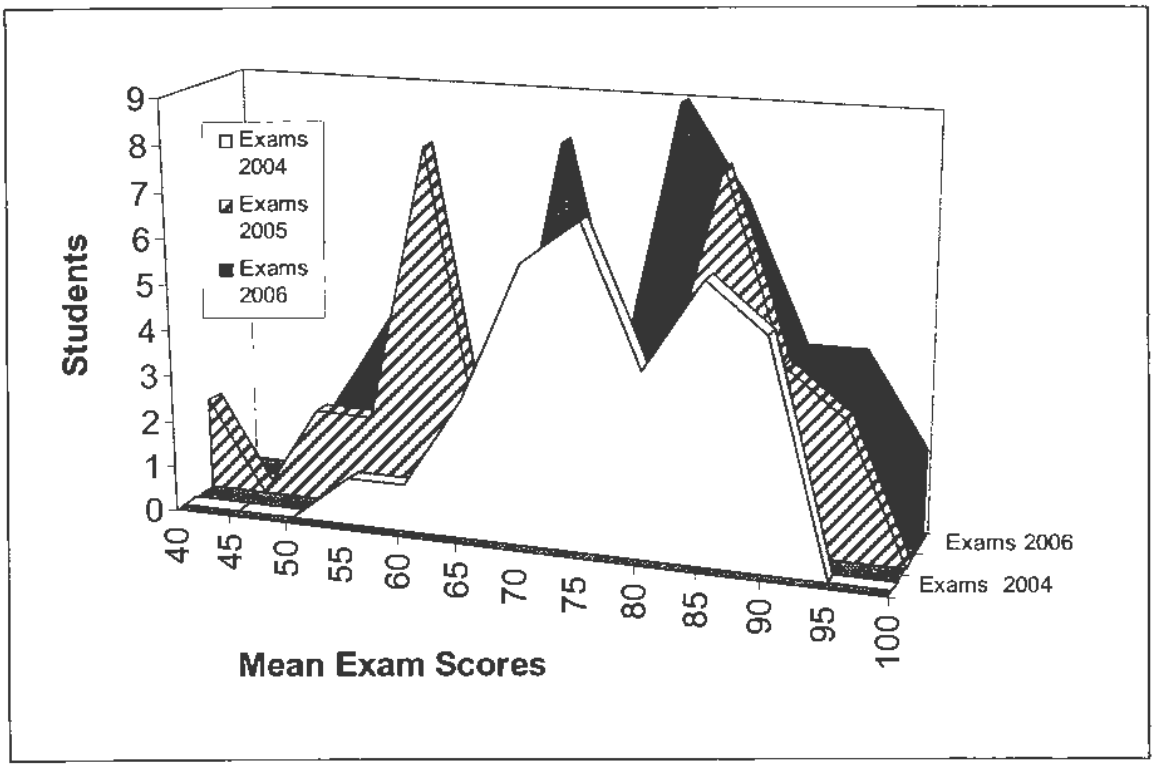
Analysis of Variance for SAT Scores

SUMMARY					
Groups	*Count*	*Sum*	*Average*	*Variance*	
SAT Score 2004	27	26570	984.07	12086.61	
SAT Score 2005	30	31780	1059.33	11661.61	
SAT Score 2006	38	39060	1027.89	8125.18	
ANOVA					
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*
Between Groups	80892.0	2	40446.00	3.90	0.02
Within Groups	953070.1	92	10359.46		
Total	1033962.1	94			

group (2004). The distribution of the second treatment group (2006) is particularly interesting because the difference in SAT exam scores between the control group and the second treatment group were statistically insignificant.

Figure 1

Percentage of students as a function of mean exam scores by year



Observing Figure 1 it would appear that the number of students in each of the distributions discussed increased from control group into each treatment group. This observed difference is do entirely to the increase in the number of students who were enrolled in the course and completed three exams for 2004, 2005, and 2006 (n = 33, n = 39, & n = 47). If however, the percentage of students scoring at a particular level are

The observable divergence in the results of this study in comparison with the literature begs the question as to what is causing this difference to occur. The most obvious response is that POGIL is not an effective teaching method for introductory chemistry courses as compared to lecture. Another possibility is that the students observed in the literature were somehow different from those in the introductory chemistry course. The results of the Springer et al. (1990) study as well studies conducted by Banerjee (1997), Bradely et al. (2002), Bowen (2000), Farrell et al. (1999), Gutwill-Wise (2001), Miller (1993), Oliver-Hoyo et al. (2004), and Williamson & Rowe (2002) all involved science and engineer majors taking chemistry or other science related courses in a cooperative learning environment. These students presumably had a strong background in science coming out of high school as well as an interest the fields of science and math. The students observed in this study were health science majors many of which have a poor background in science and particularly in chemistry. The students in this study also do not have the same level of interest in science as those observed in the literature. Another distinction between the studies in the literature and this study is the type of course. The courses observed in the literature were focused on the individual courses of general chemistry (Banerjee, 1997; Bowen, 2000; Farrell et al., 1999; Gutwill-Wise, 2001; Miller, 1993; Oliver-Hoyo et al. 2004; Williamson & Rowe, 2002) or organic chemistry (Bradely, 2002; Tien et al., 2002) over a two semester period. Whereas the introductory course in this study encompasses general, organic, and biochemistry in one semester. The number of topics and the amount of time allocated to teach them in the General, Organic, and Biochemistry course indicates that understanding at a higher level of reasoning my not be a reasonable outcome to expect. Ideally a minimum of three semesters would be taken to truly understand a bare minimum of the concepts in each discipline. The decision to use cooperative learn in the class room is best stated by Johnson et al. (1991).

> Cooperative learning is indicated whenever the goals of learning are highly important, mastery and retention are important, the task is complex or conceptual, problem solving is desired, divergent thinking or creativity is desired, quality of performance is expected, and higher level reasoning and critical thinking are needed. (p. 40)

The idea of teaching general, organic, and biochemistry in one semester is based on the direct instruction model of teaching in which the instructor can deliver large amounts of content in short periods of time. The finding of this study indicate that students achieve at a higher level on in class assessments when direct instruction is used to deliver large amounts of content in a short time interval. However, as indicated by Figure 1 (no students scored above 95) it is clear that there are less students thinking at higher levels with the direct instruction method of content delivery.

The data from this study indicates that how POGIL is implemented seems to affect the outcome. In Figure 1 the distributions of student scores between the control group (2004) and the 2006 treatment group are much more similar than those of the control group (2004) and the 2005 treatment group. In particular the students scoring at the mean in the control group were scoring 10-20 points below the mean in the 2005 treatment group. The implementation of POGIL was different for each treatment group. For the 2005 treatment group the emphasis was placed on the guided inquiry and learning cycle segments of POGIL. The implementation of POGIL in the 2006 treatment group included the previous emphasis on guided inquiry and the learning cycle with an added emphasis on the five components of cooperative learning as indicated by Johnson et al. (1991). These components are: positive interdependence, face-to-face interaction, individual accountability, interpersonal skills, and group processing. The emphasis on these components of cooperative learning decreased the negative effect of POGIL on achievement seen between the control group and the 2005 treatment group. This is particularly striking considering that the 2005 treatment group had statistically significant higher SAT score than the control group (2004). Whereas the SAT scores between the control group (2004) and 2006 treatment group showed no statistical significance. This implies that the improper implementation of POGIL has the potential to decrease student achievement in regards to introductory chemistry courses.

The implications of this study may be a pause in the drive to change instruction from the traditional lecture to guided inquiry and cooperative learning for introductory chemistry courses. A new hybrid method of direction instruction and POGIL may be need for courses that have a large number of concepts that are to be delivered in short time frame. It may also initiate a more broad discussion about what the stakeholders in introductory chemistry want from this course. Is it important for nursing majors to learn the concepts of chemistry or should the course be more of a seminar introducing the topics of chemistry with out any expectation of learning the concepts?

There are some areas of further research that might clarify the results of this study. One area of interest would be the length of time allotted to complete the introductory course. Would POGIL work more effectively in a two semester setting as opposed to a one semester setting? This would give the students more time to absorb the topics and more time to become familiar with the POGIL method. Another area of future research would be the effects of POGIL on critical thinking. One of the goals of POGIL is to increase critical thinking of students in all areas of their life not just in chemistry. The pay off for POGIL may be that it increases critical thinking for introductory chemistry students while holding achievement constant. There is general agreement among educators, politicians, and industry that it is just as important for students to learn how to use higher level reasoning and critical thinking to solve problems as it is to learn the content of any particular science course (Zoller, 1993). Therefore, a measured increase in critical thinking and high level reasoning skills would be a positive outcome of POGIL implementation.

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Appendix

The exams used are listed in Chem 120 for the control and treatment groups are listed.

Spring 2004 Exams (Control Group)

The exams used for the control group are listed.

Exam 1 (Control Group)

This was an in class exam with only a calculator and periodic table as resources. The questions included are a representative sample.

Multiple Choice
Please select the best answer

1. An atom has a mass number of 27 and an atomic number of 14. This means that it
   a. contains 27 neutrons and 14 protons
   b. contains 27 protons and 14 electrons
   c. has 27 subatomic particles in its nucleus
   d. contains 14 protons and 13 electrons

2. How many conversion factors can be derived from the equality 24 hours = 1 day?
   a. two
   b. three
   c. four
   d. an infinite number

3. If the half-life of a 2.0 gram sample of a radioactive isotope is 15 hours, then the half-life of a 1.0 gram sample of the same radioactive isotope would be
   a. 7.5 hours
   b. 15 hours
   c. 30 hours
   d. 60 hours

4. After 4 half-lives have elapsed, the amount of a radioactive sample which has not decayed is
   a. 1/4 of the sample

b. 1/8 of the sample
c. 1/16 of the sample
d. 1/32 of the sample

Problems
Show all work to receive full credit
Partial credit will be given for problems

5. Perform the following conversion 19.91 cm to m.

6. In March 1989, the Exxon Valdez ran aground and spilled 240,000 barrels of petroleum off the coast of Alaska. One barrel of petroleum is equal to 42 gal. How many liters of petroleum were spilled?

Short answer essay
Maximum length 1 paragraph
Several well phrased sentences is all that is required

7. In nuclear medicine radioactive isotopes are used for both diagnostic and therapeutic purposes. What chemical property of radioactive isotopes makes them attractive to use for the above mentioned purposes? (Hint: Do not focus on the nuclear emission think of the chemical properties).

Exam 2 (Control Group)

This was an in class exam with only a calculator and periodic table as resources. The questions included are a representative sample

Multiple
Please select the best answer

1. Elements in groups 2A and 6A of the periodic table possess, respectively, how many valence electrons?
    a. 2 and 2
    b. 6 and 2
    c. 2 and 6
    d. 8 and 8

2. Which of the following statements contrasting covalent bonds and ionic bonds is correct?
    a. Covalent bonds usually involve two nonmetals, and ionic bonds usually involve two metals
    b. Covalent bonds usually involve two metals, and ionic bonds usually involve a metal and nonmetal

c. Covalent bonds usually involve two nonmetals, and ionic bonds usually involve a metal and nonmetal
d. Covalent bonds usually involve a metal and nonmetal and ionic bonds usually involve two nonmetals

3. The atomic masses of He and Be are 4.00 and 9.01, respectively. Which of the following statements concerning He and Be is correct?
   a. a mole of Be contains more atoms than a mole of He
   b. a mole of He has a greater mass than a mole of Be
   c. a mole of Be contains the same number of atoms as a mole of He
   d. a mole of Be is 9 times heavier than a mole of He

4. The balanced equation $2CO + O_2 \rightarrow 2CO_2$ tells us that
   a. 1.00 grams of O_2 will produce 2.00 grams of CO_2
   b. 1.00 mole of CO will produce 2.00 mole of CO_2
   c. CO and O_2 react in a 2-to-1 molecular ratio
   d. CO and O_2 react in a 2-to-1 mass ratio

5. In which of the following pairings of term are the terms closely related?
   a. hemolysis, hypotonic solution
   b. isotonic solution, higher concentration of solute than in red blood cells
   c. hypertonic solution, red blood cells neither shrink nor swell
   d. crenation, isotonic solution

Problems
Show all work to receive full credit
Partial credit will be given for problems

6. Draw the Lewis structure for NH_3

7. Rewrite and balance the following chemical equation

8. What is the molarity of a solution that is composed of 19.9g of sodium chloride and 100 ml of water?

Problems
Short answer essay
Maximum length 1 paragraph
Several well phrased sentences is all that is required

9. Using the law of conservation of matter explain why we observed in class that paper, after it has been burned, has less mass than before it was burned and steel wool, after it has been burned, has more mass than before it was burned.

Exam 3 (Control Group)

Exam 3 covered the topic of organic chemistry and was given as a two part online open book exam (Stoker 2003). The questions included are a representative sample

Multiple Choice
Please select the best answer

1. Which of the following statements concerning **organic compounds** is correct?
    a. organic compounds are found only in living organisms
    b. organic compounds are always insoluble in water
    c. organic compounds must be obtained from nature; they cannot be prepared in a laboratory
    d. organic compounds always contain the element carbon

2. The distinction between a saturated hydrocarbon and an unsaturated hydrocarbon relates to
    a. boiling points
    b. flammability
    c. number of carbon atoms present
    d. types of carbon-carbon bonds present

3. Which of the following could not be the molecular formula for an alkane?
    a. C_3H_8
    b. C_5H_{10}
    c. C_7H_{16}
    d. $C_{20}H_{42}$

4. How many hydrogen atoms are present in an isopropyl group?
    a. six
    b. seven
    c. eight
    d. nine

Problems
Show all work to receive full credit
Partial credit will be given for problems

1. How many carbons atoms are present in the following compound?

    1-ethyl-2methyl-4-isoproplycyclohexane

2. Write the IUPAC name for all the structural isomers of an alkane that contains 6 carbons atoms

Spring 2005 Exams (Treatment Group)

Exams administered to the treatment group spring 2005

Exam 1 (Treatment Group)

This was an in class exam with only a calculator and periodic table as resources.

The questions included are a representative sample

Multiple
Please select the best answer

1. How many conversion factors can be derived from the equality 24 hours = 1 day?
    a. two
    b. three
    c. four
    d. an infinite number

2. If the half-life of a 2.0 gram sample of a radioactive isotope is 15 hours, then the half-life of a 1.0 gram sample of the same radioactive isotope would be
    a. 7.5 hours
    b. 15 hours
    c. 30 hours
    d. 60 hours.

3. Elements in groups 2A and 6A of the periodic table possess, respectively, how many valence electrons?
    a. 2 and 2
    b. 6 and 2
    c. 2 and 6
    d. 8 and 8

4. The correct name of the ionic compound Al_2S_3 is
    a. dialuminum trisulfide
    b. aluminum sulfide
    c. aluminum (III) sulfide
    d. aluminum trisulfide

5. Which of the following statements contrasting covalent bonds and ionic bonds is correct?
    a. Covalent bonds usually involve two nonmetals, and ionic bonds usually involve two metals
    b. Covalent bonds usually involve two metals, and ionic bonds usually involve a metal and nonmetal

c. Covalent bonds usually involve two nonmetals, and ionic bonds usually involve a metal and nonmetal
d. Covalent bonds usually involve a metal and nonmetal and ionic bonds usually involve two nonmetals

6. The atomic masses of He and Be are 4.00 and 9.01, respectively. Which of the following statements concerning He and Be is correct?
   a. a mole of Be contains more atoms than a mole of He
   b. a mole of He has a greater mass than a mole of Be
   c. a mole of Be contains the same number of atoms as a mole of He
   d. a mole of Be is 9 times heavier than a mole of He

Problems
Show all work to receive full credit
Partial credit will be given for problems

7. In March 1989, the Exxon Valdez ran aground and spilled 240,000 barrels of petroleum off the coast of Alaska. One barrel of petroleum is equal to 42 gal. How many liters of petroleum were spilled?

8. Draw the Lewis structure for NH_3

Problems
Short answer essay
Maximum length 1 paragraph
Several well phrased sentences is all that is required

9. In nuclear medicine radioactive isotopes are used for both diagnostic and therapeutic purposes. What type of radiation is most effective? Why? What type of half-life is most useful? Why? What chemical property of radioactive isotopes makes them attractive to use for the above mentioned purposes? (Hint: For the last part do not focus on the nuclear emission think of the chemical properties).

Exam 2 (Treatment Group)

This was an in class exam with only a calculator and periodic table as resources.

The questions included are a representative sample

Multiple
Please select the best answer

1. Which of the following conversion factors **is not** consistent with the equation?

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$$

a. 5 moles O_2/ 6 moles H_2O
b. 4 moles NO/4 moles NH_3
c. 4 moles NH_3/5 moles H_2O
d. 4 moles NO/5 moles O_2

2. Which of the following chemical equations is balanced?
   a. $2H_2 + O_2 \rightarrow 2\ H_2O$
   b. $2SO_2 + 2O_2 \rightarrow 3SO_2$
   c. $KClO_3 \rightarrow KCl + 3O_2$
   d. $N_2 + H_2 \rightarrow 2NH_3$

3. In the following reaction if you have 10.0 g of hydrogen and 10.0 grams of oxygen the mass of the product will be______
   $2H_2 + O_2 \rightarrow 2H_2O$
   a. equal to 20.0g
   b. less than 20.0g
   c. more than 20.0g
   d. more information is needed.

4. All of the following definitions for oxidation are correct except one. The exception is
   a. gain of one or more oxygen (O_2) molecules
   b. gain of one or more carbon atoms
   c. loss of two or more hydrogen (H_2) molecules
   d. loss of one or more electrons

5. The Bronsted-Lowry acid and base for the reaction $HCl + NH_3 \rightarrow NH^+_4 + Cl^-$ are, respectively
   a. NH_3 and NH^+_4
   b. HCl and NH_3
   c. HCl and Cl^-
   d. NH^+_4 and Cl^-

6. In which of the following pairings of term are the terms closely related?
   a. hemolysis, hypotonic solution
   b. isotonic solution, higher concentration of solute than in red blood cells
   c. hypertonic solution, red blood cells neither shrink nor swell
   d. crenation, isotonic solution

7. The balanced equation $2CO + O_2 \rightarrow 2CO_2$ tells us that
   a. 1.00 grams of O_2 will produce 2.00 grams of CO_2
   b. 1.00 mole of CO will produce 2.00 mole of CO_2
   c. CO and O_2 react in a 2-to-1 molecular ratio
   d. CO and O_2 react in a 2-to-1 mass ratio

8. Two solutions of NaCl are prepared in the lab. One solution has a molarity of 0.1 and the other solution has a molarity of 1.0. This indicates that

a. the first solution has more dissolved NaCl than the second solution
b. the first solution has less dissolved NaCl than the second solution
c. the amount of dissolved NaCl is equal in both solutions
d. more information is needed

Problems
Show all work to receive full credit
Partial credit will be given for problems

9. What is the molarity of a solution that is composed of 21.35 g of NaCl and 500 mL of water?

10. In the following chemical reactions list the element that has been oxidized and the element that has been reduced.
    a. $Li + S \rightarrow Li_2S$
    b. $Cu + MgCO_3 \rightarrow CuCO_3 + M$
    c. $CaS \rightarrow Ca + S$

11. Gasohol is fuel containing ethanol (C_2H_6O) that burns in oxygen (O_2) to give carbon dioxide and water. **(4pts per response)**

    a. State the reactants and products for this reaction
    b. How many moles of O_2 are needed to completely react with 4.0 moles of C_2H_6O?
    c. If a car produces 88g of CO_2, how many grams of O_2 are used up in the reaction?
    d. If you add 125 g of C_2H_6O to your gas, how many grams of H_2O are produced?
    e. Was the ethanol oxidized, reduced or neither? Explain.

Problems
Short answer essay
Maximum length 1 paragraph
Several well phrased sentences is all that is required

12. A piece of paper is scaled in a box and weighed and then the piece of paper is ignited and the box is resealed and the paper is allowed to burn until it goes out. The sealed box is then weighed again. The seal on the box is then broken and the box is weighed a third time. Compare and contrast the three weights. Explain any differences and/or similarities.

Exam 3 (Treatment Group)

This was an in class exam with a calculator and textbook as a resource (Timberlake 2003). The questions included are a representative sample

Multiple Choice
Please select the best answer

1. Which of the following statements concerning **organic compounds** is correct?
   a. organic compounds are found only in living organisms
   b. organic compounds are always insoluble in water
   c. organic compounds must be obtained from nature; they cannot be prepared in a laboratory
   d. organic compounds always contain the element carbon

2. The IUPAC name for the compound CH_3-$CH(CH_3)$-CH=CH-CH_3 is?
   a. 2-methylpentene
   b. 2-methyl-3,4-pentene
   c. 2-methyl-3-pentene
   d. 4-methyl-2-pentene

3. Which of the following comparisons illustrates the structural difference between an aldehyde and a ketone?
   a. –H versus -OH
   b. –H versus -R
   c. –OH versus -R
   d. –OH versus -OR

4. The distinction between a saturated hydrocarbon and an unsaturated hydrocarbon relates to
   a. boiling points
   b. flammability
   c. number of carbon atoms present
   d. types of carbon-carbon bonds present

5. Comparison of the boiling points of aldehydes and ketones with those of other compounds of similar molecular mass show that they are?
   a. lower than those of alcohols and alkanes
   b. higher than those of alcohols and alkanes
   c. higher than those of alcohols but lower than those of alkanes
   d. higher than those of alkanes but lower than those of alcohols

6. The IUPAC name for the compound CH_3-CH_2-CH_2-COOH is
   a. propanoic acid
   b. butanoic acid
   c. propyl carboxylic acid
   d. butyl carboxylic acid

7. The reactants for an esterification reaction are
   a. an alcohol and an aldehyde
   b. an alcohol and a carboxylic acid
   c. an aldehyde and a carboxylic acid
   d. a carboxylic acid and a ketone

8. Carbon almost always form _____ bonds when it combines with other atoms
   a. 3
   b. 4
   c. 5
   d. 6

Problems (2pts each)
Partial credit will be given for problems

9. Draw (any style) the structure for 2,3-dimethylpentanal

10. Write the IUPAC name for the following compound.

$$CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-CH_2-CH_3$$

Problems
Show all work to receive full credit
Partial credit will be given for problems

11. Write the chemical equation for the oxidation of 1-butanol and write the IUPAC name of the product.

Spring 2006 Exams (Treatment Group)

Exams administered to the treatment group spring 2006.

Exam 1 (Treatment Group)

This was an in class exam with only a calculator and periodic table as resources.

The questions included are a representative sample

Multiple Choice
Please select the best answer

1. An atom has a mass number of 27 and an atomic number of 14. This means that it
    a. contains 27 neutrons and 14 protons
    b. contains 27 protons and 14 electrons
    c. has 27 subatomic particles in its nucleus
    d. contains 14 protons and 13 electrons

2. If the half-life of a 2.0 gram sample of a radioactive isotope is 15 hours, then the half-life of a 1.0 gram sample of the same radioactive isotope would be
    a. 7.5 hours
    b. 15 hours
    c. 30 hours
    d. 60 hours.

3. After 4 half-lives have elapsed, the amount of a radioactive sample which has not decayed is
    a. 1/4 of the sample
    b. 1/8 of the sample
    c. 1/16 of the sample
    d. 1/32 of the sample

4. Elements in groups 2A and 6A of the periodic table posses, respectively, how many valence electrons?
    a. 2 and 2
    b. 6 and 2
    c. 2 and 6
    d. 8 and 8

5. The correct name of the ionic compound Al_2S_3 is
    a. dialuminum trisulfide
    b. aluminum sulfide
    c. aluminum (III) sulfide
    d. aluminum trisulfide

6. Which of the following statements contrasting covalent bonds and ionic bonds is correct?
    a. Covalent bonds usually involve two nonmetals, and ionic bonds usually involve two metals
    b. Covalent bonds usually involve two metals, and ionic bonds usually involve a metal and nonmetal
    c. Covalent honds usually involve two nonmetals, and ionic bonds usually involve a metal and nonmetal
    d. Covalent bonds usually involve a metal and nonmetal and ionic bonds usually involve two nonmetals

7. Which of the following chemical equations is balanced?

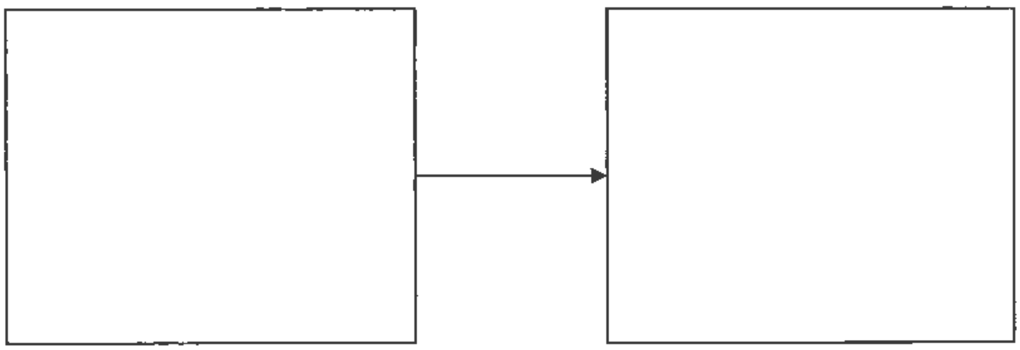
a. $2H_2 + O_2 \rightarrow 2\ H_2O$
b. $2SO_2 + 2O_2 \rightarrow 3SO_2$
c. $KClO_3 \rightarrow KCl + 3O_2$
d. $N_2 + H_2 \rightarrow 2NH_3$

Problems
Show all work to receive full credit
Partial credit will be given for problems

8. Label each of the following equations as balanced or unbalanced. Explain your reasoning.
   a. $CuO + H_2 \rightarrow Cu + H_2O$
   b. $NO + O_2 \rightarrow NO_2$
   c. $CH_4 + O_2 \rightarrow H_2O + CO_2$

9. Draw the Lewis structure for NH_3

10. A container is filled with methane (CH_4) and oxygen (O_2), which react to form carbon dioxide and water. Draw a representation (picture) of the molecules in the container before the reaction and the molecules after the reaction. Indicate what the symbols in your representation mean.



11. How long would it take for a 100 g sample of carbon-14 to decay until less then 1g of the original isotope remained?

Problems
Short answer essay
Maximum length 1 paragraph
Several well phrased sentences is all that is required

12. A piece of paper is sealed in a box and weighed and then the piece of paper is ignited and the box is resealed and the paper is allowed to burn until it goes out. The sealed box is then weighed again. The seal on the box is then broken and the box is

weighed a third time. Compare and contrast the three weights. Explain any differences and/or similarities.

13. In nuclear medicine radioactive isotopes are used for both diagnostic and therapeutic purposes. What type of radiation is most effective? Why? What type of half-life is most useful? Why? What chemical property of radioactive isotopes makes them attractive to use for the above mentioned purposes? (Hint: For the last part do not focus on the nuclear emission think of the chemical properties).

Exam 2 (Treatment Group)

This was an in class exam with only a calculator and periodic table as resources. The questions included are a representative sample

Multiple Choice
Please select the best answer

1. Which of the following conversion factors **is not** consistent with the equation?
   $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$
   a. 5 moles O_2/ 6 moles H_2O
   b. 4 moles NO/4 moles NH_3
   c. 4 moles NH_3/5 moles H_2O
   d. 4 moles NO/5 moles O_2

2. The atomic masses of He and Be are 4.00 and 9.01, respectively. Which of the following statements concerning He and Be is correct?
   a. a mole of Be contains more atoms than a mole of He
   b. a mole of He has a greater mass than a mole of Be
   c. a mole of Be contains the same number of atoms as a mole of He
   d. a mole of Be is 9 times heavier than a mole of He

3. How many conversion factors can be derived from the equality 24 hours = 1 day?
   a. two
   b. three
   c. four
   d. an infinite number

4. In the redox reaction $4Al + 3MnO_2 \rightarrow 2Al_2O_3 + 3Mn$ the element oxidized is?
   a. Al
   b. Mn
   c. O
   d. All of the above

5. In Bronsted-Lowry acid-base theory a base is defined as a(n)?
   a. proton donor

b. proton acceptor
c. electron donor
d. electron acceptor

6. All of the following definitions for oxidation are correct except one. The exception is
    a. gain of one or more oxygen (O_2) molecules
    b. gain of one or more carbon atoms
    c. loss of two or more hydrogen (H_2) molecules
    d. loss of one or more electrons

7. In which of the following pairings of term are the terms closely related?
    a. hemolysis, hypotonic solution
    b. isotonic solution, higher concentration of solute than in red blood cells
    c. hypertonic solution, red blood cells neither shrink nor swell
    d. crenation, isotonic solution

8. The balanced equation $2CO + O_2 \rightarrow 2CO_2$ tells us that
    a. 1.00 grams of O_2 will produce 2.00 grams of CO_2
    b. 1.00 mole of CO will produce 2.00 mole of CO_2
    c. CO and O_2 react in a 2-to-1 molecular ratio
    d. CO and O_2 react in a 2-to-1 mass ratio

9. Two solutions of NaCl are prepared in the lab. One solution has a molarity of 0.1 and the other solution has a molarity of 1.0. This indicates that
    a. the first solution has more dissolved NaCl than the second solution
    b. the first solntion has less dissolved NaCl than the second solution
    c. the amount of dissolved NaCl is equal in both solutions
    d. more information is needed

Problems
Show all work to receive full credit
Partial credit will be given for problem

10. To prevent bacterial infection, a doctor orders 4 tablets of amoxicillin per day for 10 days. If each tablet contains 250 mg of amoxicillin, how many ounces of the medication are given in 10 days?

11. How many moles of glucose are present in 20.02 g of glucose ($C_6H_{12}O_6$)

12. If you were in the laboratory, how would you prepare 0.5 L of a 2 M KCl solution?

13. In the following chemical reactions list the element that has been oxidized and the element that has been reduced.
    a. $Li + S \rightarrow Li_2S$
    b. $Cu + MgCO_3 \rightarrow CuCO_3 + Mg$
    c. $CaS \rightarrow Ca + S$

14. Gasohol is fuel containing ethanol (C_2H_6O) that burns in oxygen (O_2) to give carbon dioxide and water.

$$2C_2H_6O + 7O_2 \rightarrow 4CO_2 + 6H_2O$$

   a. How many moles of O_2 are needed to completely react with 4.0 moles of C_2H_6O?
   b. If a car produces 88g of CO_2, how many grams of O_2 are used up in the reaction?
   c. Was the ethanol oxidized, reduced or neither? Explain.

Problems
Short answer essay
Maximum length 1 paragraph
Several well phrased sentences is all that is required

15. In a brief statement describe the difference between a solution, colloid, and suspension. Please include a label diagram with your response.

Exam 3 (Treatment Group)

This was an in class exam with a calculator and textbook as a resource (Timberlake 2006). The questions included are a representative sample

Multiple Choice
Please select the best answer

1. Which of the following statements concerning **organic compounds** is correct?
   a. organic compounds are found only in living organisms
   b. organic compounds are always insoluble in water
   c. organic compounds must be obtained from nature; they cannot be prepared in a laboratory
   d. organic compounds always contain the element carbon

2. The IUPAC name for the compound CH_3-$CH(CH_3)$-CH=CH-CH_3 is?
   a. 2-methylpentene
   b. 2-methyl-3,4-pentene
   c. 2-methyl-3-pentene
   d. 4-methyl-2-pentene

3. Which of the following comparisons illustrates the structural difference between an aldehyde and a ketone?
   a. –H versus -OH

   b. –H versus -R
   c. –OH versus -R
   d. –OH versus -OR

4. Comparison of the boiling points of aldehydes and ketones with those of other compounds of similar molecular mass show that they are?
   a. lower than those of alcohols and alkanes
   b. higher than those of alcohols and alkanes
   c. higher than those of alcohols but lower than those of alkanes
   d. higher than those of alkanes but lower than those of alcohols

5. The IUPAC name for the compound CH_3-CH_2-CH_2-COOH is
   a. propanoic acid
   b. butanoic acid
   c. propyl carboxylic acid
   d. butyl carboxylic acid

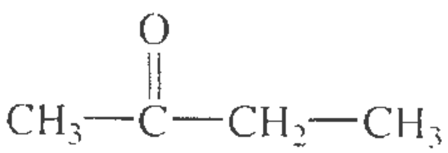
6. The reactants for an esterification reaction are
   a. an alcohol and an aldehyde
   b. an alcohol and a carboxylic acid
   c. an aldehyde and a carboxylic acid
   d. a carboxylic acid and a ketone

7. Carbon almost always form _____ bonds when it combines with other atoms
   a. 3
   b. 4
   c. 5
   d. 6

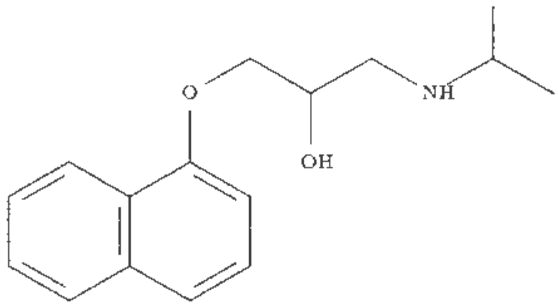
Problems (2pts each)
Partial credit will be given for problems

8. Draw (any style) the structure for 2,3-dimethylpentanal

9. Write the IUPAC name for the following compound.



10. List 3 of the 4 functional groups in the following compound. Please only include a list of a maximum of 4 functional groups in your answer.



11. Write the chemical equation for the oxidation of 1-butanol and write the IUPAC name of the product.

$CH_3{-}CH_2{-}CH_2{-}CH_2{-}OH + O_2 \rightarrow$

1-butanol