GUIDED LEARNING CHEMISTRY ACTIVITIES IN THE PHYSICAL SCIENCE (PSCI 1030) LAB AT MIDDLE TENNESSEE STATE UNIVERSITY

by

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ABSTRACT

GUIDED LEARNING CHEMISTRY ACTIVITIES IN THE PHYSICAL SCIENCE (PSCI 1030) LAB AT MIDDLE TENNESSEE STATE UNIVERSITY

Barry Farris

Guided learning labs as alternatives to traditional style chemistry-related labs were tested in the course, Topics in Physical Science. Guided learning labs emphasized students' conceptual understanding of the science content and actively involved the instructor during the lab. The control group performed traditional lab exercises while students who carried out the guided learning activities formed the treatment group. Both groups had similar demographic and academic backgrounds. This research compared student performances on the three labs: Density, Kinetic Theory and Chemical Reactions. Both groups completed pre-lab and post-lab quizzes and answered conceptual questions for each lab. Students also participated in a post-course quiz via email. Scores on all these assessments were compared using independent samples t tests.

The treatment group outscored the control group on all summary assessments, and performed significantly better than the control group on the post-lab quizzes and conceptual questions for all three labs. Students in the treatment group demonstrated stronger Pearson's correlations between their ACT Mathematics, Science Reasoning and Reading Comprehension scores and their scores on the assessments. Student reactions to

the guided learning style of lab were favorable. The implication is that guided learning labs improve conceptual understanding of chemistry concepts in a physical science lab course.

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CHAPTER 1

INTRODUCTION

General Education Courses and the Natural Sciences

Among the learning goals listed in the Mission Statement of Middle Tennessee State University (MTSU) (*1*), the university intends for the educated student to be prepared to "become a lifelong learner" and to "acquire a working knowledge of a discipline or a group of related disciplines." Another goal is that the student can "participate actively in the world community by seeking and sharing knowledge, expertise, and creative undertakings." To accomplish this, the university requires students to take general courses in language and literature studies, biological and physical sciences, history and social sciences, visual and performing arts, mathematics, and philosophy and religion. In addition to knowledge gained in these areas, students develop skills and problem-solving abilities needed in daily living. Although they receive further training that is specific for their major, students who complete a general education course of study are equipped to be lifelong learners.

The Tennessee Board of Regents (TBR) is the governing body of MTSU. In its Philosophy of General Education (*2*), this governance states that the purpose of general education core courses is to "ensure that college students have the broad knowledge and skills to become life-long learners in a global community that will continue to change."

Students attending TBR schools are required to take eight semester hours of natural science courses as part of the general education core curriculum. Natural science courses are from the following areas: astronomy, biology, chemistry, physics, geology, and interdisciplinary studies in physical science. As with other general education courses, natural science courses provide broad exposure to its disciplines rather than focusing narrowly on skills, techniques or procedures of a particular discipline. Students enrolled in natural science courses are also required to experience science through participation in labs. Natural science course requirements for TBR's constituent colleges and universities (*3*) are to assure that students develop a scientific view of the world and to enhance students' creative thinking and problem-solving skills.

The TBR has defined the general education outcomes for the natural sciences (*3*). After completing a natural science course, students should be able to investigate a phenomenon by conducting an experiment. They collect and examine data and draw conclusions based on evidence from the experiment. Students should be able to recognize patterns in and the diversity of nature as well as identify and know the meaning of terms such as hypotheses, theories and natural laws. Those who complete a natural science course should also be able to contribute to a discussion regarding the impact scientific endeavors have had on human thought, civilization, and the natural environment. Students should also be capable of making informed decisions about issues related to the management of shared resources such as air, water, energy reserves, national forests and space.

MTSU General Studies Course Requirements and PSCI 1030 Course Description

General studies courses at MTSU were designed to address skills and competencies that students need. These skills and competencies (*4*) include the development of critical thinking skills, various methods of inquiry for understanding the world, communication skills (written, oral, quantitative, and artistic), and a perspective of his or her role in the changing world.

All MTSU students who are candidates for baccalaureate degrees are required to complete eight semester hours in the natural sciences (*5*). These hours must come from two nonsequential courses in astronomy, biology, chemistry, geology, physics or physical science. The catalog description for Topics in Physical Science, PSCI 1030, reads (*6*):

> Topics in Physical Science. Four credits. Language, development, structure, and role of physical science (physics, chemistry, astronomy, and geology) as it relates to the knowledge and activities of the educated person. For non-science majors. Three hours lecture and one two-hour laboratory. (A General Studies course [Area IV-A]. Does not count toward any major or minor.)

The lab in PSCI 1030 was the focus of this research. Todd (7) underscored the value of labs in this course when he pointed out that labs teach students to read and follow directions. He also stressed that labs give students experience with materials and techniques they read about in the textbook or heard in the lecture. Labs also help students learn basic lab skills and lab safety.

According to Thomas (*8*), an average of almost 1400 non-science majors take PSCI 1030 as part of their general studies requirement during the academic year and an average of 105 students enroll in PSCI 1030 during the summer (Appendix A). Faculty members from the Department of Chemistry or the Department of Physics and Astronomy teach the course. Faculty members or graduate students teach the lab sections. There are three hours of lecture and two hours of lab experiences each week.

Statement of the Problem

Science labs provide a venue where facts or theories of science are illustrated. Science is more than a body of facts or theories, and labs should be too. Labs provide an opportunity for students to mimic some of the processes of scientists when they engage in activities in the lab. These processes of science include but are not limited to: making observations, collecting and analyzing data, using scientific equipment, questioning, arguing, making assumptions and hypothesizing, calculating, graphing, and communicating results.

Todd and Todd (*9*) wrote the lab manual which was used for PSCI 1030 during the time of this study. Each lesson in the manual provided factual scientific background along with detailed information regarding techniques that were used in each lab. The design for each lab used a step-by-step format which led the students to verify scientific facts or theories presented in the text or lecture. The first lab, *The Scientific Attitude and Method*, identified scientific thought processes that were to be used in labs. These processes included questioning, forming a hypothesis, predicting, proposing solutions and providing explanations. However, in the remaining labs in this manual, students were seldom required to use those scientific processes. For example, students in the Organic Qualitative Analysis lab (*9*) were given instructions on how to identify a positive test for the presence of a particular organic functional group. The students were asked to identify the class of unknown compounds based on the results of experimental tests. Students' initial thoughts were not sought, nor were students given an opportunity to design a method to solve the problem. Students were provided step-by-step instructions of how to perform the activity and were told what a positive test would look like. Students compared their experimental results to the outcome of a positive test to determine how well the experiment was performed.

The labs in PSCI 1030 required students to use scientific equipment to verify values or topics pointed out in the lecture. Students had little opportunity to practice such components of scientific thinking as forming a hypothesis, questioning, arguing and communicating ideas. Students usually worked with one partner, followed directions in the designated lab manual, collected data, performed calculations using a provided formula and checked the answer against a standard value. This lab pedagogy met only some of the expectations for general education established by MTSU and TBR.

Purpose

The purpose of this research was to investigate whether the style of lab instruction in PSCI 1030 had an impact on concept mastery of density, kinetic theory and chemical reactions. Students' scores on pre-lab and post-lab quizzes, on conceptual questions and on post-course quizzes were collected. This research compared an experimental lab pedagogy called guided learning to the existing traditional instructional methodology used in PSCI 1030 lab.

Research Questions

The following questions were proposed for this research:

Do students who participated in experimental guided learning labs in PSCI 1030 at MTSU have an increased level of conceptual understanding compared to those in the control group who participated in the traditional-style labs?

Hypothesis 1: Treatment-group students taught using a guided learning lab instructional style will produce significantly higher mean total scores than control-group students taught using the traditional lab instructional style, as measured by their scores on the post-lab quizzes questions.

Hypothesis 2: Treatment-group students taught using the guided learning lab instructional style will produce significantly higher mean total scores on their post-lab quizzes after adjusting for the groups' scores on their pre-lab quiz mean total score.

Hypothesis 3: Treatment-group students taught using the guided learning lab instructional style will produce significantly higher mean total scores on the conceptual questions than the control-group students taught using the traditional lab instructional style.

Do students who are instructed using guided learning lab methodology retain physical science content knowledge after completing the course longer than those who are instructed using a traditional style of lab instruction?

Hypothesis 4: Treatment-group students taught using the guided learning lab instructional style will produce a significantly higher score on a post-course quiz than the control-group students taught using the traditional lab instructional style.

CHAPTER 2

LITERATURE REVIEW

Introduction

How students learn, and more specifically how they learn science, has been studied for many years. For this research, a review of the literature about learning, misconceptions, and conceptual change was conducted. Different lab instructional styles were investigated. The purposes of lab instruction in college or university physical science courses were examined. Stated goals and objectives of lab manuals for physical science and chemistry have been reviewed. Student-centered and content-centered lab instructional styles have been characterized and compared. An investigation of student-centered physical science and chemistry lab investigations has also been made.

Two Theories of Learning

Herron and Nurrenbern (*10*) wrote that there have been two broad views of learning which have shaped science education: behaviorism and constructivism. Behaviorism is a philosophy of learning which proposes that the mind is not directly observable. According to Skinner (*11*), learning is measured in terms of responses given to various stimuli. In the behaviorist learning framework, students' behavior, molded by the consequences of past experiences, could be manipulated or programmed by those who presented the material. The idea that students can be programmed implied that student learning depended solely on how capable the instructor was. Gilbert et al. (*12*) described the behaviorist perspective as one in which learners possessed "blank minds," tabula rasa, which were subsequently "filled" with "teacher's science knowledge."

Herron and Nurrenbern (*10*) pointed out that the work of Jean Piaget helped to develop the philosophy of learning known as constructivism. Jean Piaget was a Swiss psychologist whose life was spent investigating cognitive development and its application to learning. According to Wadsworth (*13*), Piaget maintained that humans traverse four stages of cognitive development from birth to adulthood. The first level is the sensory-motor stage that ranges from birth up to two years of age. This stage is marked by initial reflex action, followed by coordination of vision and touch, by object permanence, by problem solving through experimentation, and then an ability to solve problems using mental activity. The second is the preoperational stage that lasts up to age seven. During this time, the child becomes able to recognize events by thinking about them instead of relying solely on sensory-motor actions. During the preoperational stage, the child is egocentric, develops a spoken language, and is unable to acknowledge transformations – that is, to follow a procedure from beginning to end and note all the different steps along the way. The third level, known as the concrete operational stage, is marked by ages up to 11 years old. In the concrete operational stage logic, reversibility of mental operations and the ability to solve conservation problems begin to emerge as long as the objects being thought of are permanent or concrete. The fourth level is the formal operational or abstract stage. This level of mental capability begins at 12 years of age. It is marked by the ability to think and operate logically on ideas and concepts that are not necessarily founded in real, tangible objects. It is during these last two Piagetian stages that a student begins to make sense of the world. The transition from adolescence to adulthood is marked by periodic swings between the concrete and formal operational stages as new knowledge is learned. During this transition, the student begins to construct an understanding of the natural world.

Based on the constructivist philosophy, Herron and Nurrenbern (*10*) noted that instructional methodologies must shift from focusing on what science content the teacher knows to what mental constructs students form from the teacher's instruction. Treagust et al. (*14*) explained that the constructivist paradigm suggests that instructors cannot transfer knowledge directly to the minds of students. Teachers must carefully create labs so students construct their own meaning of a phenomenon. This gives students ownership of learning rather than "borrowship" of knowledge from the teacher.

Students have already developed ideas of how or why an event occurs before they begin a lab. Wandersee et al. (*15*) noted that learners of all ages, cultures and abilities come to instructional settings with a broad set of homemade explanations about how natural events occur. These alternative conceptions are tenacious and are difficult to correct. Teachers need to begin instruction by considering what students already know and understand. Ausubel (*16*) stated, "The single most important factor influencing learning is what the learner already knows. Ascertain this and teach him [sic] accordingly." Eaton et al. (*17*) pointed out that students' prior knowledge has a bearing on the effectiveness of a teacher's instruction. If students' prior ideas are not scientifically sound, understanding of science concepts could be hampered.

Misconceptions and Learning

Students' initial concepts are sometimes at odds with what the scientific community considers acceptable. Such concepts are often difficult to change by instruction. The pre-instruction ideas of students have been called alternative conceptions (*15, 18*) and naïve ideas (*19*). The most common term used for a non-scientific idea is misconception (*17, 18, 20, 21*). The term misconception suggests an illogical explanation for a phenomenon, which would be illogical to the scientifically-literate person. A misconception to a scientifically-literate person may not be a misconception at all to students who have limited scientific knowledge. Students may see their own ideas as simpler and more-useful alternatives to scientific explanations.

Wandersee et al. (*15*) noted that scientifically-inadequate concepts are often similar to ideas proposed by previous generations of scientists and philosophers. A similar observation was made by Harrison (*22*) who noted that the idea that matter is continuous correlates to the Aristotelian concept that lasted for nearly two millennia. Wandersee et al. (*15*) also pointed out that teachers sometimes hold the same misconceptions as their students, such as, gases have no mass or if an object is traveling at a constant velocity, there is a net force on that object. They asserted that teaching methods aimed at conceptual change can be effective. Teachers who are aware of student misconceptions can tailor instruction to modify nonscientific ideas.

Chemistry-Related Misconceptions

Fensham (*23*) pointed out that a number of chemistry misconceptions existed in students whose ages ranged from 12 to 15. One misconception noted was that solids, liquids and gases are not made of particles. Another misconception was that water is a mixture of hydrogen and oxygen. He also stated that "college graduates who have studied chemistry extensively" also have persisting misconceptions. Students believed that substances such as rust can be separated into rust atoms. Others, according to author, believed that boiling water turned water into hydrogen and oxygen just as electricity can be used to make water turn into hydrogen and oxygen. Fenshem also indicated that some students believed that matter is continuous.

Misconceptions have been noted in the areas of density, kinetic theory and chemical reactions. Roach (*24*), using a series of short-answer quizzes, found that her students equated density with thickness, heaviness or size. She found that some students believed that a large lead fishing weight had a greater density than a small lead fishing weight. She determined that when students had more opportunities to test, to explore, and to discuss the concept of density, they demonstrated a better understanding of the topic.

Researchers have investigated student misconceptions about the particle nature of matter, which is also known as the kinetic theory of matter. Nakhleh (*21*) reported that some students think matter is continuous rather than being composed of tiny particles with empty space between them. She also noted that some students explain the expansion of heated objects by the actual enlargement of particles. Mas et al. (*25*) reported results from a survey they conducted using students ages 12 to 18. These students held the misconception that gases are massless and are subsequently weightless. Novick and Nussbaum (*26*) reported that sixty percent of the university students in their study had the misconception that air, oxygen, vapor or pollutants exist between air particles.

There are misconceptions about the nature of the particles when a liquid boils. Osborne and Cosgrove (*27*) found that 33% of the 17 year olds in their survey believed the bubbles emerging from an electric heating element submerged in a pot of water were steam, 35% said the bubbles were oxygen and hydrogen and 20% said the bubbles were air. Bodner (*28*) found that 20% of 120 students entering graduate chemistry programs said that the bubbles in water that had been boiling for an hour were air or oxygen, and 5% said the bubbles were a mixture of hydrogen and oxygen gas.

Students have demonstrated misconceptions about chemical reactions and chemical changes. Hesse and Anderson (*29*) found the misconception that heat and cold were material objects in chemical reactions. They also found a common misconception that mass did not have to be conserved in chemical reactions.

Watson et al. (*30*) found that students had misconceptions about burning or combustion of a candle. Some students thought that combustion involved the wax just changing states of matter, a process they called modification. Other students thought when a candle burned, its wax simply turned into a flame, a process the authors called transmutation. They noted that a "low number of students gave 'chemical reaction' explanations in which atoms rearranged to form new combinations."

Conceptual Change

A goal of science instruction is to help students change from using incomplete or faulty concepts to accepting explanations that are scientific. According to Piaget (*31*), when a person first experienced a new phenomenon, the individual tried to add the new knowledge to his or her existing set of knowledge or schema for that phenomenon. If the person successfully connected the new experiences to existing knowledge, he called that process assimilation. If the new knowledge did not fit, either a new schema or knowledge framework had to be created or an existing one had to be modified. He called that process accommodation. In a discussion of conceptual change, Duit and Confrey (*32*) noted that conceptual growth, correlating to Piaget's assimilation, was a process whereby new knowledge only added to existing understanding. They called conceptual change, which correlated with Piaget's process of accommodation, a process whereby new knowledge did not fit with existing knowledge and the mind restructured itself to make sense of that new knowledge.

Posner et al. (*33*) offered their description of conceptual change. For accommodation to occur, they suggested that the learner must first become dissatisfied with existing conceptions. The new conception must be understandable, must adequately explain the phenomenon, and the conception must open new grounds for study.

Nussbaum and Novick (*34*) noted that students come to class with ideas that are largely incapable of explaining phenomena in a manner consistent with how the science community explains events. If students do not experience conceptual change during instruction, they will leave the classroom retaining their initial ideas. Nieswandt (*35*) asserted that for conceptual change to occur students need to be aware of their own explanations of science phenomena and they must compare them to accepted scientific concepts. He pointed out that once students recognized the discrepancy between scientific evidence and their own conception, they changed superficial explanations to more-scientific concepts. Conversely, Chinn and Brewer (*36*) pointed out that students responded in alternate ways when they are introduced to scientific concepts. Students modified the concept before accepting it, or they ignored, rejected or disbelieved it.

Nussbaum and Novick (*34*) emphasized that teachers may not have realized their students had misconceptions, or they may have assumed that students' misconceptions were cleared up by instruction. Eaton, et al. (*17*) held the view that effective instruction is not merely the presentation of scientific information. They suggested that it was unreasonable to expect students to develop or discover the knowledge on their own through discovery labs. The teacher needed to provide instruction aimed at directly contrasting scientific concepts and student misconceptions. By teaching this way, the teacher guided the students to achieve conceptual change. Moog and Farrell (*37*) pointed out that the instructor's role is one of instruction designer and learning facilitator so students could be active in gathering, organizing and analyzing data.

Techniques to Effect Conceptual Change

Hewson (*38*) pointed out pedagogical techniques which helped bring about conceptual changes in students. One technique was for the instructor to elicit student ideas rather than being the only one providing ideas. This gave students a sense of being contributors to the education process rather than being merely receivers of information, and it conveyed to the class that student ideas were welcomed and respected. He recognized that this allowed students to compare ideas and be receptive to ideas presented by other people.

Another pedagogical technique proposed by Hewson (*38*) was for the instructor to present activities that caused students to examine the usefulness of their own ideas. This technique of metacognition caused students to think about their thinking. He believed that teachers who used student metacognitive techniques in class brought about a greater level of conceptual change compared to those who did not. Clough (*39*) agreed with Hewson that teachers should encourage students to contemplate what they are thinking about, especially as it related to labs. Clough said, "effective laboratory experiences are highly interactive and make explicit students' relevant prior knowledge, engender active mental struggling with that prior knowledge and new experiences, and encourage metacognition."

While McDermott's work (*40*) specifically targeted introductory physics instruction, her comments have a broader application to all science instruction. She suggested that the key to conceptual change for the students is not in the ability of the lecturer or the clarity of the lecture but is in the level of intellectual activity of the student. She pointed out that instruction needs to focus on what the student already knows, and the design of the instruction should be such that students "go through the reasoning involved in the development and application of concepts." The author proposed that students be presented with activities with which students are likely to have conceptual difficulty. She further suggested that conceptual change occurred when students are forced to "*confront* and *resolve* the issue." McDermott admitted that such a method of instruction involved more time than the traditional instructional approach, and that this approach limited the topics an instructor could cover in a course, but it was necessary if students were to experience conceptual change. She added, "unless we design instruction to meet the needs and abilities of students, efforts to update the teaching of introductory physics will produce little of either intellectual or motivational value."

One technique that has been used successfully in helping students in metacognition and conceptual changes is the concept map as proposed by Novak (*41*). A concept map is a diagram using related terms or phrases written in boxes or ovals. These phrases are interconnected with lines having connecting words on them. As students increase their conceptual understanding of the topic, the interconnectedness becomes greater because students see how the pieces of the topic fit together. Pendley et al. (*42*) used concept maps to assess understanding. By comparing pre-instruction and post-instruction concept maps for a group of graduate students, they noted that students corrected misconceptions after performing labs.

Nieswandt (*35*) used class discussion and individual writings to monitor students' conceptual change regarding chemical reactions. The two aspects of chemical reactions were the changes in physical properties of substances accompanying chemical changes and the process of combustion. She discovered through their writing that students changed from naïve to scientific explanations of their understanding of a chemical reaction after performing three activities that addressed physical changes accompanying chemical changes. However, the author noted in students' writing that they reverted to their initial misunderstanding of combustion on the third activity after indicating a conceptual change following the performance of only one activity. Nieswandt pointed out that this showed the tenacity of misconceptions.

Successful questioning has been used to help bring about conceptual change. Torrance (*43*) pointed out that Socrates effectively asked his students questions. Socrates asked his students first to explain a phenomenon. Then, through further questions, Socrates led his students to experience cognitive conflict. The students subsequently recognized conceptions that needed changing.

Roach (*24*) used two methods to successfully bring about conceptual change. She found, by using pop quizzes and reteaching material, that students demonstrated a better understanding of the concept of density. Roach suggested that by giving a student more experiences "through experimentation, discussion and processing time, the greater his or her understanding became."

Problem solving helps to bring about conceptual change. Nurrenbern and Pickering (*44*) tested 331 general chemistry students' problem-solving abilities using diagrams. They found that students were able to solve problems using an algorithm but were less capable of solving problems using diagrams of particles. Nakhleh (*45*) used particle diagrams, drawings composed of various shapes to represent particles of a material, to identify conceptual thinkers in general chemistry classes. Her research indicated that more students were capable of working problems using an algorithm than by thinking of the problems in terms of particle behavior.

Conceptual change can be brought about by the sequence in which an instructor explains a concept. Gabel (*46*) pointed out that chemistry instruction was more effective in producing student understanding when students studied the macroscopic world first, then explained the phenomenon using the particulate nature of matter. Her reasoning was that chemists are capable of communicating about matter on the macroscopic, particulate, and symbolic level using chemical symbols, formulas and equations, but novices thought about phenomena on the macroscopic level only. She argued that if a student had a physical or visual model such as a particle diagram representing a balanced equation, the student was more likely to make the mental association of the concept with the symbols.

Lewicki (*47*) recognized the importance of conceptual change and suggested that the teacher play the role of an antagonist. That is, the teacher could persistently question a student about an issue and challenge the student to defend his or her ideas. The instructor's work is to provide events where students become dissatisfied with their existing conceptions.

Nussbaum and Novick (*34*) were convinced that an essential factor in conceptual change was for students to become aware of their initial ideas. They pointed out that teachers need to ask students to predict what they thought would happen when a given situation occurred and to give the reasons for their predictions. By having students make initial predictions with explanations at the outset of the new lesson, students were given an opportunity to explore with their understanding. Teaching strategies used by Nussbaum and Novick (*34*) to bring about conceptual change began with an "exposing event" to evoke students' preconceptions. Pictures and discussions were used to defend students' positions. The teacher encouraged student discussion or even debate so clarification and ownership could be given to student ideas. Next, the authors introduced a discrepant event to cause conceptual conflict in the students' minds. Student ideas that were built on misconceptions could not explain what students observed. At this point, students were prepared to search for a model that could successfully explain the phenomenon. The pedagogy paralleled that of the CPU Project (Constructing Physics

Understanding in a Computer-Supported Learning Environment Project) (*48*). This was a program designed to teach physics concepts using a conceptual change model. The CPU Project was aligned to the National Science Education Standards (*49*) and the Benchmarks for Science Literacy (*50*).

Specific Examples of Conceptual Change

Ben-Zvi et al. (*51*) were interested in changing students' misconception that properties of individual atoms were the same as properties of a sample containing large numbers of the same atoms. For example, a copper atom was thought to conduct electricity because the bulk material conducted electricity. The authors developed and administered a teaching unit to a treatment group of 540 students using the historically-changing picture of the atom as its foundation. The control group of 538 students received traditional instruction based solely on the modern view of the atom. Students were given a list of properties of matter and were asked to identify the properties that a single copper atom would have. Students who were taught the historically-changing view of the atom were more capable of distinguishing properties of single and multiple-atom groups. There were, however, still properties such as electrical conductivity and color that were attributed to individual atoms by the treatment group. This result suggested that, even with instruction, students had difficulty comprehending such concepts.

McGoey (*52*) conducted a study in which students explored the kinetic theory. Students were given drawings and a brief description of a lab activity. They were asked to make predictions about the outcome before the activity was done. For example, students were asked to predict what would happen to the mass of a volumetric flask sealed with a balloon if it was placed in hot water. Students were required to provide both a prediction and a reason for the prediction. One prediction was that the air totally exited the flask and entered the balloon. The author labeled this concept "Hot air rises." Students also explained their predictions by stating that objects such as doors get larger when they are hot. Students said, "You put hot water in the beaker and the balloon fills up with hot air." The labs in this study were discrepant. Students realized their initial ideas did not adequately explain their observations.

Different Pedagogical Lab Styles

Various styles of lab instruction have been used in order for students to investigate the natural world. Several of the styles were based on inquiry. According to the Exploratorium Institute (*53*), inquiry is "an approach to learning that involves a process of exploring the natural or material world that leads to asking questions and making discoveries in the search for new understandings." Herron (*54*) has identified three inquiry lab styles. Structured Inquiry is a pedagogical style where students investigated a teacher-presented question through a prescribed procedure. Guided Inquiry is one where students investigated a teacher-presented question using student designed/selected procedures. Open Inquiry is the style where students investigated topic-related questions they formulated using procedures they designed or selected themselves. A fourth lab style, not based on inquiry, is called Confirmation or Verification. According to Herron, the Confirmation or Verification style is one in which "students confirm a principle through a prescribed activity when the results are known in advance."

Purposes of Lab Instruction

A lab component has been part of science classes for many years. Siebring and Schaff (*55*) pointed out "the early stages of development of laboratory instruction were influenced to a large degree by the Americans who studied at the German universities in the latter half of the 19th century." According to Kapusincinski (*56*), a lab component in a chemistry class was added at Harvard University in 1886, so students could begin their study of chemistry with observation.

Different purposes of lab instruction have been reported in the literature. Smith (*57*) wrote that the purpose of lab instruction is for the student to develop critical thinking skills, to gain interest in science, and to better understand methods and processes used by scientists. Stekel (*58*) pointed out that labs provide concrete experiences for concept learning and give students experience in empirical testing and experimentation.

Amend and Hermens (*59*) described the science lab as a place where students were presented with "opportunities to think about, discuss, and solve real problems" as they verify known scientific principles. Another purpose of labs was to "allow each of the students to devise and evaluate his or her own recipe, rather than following the "cookbook recipe" of traditional science labs."

A survey by Abraham et al. (*60*) reported lab goals of 199 general chemistry programs at U. S. colleges and universities. In summary, labs were intended for students to learn concepts and scientific processes, gain lab skills, develop positive attitudes, and know facts. Eighty-nine percent of the departments in the survey claimed that lab quizzes or exams stressed mastery of concepts. Students, according to the survey, stated that they believed that the main purpose of labs was learning facts. The survey further indicated that in introductory chemistry lab courses, most were step-by-step exposure and verification-type labs. This study showed that students were seldom allowed to go beyond the scripted labs for further investigation. Students were not asked to identify the problems to be investigated.

Abraham et al. (*60*) pointed out that traditional lab formats allowed concepts from the lecture to generate data. This is a deductive use of labs. In inquiry-style labs, the data obtained from experiments lead the student to generalize observations. This is an inductive use of the labs. This survey indicated that only eight percent of the colleges and universities who participated in the research used the inductive method for chemistry labs in 1997.

Pickering (*61*) questioned the value of lab courses. He argued that labs have little ability to illustrate content of the lecture because scientific content, built on results of numerous experiments requiring months or years to conduct, cannot be taught in a two or three hour lab period. Further, he pointed out that the manipulative skills taught in labs, such as dissection for biologists or titrations for chemists, are seldom used by professional scientists. In their present state, the purpose of a lab is to verify what students already know. As a lab coordinator in the Department of Chemistry at Princeton University, the author recognized that "good lab teaching is essentially Socratic. It is the posing of carefully defined questions to be asked of nature." Through mental engagement, students learn that it is difficult to get unambiguous results. He noted that verification labs do not confront the student with what is unknown in science. Labs have been reduced to obtaining a result whose value is already known. Labs could be enhanced such that good grades would not be based on how well the notebook was kept or how closely the accepted answer was obtained. Pickering suggested students be given open-notebook quizzes where they could retrieve observations from their lab notes or where they could use their notes to answer hypothetical questions that were extensions of the lab.

Hofstein and Lunetta (*62*) were suspicious of claims touting the superior learning gains of the lab over more-conventional methods of classroom instruction. They admitted that lab activities have the capacity to promote development of logical thought, inquiry and problem-solving skills. Lab activities can also promote observational skills, technical skills, positive attitudes toward science and help students develop cooperative and communication skills. However, they believed that more research was needed to corroborate the reported successes. These researchers suggested there were many variables that still needed to be controlled. These variables included the use of stricter experimental design, more specific assessment instruments, and a closer monitoring and categorizing of lab instruction.

Objectives of Physical Science and Chemistry Lab Manuals and/or Activities

Long and Long (*63*) wrote an in-house physical science lab manual for Columbia State Community College. They stated that their labs gave students experience in "making experimental measurements and attached numerical meaning to physical concepts addressed in the classroom." They also stated their labs provided students with opportunities to "develop technical skills and allow students to verify that physical principles and mathematical models studied in the classroom correctly predict physical behavior."

Todd proposed (*9*) to help students better understand attitudes scientists needed and how scientists solved problems as they worked. Another goal proposed by Todd was for students to get a realistic sense of scientific laws and theories. Todd claimed that the labs were designed to help students develop written communication, listening and mathematical skills.

Tillery (*64*) claimed his physical science lab manual was "designed to provide a hands-on introduction to experimental methods for scientific investigation." These methods included measuring physical quantities and drawing generalizations from the data. He advised students to concentrate on their work so the data they collected would be accurate. The author told students that they would be "solving problems and working out conclusions." He added that results from some of the experiments would be "compared to some value derived from theory."

Tillery et al. (*65*) told students who used their lab manual that they would have an "opportunity to 'get your hands on science' beyond the reading and enter the process of doing science." This manual had both traditional labs and a section containing "open-ended *Invitations to Inquiry.*" This latter feature was an additional investigation at the end of each lab. Students were reminded that these investigations would come with "less student support" and were expected to be completed by "more mature students." The aim of these inquiry activities was for the student to "discover for yourself" scientific principles.

New lab manuals have been designed which are more learner-oriented. The lab manual, *Inquiries into Chemistry* by Abraham and Pavelich (*66*), was designed to provide guided-inquiry chemistry lab experiments. The authors pointed out that lab experiments serve the purpose of acquainting the student with lab techniques and procedures used by scientists. They went on to stress that the labs in their manual were also designed to give students an opportunity to practice basic processes that scientific researchers use, such as interpreting data, forming and testing hypotheses and generating explanations. An example of the guided-inquiry lab format design was illustrated in the lab on acids and bases. In every case, the authors used a Data Collection – Data Analysis – Interpretation format.

Bauer et al. (*67*) designed their inquiry-based chemistry lab manual so students would acquire problem-solving skills while learning lab techniques. They expected students to use critical-thinking skills that practicing chemists use and develop skills such as the capability to communicate ideas, negotiate with others, and value the contribution of all group members. The authors noted that they had "removed the recipes" often associated with chemistry lab manuals so students would plan their own methods of investigation to solve the problem or answer the question of each lab. Their lab manual was designed so that four-student lab groups would learn to function effectively in a team-structured environment. During the semester as they conducted various labs, students would rotate between the duties of being the team leader, assistant leader, data collector and the experimental technique expert. Each activity in the lab manual began with a background story and a problem to be solved. Students were told the goals and materials for the activity. They were also given general background information regarding the subject of the lab along with safety precautions. Students were not given detailed procedures to follow, but they were told they could use their chemistry text, fellow students, the library and the Internet to get ideas of how to solve the problems. The labs were designed to last up to two weeks if the instructor so desired. Students designed the experiment during the first week, deciding as a group what information they needed. Students conducted the experiment in the second week. Students also were required to write detailed lab reports of their experiment.

Pickering (*68*) commented on the design of chemistry labs used at Princeton. He suggested that labs should be structured like puzzles with elements of adventure and surprise incorporated in the labs rather than having students just confirm what is already known. The labs should occasionally include topics that are not completely understood by either the teacher or the student. This gives the student a sense of making a scientific contribution. Lab reports are graded on both the quality of the report and the completeness of the conclusions drawn. Students are not allowed to bring a lab manual into the lab, but they must record a succinct procedure in their lab notebook before they begin the lab. Lab reports are graded on an "accepted," "accepted with varying degrees of correctness," and "rejected" basis. Students enjoy the option to resubmit their lab reports, albeit once, with corrections. To encourage students to keep good lab notebooks and record observations, there is an open-lab notebook exam at the end of the semester along with a practical exam. Pickering reported that students have not grumbled about the nature of the chemistry labs. He cited the helpful nature of the teaching assistants as a contributing factor in the success of the labs at Princeton. He added, "the challenge in teaching is not to take an easy subject and make it fun; it is to take hard subjects and make them learnable."

The Guided Learning Lab Instruction Method

The guided learning instructional method combines both the science content and pedagogical knowledge of the teacher and the capability of the student to think and understand the physical world. Billett (*69*) defined guided learning as a "process through which more-experienced individuals aid learners in the problem-solving process." This provided the learner an opportunity to develop an understanding the phenomenon while a mentor was nearby to guide the novice as he or she learned.

Ojemann and Pritchett (*70*) defined guided learning as a process in which the teacher purposefully designed an environment so the learner would reach an intended conclusion. They illustrated guided learning by describing a scenario where elementary students were studying about objects floating in water. Serving as a guide, the teacher provided a variety of objects for the class to use to test their original idea. The teacher also provided demonstrations of objects floating in water and hinted that they should try to see "if the weight of water displaced had anything to do with the problem."

Evans and Omaha Boy (*71*) described a guided learning technique in which the lecture was replaced by study sheets in a non-science major's biology course. An alternative to the lecture format was tested to see if grades would increase and student interest would improve. Students were given prepared study sheets to accompany reading assignments and to guide students' learning. Class began with a 30-minute question/answer period and then students took a 45-minute test and received immediate scores. A break followed the test. During this time, students met with the instructor and discussed the readings. Those who wished were allowed to take another test that same evening. Students satisfied with their grades did not have to stay for the second exam. The higher of the two scores was accepted. They reported that student grades improved and students came to class with fewer, and more-specific, questions. These researchers believed that the use of reading guides helped the student study the material more thoroughly. They also believed that the study guides also helped students focus on what questions they needed the instructor to answer.

Osterman (*72*) described a guided learning methodology in which written guides were used to help students follow the flow of the lecture. The lectures were segmented to give students time to answer prepared questions while the instructor moved among and interacted with the students in the class.

Comparing Traditional (Verification) Labs to Student-Centered Labs

Ivins (*73*) listed five different types of labs. These types are: exposure, verification, guided discovery, teacher-created problem, and student-created problem. Exposure labs introduced students to new techniques or observations such as how to use a triple-beam balance, microscope or a spectrophotometer. A written guide for the exposure labs served as an instruction manual and required no formal reasoning. Verification labs had students replicate known experimental work. A lab book that gave a problem statement, expectations of results, and explicit procedures to follow usually guided students. Verification labs were designed to be used after content had been introduced in the lecture. In guided-discovery labs, students obtained the procedures from either the lab manual or the instructor, but the students could not anticipate what the results of the experiment would be. In guided-discovery labs, students had to decide when they had obtained the correct answer. Guided-discovery labs were designed to be used before content was introduced in the lecture. The fourth type of lab was a teacher-created problem lab. This kind of lab could be an extension of an activity already done. In the teacher-created problem lab, the lab instructor decided what direction the students had to take but left the procedures up to the students. The student-created problem lab is one where the student chooses a problem to investigate and to solve. This type resembled the work of research scientists where the student had to decide on the problem, procedure and when the answer had been obtained. Ivins noted that traditional labs are usually exposure and verification labs. These two lab styles are favored by instructors because they often have only one correct result, which makes them easy to grade. Exposure and verification labs are also easy to predict how long the labs will take to finish. With these types of labs, equipment needs are also easy to predict.

Spears and Zollman (*74*) pointed out two different lab instructional styles. The first style emphasized verification of physical principles covered in lecture by having the student follow detailed procedures. The second type of lab instructional style used inquiry or discovery techniques whereby students invoked creativity to design and implement a plan to discover the principles discussed in the lecture.

Traditional labs have been described by Stekel (*58*) as those where students measured a physical quantity or validated a principle using lab apparatus and following detailed experimental procedures given by the instructor or institution. Allen et al. (*75*) described verification labs as those in which students followed a prescribed set of instructions to confirm principles taught in the lecture or to determine an accepted value, such as *g* equals 9.8 m/s^2. The authors pointed out that some students could read and carry out the instructions in traditional labs and still not be conceptually challenged.

Hilosky et al. (*76*) defined "cookbook" labs to mean "following detailed printed directions." They emphasized that students seldom read the directions, preferring to rely on oral instructions from the teacher. They noted that in the United States, so much time is consumed in general chemistry labs following directions that it "takes away from time students could be engaged in higher-order cognitive skills." Ausubel (*77*) commented that it is "self-evident that performing lab experiments in cookbook fashion, without understanding the underlying substantive and methodological principles involved, confers precious little meaningful understanding." Hanson (*78*) related an instance in which a student asked his colleague to explain what a reaction was. The colleague turned the question around and asked what the student thought a reaction was. This student, who was accustomed to cookbook style labs, told his professor, "You don't have to think in lab!" Clough (*39*) remarked that "(p)re-fabricated cookbook activities, so ubiquitous in science teaching, rarely engaged students in ways necessary to facilitate an understanding of the scientific community's explanation for natural phenomena."

Hanson (*78*) noted that there are reasons why students do not think highly of labs. He said that students have the following views: "Laboratory seems so detached and it does not always synchronize with lecture"; "There are difficulties with laboratory grading"; and "Laboratory work is dull and boring." Hanson suggested that negative sentiments regarding verification labs could be improved if "we simplify procedures, reduce the amount of time spent in *doing* and put more emphasis on reflection and evaluation of results."

Hilosky et al. (*76*) investigated introductory chemistry lab styles at sixteen colleges and universities in the United States and one in Germany. They found that in the United States, activities in the lab were instructor-controlled. Students depended on the instructor for directions of how to proceed. The flow of the lecture was typically independent of the lab, and logic and thinking were not addressed in the labs. In the German university, the instructor was seldom present and students were expected to get procedural information from the literature or to design their own procedures. The first-year chemistry courses in Germany were largely lab driven and students interacted with the instructor to discuss theory.

According to Pavelich and Abraham (*79*), most commercially-available lab manuals contained verification labs in which students confirmed concepts presented in lecture. In these activities, students were provided with the theory, the exact procedure to follow and were told how to analyze the data. They claimed that since so much procedural information was provided, students did not need to do any independent, abstract thinking. Verification labs did not give the students adequate practice in data interpretation, hypotheses formation or hypotheses testing. In contrast to verification labs, the authors' guided-discovery labs were used as an introduction to a concept and were designed to solve either teacher-created or student-created problems. This style of lab placed more responsibility on the student with less direct guidance by the teacher. However, guided-discovery labs were not easily implemented in a lab setting where limited time was a factor. Students benefited when they used guided-discovery labs.

Students developed a personal interest in the problem and took ownership of the analysis they made. Students also enjoyed a sense of testing their ideas and making modifications where appropriate. As a result, guided-discovery labs provided students with first-hand experience of the way scientific knowledge is acquired.

Lewicki (*47*) compared the constructivist lab instructional method to verification-type labs. The treatment labs had four components. The first component was conceptual integration in which the concepts of each lab were incorporated into later labs. The second component was student inquiry. Students were encouraged to identify and explore solutions to problems. The third component was the use of guidance to promote conceptual change. The instructor asked questions to make sure the student was certain of what he or she was saying. The fourth component was social interaction. Students who talked to others about what they were learning promoted their own learning and developed appreciation for their own actions and the work of others in their group.

Stekel (*58*) examined the effects that two different styles of lab instruction had on students' understanding of science content and processes, critical thinking abilities, attitudes toward science and retention of science knowledge content. The two types of instruction were called traditional and open-ended. In traditional labs, students followed pre-set directions to confirm a physical value or principle. In open-ended labs, students were given the general topic for the experiment and the apparatus to be used, but students had to make decisions about which procedures to use and how to analyze the data. The treatment lab group developed a better understanding of scientists' skills such as observation, measurement and experimental design when compared to students in a traditional lab program. The two groups, however, were equivalent with respect to critical-thinking ability, improved attitudes toward science or retention of science concepts. Stekel claimed that labs which simply verify what the teacher or text claims were unlikely to help students learn concepts and do not represent the way scientific research is conducted.

Hilosky et al. (*76*) pointed out that "inquiry-based laboratory experience did result in significantly improved cognitive and noncognitive content learning." They observed 24 introductory chemistry labs being conducted and cataloged the behavior of instructors and students. The most frequently observed teaching strategies did not promote higher-order thinking skills. These strategies included instructors monitoring student activity in the lab and discussing the lab procedures with individual students or the whole group. Teaching strategies designed to enhance higher-order thinking skills, such as adjusting student misconceptions or listening while students explained science concepts, were "infrequently used." To reform chemistry labs from verification or cookbook style to an inquiry style, the authors recommended that colleges and universities should reduce the number of required investigations and use the outcomes from labs to drive the content of the lecture. Reform efforts should also include helping instructors learn how to be facilitators instead of information dispensers. Assessments should be redesigned to test student learning rather than judging a student's performance on a lab based solely on a percent yield of product or a percent error relative to an accepted value. They also noted that adding topics of study that are of current interest did not constitute lab reform.

Physical Science Labs

Spears and Zollman (*74*) used the Science Process Inventory (SPI), by Welch (*80*), to measure the effectiveness of the structured versus the unstructured labs on students' abilities to discern areas of assumptions, activities, nature of outcomes, and ethics and goals. The students in structured lab group received procedures outlining how to solve the problem while students in the unstructured lab group did not receive any explicit directions on how to solve the problem. Both groups were expected to draw conclusions from their data.

Both groups' scores were statistically equivalent on the SPI in the areas of assumptions, nature of outcomes, and ethics and goals. However, the researchers discovered that students using the structured lab methodology performed statistically better on the activities portion of the SPI than those in an unstructured lab that covered the same experiments. Spears and Zollman (*74*) explained the results by suggesting that the students in this study "did not as yet apply formal-operational processes to physics." The researchers noted that students in the unstructured labs seldom went through the sequence of observing, building and testing models. They observed that students in the unstructured labs also "seldom hypothesized or predicted because they were not intellectually prepared to do so." Typically, the results of their labs were simply descriptions of observations, occasionally referring to the theory from the textbook. The researchers noted that these students were operating at Piaget's concrete-operational stage. The results indicated that students in unstructured labs needed guidance in developing their processes of science background before they performed as independent researchers.

Burron et al. (*81*) studied the effects of cooperative learning, or group learning, on student achievement, collaborative skills, and attitudes about the course for preservice teachers in a physical science lab. All 51 students were in the same lecture. The class was divided into two lab sections with 24 in the cooperative-learning group and 27 in the traditional lab group. The treatment group was instructed to use specific cooperative-learning skills such as addressing members of a group by name, encouraging ideas from group members, paraphrasing and summarizing of ideas presented and active listening. Students assumed roles such as reader, questioner, checker, or summarizer to encourage cooperative learning. Student groups in the traditional lab developed their own rules of group conduct. The groups were scored on items such as individual contributions of ideas to the group, encouragement of ideas from others in the group, time on task, active listening, paraphrasing, and group decision making. The authors discovered that both groups were statistically equivalent when academic achievement on course content and lab skills were measured. A 28-item post-test and a 13-item essay lab exam measured course content and lab skills. The cooperative-learning lab section significantly outscored the traditional lab section on affective and social measures when students evaluated the relative strengths and weaknesses of the cooperative learning instructional style.

Increased student enrollment has created demands on colleges and universities to provide additional staffing, facilities and lab time for students in physical science. Crawford and Backhus (*82*) wanted to determine if alternate lab styles could alleviate some of the problems associated with increased student population at Kansas State Teachers College. The researchers examined the effectiveness of three different types of college physical science lab styles. One was a traditional, highly structured lab which met at a set time and had a lab instructor to give the students preparatory notes for the lab. The second provided lab instructions using a brief audiotaped lecture, and it allowed the students to come to lab when it fit the students' schedules. During this "audio-tutorial free lab" style, a lab supervisor was present during those sessions but did not teach the lab. The third style was one in which students could check out minimal equipment or use simple equipment at home or in the residence hall to complete the lab assignment. This was called a "loosely-structured home lab."

All three styles were designed so students would learn the same science content. The researchers used both instructor-written unit tests and the Test On Understanding Science, TOUS, (*83*) to assess the effectiveness of the lab styles. The results (*82*) showed no significant differences among the students in their knowledge of science, but students in the "audio-tutorial free lab" and the "loosely-structured home labs" scored significantly higher on their understanding of science, as measured by TOUS, than those in the highly-structured scheduled labs. The results of this research showed that when students are forced to understand procedures of a lab for themselves, they demonstrated that capability and developed an improved understanding of science.

Gunsch (*84*) conducted a study comparing a traditional lecture-demonstration format physical science college course to one using the Physical Science for Non-Science Majors (PSNS) (*85*) curriculum. The PSNS curriculum of the early 1970s was one in which students in a class performed experiments at their desks, such as the reaction between zinc and iodine, and discussed observations while being guided by the teacher. Students were free to use any equipment at the institution they needed to perform the experiments. Gunsch (*84*) noted that an unspecified number of students returned after class to repeat the activities, do follow-up activities, or to try additional experiments not prescribed in the course. The assessments in this project were multiple choice and short-answer teacher-created tests as well as the attitude survey called the Scientific Attitude Inventory (*86*). The result of this research was that students in the PSNS group performed higher than those in the lecture-demonstration class.

Smith (*57*) cited the problems of managing large class sizes, having to purchase costly apparatus and having to deal with a shortage of teachers as reasons why it was difficult to have physical science labs that actually promoted critical thinking. Vicarious experiments were proposed as a possible solution to these problems. He described vicarious labs as those in which students were given complete instructions to perform the lab and were also given the data from successfully-completed runs of the experiment. The methodology included having students manipulate data while conserving lab time and reducing the expense of purchasing multiple sets of equipment for students. Smith justified using prepared results of experiments rather than the student having to obtain the data firsthand. He commented that students often were given results of others' work by techniques such as "television instruction, simulation, and computer assisted instruction." He argued that physically gathering the data in the lab is less important in learning than in manipulating the data to obtain the answer to the problem being studied. The author suggested that providing students with valid data gave them more time for analysis instead of using possibly flawed data generated by the students. Smith noted that when vicarious experiments were used in physical science courses, colleges or universities would have to spend less money on equipment and supplies.

Smith (*57*) compared science content knowledge, critical thinking skills, attitude and IQs of students who were taking the general education course, Basic Education 60. The results of the comparisons indicated that the treatment group outperformed the control group in science content knowledge. The treatment group also outperformed the control group in critical thinking skills when the scores were adjusted to mathematically equilibrate reading and IQ ratings of the participants. The results also indicated there were no significant differences between the males of the two groups in their ability to do critical thinking. The results showed that females in both group significantly preferred the vicarious experiments more than the males did. The overall results from Smith's study suggested that learning in the lab is independent of the teaching methods used but is more related to student manipulation of data and its proper interpretation.

Stekel (*58*) compared the performance of students in traditional physical science labs to those who engaged in open-ended labs. He questioned the effectiveness of traditional labs when he observed that students engaged in traditional labs do not have to propose hypotheses or procedures but merely practice techniques used by scientists. He described open-ended labs as those in which students were given topics and general objectives. These students were given the freedom to design the experimental procedures and decide how to analyze the data. The author noted that these labs necessarily take more time, thus reducing the number of labs that could be performed in a semester. Open-ended labs made supervision more difficult for the instructor because in a lab, several different experiments could be taking place at the same time. Evaluation by instructors was also more difficult because it would be hard to objectively measure the thoroughness, correctness, and amount of science learned when different projects were being conducted simultaneously. He hypothesized that students who are more active in the process of experiment design would perform better. Students in the treatment group had more understanding of science processes such as observation, measurement and experimentation than did the control group. However, students in both groups were equivalent in critical thinking skills and on attitudes toward science. In a post-course test taken nine months later, there was no significant difference between the two groups on science content knowledge retention.

Chemistry Labs

Alternative chemistry lab formats have been used successfully in a number of studies. Pavelich & Abraham (*79*) changed their general chemistry labs to a guided-inquiry format that would acquaint students with techniques and procedures and would require students to use more abstract thinking. These new lab formats gave students more opportunities to interpret data and to develop hypotheses. To test the validity of this change, four lab sections (120 students) were taught using the verification style while 18 sections (540 students) used guided inquiry. The four chemistry concepts used in the study were: the constant composition of substances, laws governing heats of reactions, periodicity, and acid-base behavior. These labs had an exploration phase, an invention phase and a discovery phase. They used Piaget's Equilibrium in Balance and Flexibility (*87*) to measure abstract thinking ability. They concluded that guided-inquiry labs were just as effective as verification labs in helping students increase their abstract thinking. Students were given 25 statements to rank sequentially regarding their general lab experiences. Students were to identify the five most appropriate statements they believed were most descriptive of their labs, then the five most appropriate statements they believed were somewhat descriptive of their labs, etc. until they selected the five most appropriate statements which they thought were least descriptive of their labs. Students in the experimental group ranked first the statement, "Lab reports require the interpretation of data." The control group ranked first the statement, "Lab activities require students to solve problems." The experimental group ranked second the statement, "Lab reports require that students use evidence to back up their conclusions" while the control group ranked that statement thirteenth. The results indicated that the guided inquiry labs were more effective than the verification labs at acquainting students with scientific inquiry.

Herron and Nurrenbern (*10*) suggested that cooperative learning labs would move students away from rote memorization and toward learning that is meaningful. The cooperative learning labs would help students develop their interpersonal and communication skills. In labs that stressed student learning and conceptual understanding, teachers' roles have changed from being knowledge dispensers to facilitators of learning. To be successful, the authors asserted that instructors must be trained in inquiry teaching methods and that "students are given the time and guidance required to become comfortable with the new methods and expectations." Duit et al. (*88*) referred to the role of teachers of inquiry labs as that of a mentor and sometimes a cheerleader. An instructor in inquiry labs was seen to be more than one who just monitored for safety or one who simply gave students instructions.

Bodner et al. (*89*) noted that students have become frustrated because they are often asked to perform labs which are not well understood. Students are subsequently asked to explain underlying concepts. The authors described their research using discovery labs in a general chemistry course. The intent was to implement labs which would require students to be more mentally active. These discovery labs were designed to address just one question or concept. The activities were based on the predict-observe-explain (POE) technique outlined by White and Gunstone (*90*). The POE method was designed for students to predict the outcome of an event, justify the reasoning for their predictions, watch the phenomenon, and comment on any discrepancies between their prediction and observation. Students in the study by Bodner et al. (*89*) were given minimal information and instructions to carry out the investigation. Students were given questions to consider during the experiment. These students worked in small groups collecting data for different parts of the bigger experiment. The groups then pooled their results and discussed their findings as a class. This process took much more time than the collection of data. It was found that students who participated in the discovery labs performed equally as well as those who were engaged in the traditional labs. Students who participated in the discovery labs commented about having an improved understanding of the concepts covered and an overall improved attitude about chemistry.

Deckert and Nestor (*91*) described a guided-inquiry chemistry lab course which they developed. Its goals included guiding students toward more independent data analysis and interpretation and preparing students to be more mentally engaged in the course of the lab. This course underscored the benefits of collaborative work with fellow students. The authors required the groups to submit a proposal of how the problem was going to be solved prior to actually beginning the lab. By submitting this proposal, they noted that "students come to lab better prepared and they are more likely to be active participants during the lab." Success of the labs was shown by a heightened level of peer teaching. This was indicated by students who had successfully performed an analysis, helping team members who were having difficulty. The higher level of scientific writing the lab reports displayed compared to the illogical and poorly written reports from students of earlier classes also was a measure of success. In a survey of the 31 students who participated in this project, 55% said that the course had helped them to become more creative while 49% indicated they were encouraged to develop independence. Sixty-five percent of the students claimed to have a heightened awareness of lab skills and awareness of scientific research skills. Sixty-five percent of the students said they developed or improved interpersonal relationships such as negotiation and conflict-management.

DeMeo (*92*) designed an inquiry lab in which students investigated the density of an object. The students identified factors they thought might affect density. The lab instructor assisted the students in identifying those variables and helped students notice relationships among the data. From this activity, he pointed out the value of having the instructor guide the students to an understanding of density.

Cherif et al. (*93*) taught students about atoms, molecules, elements and ions and their relationship in chemical reactions. They used a variety of approaches, including hands-on activities, visualization, writing, demonstrations, role-play, and guided inquiry in their classes and labs. The researchers also placed an emphasis on writing so students could reveal pre-instructional knowledge. The writing forced students to develop and organize ideas as the lesson developed. While using reference materials and guiding questions, students participated in group activities that helped them develop an understanding of the information they received about atoms, molecules, elements and compounds.

Lewicki (*47*) developed constructivist-type labs for the treatment group to match the chemistry content of the verification-type labs for the control group. He interviewed three students from the control group and three students from the treatment group. These students were questioned weekly to see how they thought their knowledge was changing. The interviewed students were asked to comment on how the labs related to each other. They were also asked probing questions about chemical concepts learned in the lab. In addition to the analyzed transcription of the interviews, the subjects' pre-lab and post-lab quiz grades were used to assess the effectiveness of the lab types. The results of the research revealed that students in the constructivist labs readily recognized integrated concepts among the six labs. The verification-lab students only recognized similarities among the lab skills and techniques and not among the concepts of the labs. Students in the treatment labs indicated a belief that the labs played an important role in their understanding of chemistry. Students in the verification labs did not make the same claim. Interviewed students from the verification labs expressed disappointment in the lab experience. The verification lab students felt that there was little or no leadership from the teaching assistants to help the class discuss what had been done. The lab instructors had simply told them "here's how you do it, do it, and tell me what you get." From these results, Lewicki noted that at the very least, the constructivist method of conducting labs served as well as the verification labs.

Wulfsberg (*94*) realized that inorganic chemistry courses were being taught and learned as a body of disconnected facts, and that students and teachers alike were not particularly excited about the subject. In an effort to change the way inorganic chemistry was being taught, he taught descriptive inorganic chemistry based on classes of compounds (halides, oxides, etc.) rather than simply by studying groups of elements. This improved the way the material could be learned and understood because it was organized in a manner for students to see similarities among what he claimed could be otherwise viewed as "seemingly unrelated facts." He enhanced the labs for the course using a cyclic process of first exposing students to the new concepts through experimentation with materials, then developing the principles that explain the observed behavior, and then having the students apply the principles to new situations.

Wulfsberg (*94*) noted Piaget's theory (*31*) that humans pass through four stages of mental development, the last two being the concrete operational and formal operational stages. Wulfsberg recognized that not all university chemistry students were at the formal operational level of conceptual development. This assessment of university chemistry students' developmental preparedness was in agreement with Herron (*95*) who gave examples of university students who operate at the concrete operational stage. Wulfsberg modified labs for conceptual building and understanding. He reported that students scored more than two standard deviations above the normative mean in 1980 and one standard deviation above the normative mean in 1981 on the Graduate Record Exam Undergraduate Assessment Program. Further, the students gave high evaluation marks at the end of the course to the instructor, to the course and to the lab. The labs, though relatively simple, required the students to think critically and to be creative in designing simple experiments to test their ideas – something the students admitted was enjoyable.

Summary

This chapter briefly reviewed behaviorism and constructivism with emphasis on misconceptions students have in physical science and chemistry. The purposes of lab instruction and objectives of lab manuals in college or university physical science courses were examined, and lab pedagogies that addressed conceptual change were investigated.

CHAPTER 3

METHODS

Purpose of This Research

The purpose of this research was to test the effectiveness of a guided learning approach versus a traditional lab instructional style to determine student mastery of chemistry concepts in the physical science course (PSCI 1030). The three labs in the course that were modified were Density, Kinetic Theory and Chemical Reactions. Differences in the instructional styles were measured by comparing students' scores on pre- and post-lab quizzes, conceptual questions and post-course quizzes. Students' scores were compared for statistically-significant differences. This chapter describes the methods used to determine and compare assessment scores of students who engaged in both types of lab instruction.

The Student Participants

All students who participated in this research were students enrolled in Topics in Physical Science, PSCI 1030, at Middle Tennessee State University (MTSU) in Murfreesboro, Tennessee. The control group in this study was the group of students who participated in the traditional, verification lab format. The treatment group was composed of students who studied the same lab content material but who participated in the guided learning lab format.

This project involved 176 students of which 60 (34%) were in the treatment group and 116 (57%) were in the control group. The students were from three lecture classes for the treatment group and from five lecture classes for the control group. One instructor, Cook, allowed two different classes of his to be part of the control group in this project. One of his classes met during the Fall 2002 semester and the other class met during a May 2002 session. Differences in assessment scores for the 14-day course and for the semester-long courses for the control group will be discussed. There were no academic year treatment group classes. The data in Table 1 shows a breakdown of the number of participants in the treatment and control groups, the instructors for the courses and the sessions when the courses were taken.

Table 1. List of Sections Participating in This Research

Category	Lecturer	Session	Number of Participants
Treatment	Chong	June 2001	21
	Melton	June 2002	20
	DiVincenzo	June 2002	19
Total (Treatment)			60
Control	MacDougall	July 2001	14
	Devendorf	July 2001	1
	Cook	May 2002	22
	Ooi	May 2002	18
	T. Lee	July 2002	6
	Cook	Fall 2002	55
Total (Control)			116

Acquisition of Student Data

An IRB proposal was submitted to the MTSU Institutional Review Board. A copy of the IRB proposal is in Appendix B. The proposal included the nature of the research, the type of data that would be collected about the human subjects, how the data would be used and how the data would be kept secure. With the permission of the instructor, classes were selected to be included in the treatment or in the control lab group based on availability and convenience for this research to be conducted. Demographic data were collected to compare students in the two lab groups for similarities and differences.

On the request for student data, students were informed of the research, and they were insured that their privacy would be protected. The students affirmed that they would be willing participants. The students were informed that their performance on the pre-lab and post-lab quizzes would not affect their grade in the course. Participating students signed a consent form, which was part of the IRB proposal. A copy of the consent form is in Appendix C. In the consent form, students were asked to provide limited demographic data that included their gender, major course of study, age category, nature of high school attended, and math and science courses taken in high school. Students granted permission for their social security number to be used to obtain ACT Math, Reading, and Science Reasoning scores. Students were asked to provide their email addresses if they wished to participate in a post-course quiz via email. Participants were asked to provide a self-assessment of their academic preparation and to recall anything interesting about their high school science experience.

Common Procedures in Treatment and Control Labs

Each lab session began with students taking a pre-lab quiz. The pre-lab quizzes and scoring rubrics for the three topics studied are in Appendixes D, E and F. Following each lab activity, the treatment and control groups took a post-lab quiz similar to the pre-lab quiz. Since student participation was on a volunteer basis, not all students took the pre-lab and the post-lab quizzes. Only the scores for those students who voluntarily answered both the pre-lab and post-lab quizzes were included in comparisons of results for the pre-lab and post-lab quizzes. Copies of the post-lab quizzes and scoring rubrics for the Density, Kinetic Theory and Chemical Reactions are in Appendixes G, H and I respectively. Students in both groups were also asked to answer conceptual questions after each of the three labs was completed and to return these completed questions to their lecture professor the next day. Not all students answered the conceptual questions. Using the rubrics, students received minimal credit for attempting to answer the question and for providing a reason for their response. More credit was awarded for correct responses. Copies of the three sets of conceptual questions and scoring rubrics are in Appendixes J, K and L. Students volunteered to take a post-course quiz by email after they had completed the class. A copy of the post-course quiz and scoring rubric is in Appendix M. The post-course quiz used a short-answer format and was composed of four questions from each of the three lab activities.

General Description of a Control Lab

Students in the control group began their lab sessions by listening to a briefing by the lab instructor who was either the lecture instructor or who was a graduate teaching assistant. This briefing covered major points of the lab including all safety information. The control groups' Density lab, Kinetic Theory lab, and Chemical Reactions lab activities were taken from Todd's *Physical Science Laboratory Manual*, 5th ed. (*9*). The students often worked in pairs and followed directions as specified in the lab manual. The lab activities typically took most of the allotted 110-minute period. When the students completed the data sheets for that lab activity, they submitted the lab report to the lab instructor. During the control lab, the instructor served as a resource to answer student questions and to monitor safety of the lab.

General Description of a Treatment Lab

Students in the treatment group's labs received copies of the lab activities found in Appendixes N, O and P. Modeled after the design of the CPU Project (*48*), these guided learning labs incorporated elicitation and development activities whose learning objectives were the same as the control groups' labs. This graduate student served as the lab instructor for the treatment group so the experimental pedagogical style would be consistent for all treatment groups. The outcome of this research must be viewed in terms of this inherent bias, though every effort was made to not intentionally skew the results. The instructor-interactive elicitation activities were designed to encourage students to make predictions about the phenomenon being studied. The goal was to bring about conceptual change for students. Elicitation activities in the treatment group labs were also modeled after those used by Nussbaum and Novick (*34*). These activities exposed students' preconceptions by having the students predict and discuss the potential outcome of an event. The students then performed or observed the activity, which often produced an unexpected outcome for them.

The development activities of the guided learning pedagogy taught the same science content as the control groups' labs. The guided learning activities made use of inexpensive materials found in one's home or which could be purchased at grocery or department stores. The activities also used standard lab equipment typically found in physical science labs. Students, who were placed in groups of four, were encouraged to discuss the activities within their groups and organized the workload so all group members participated. During the development activities, the instructor prompted the students to examine their observations.

Description of the Control Group's Density Lab

Students in the control group read an explanation (*9*) of what density means and how it is calculated. The description included a focus on different density objects having different masses for the same volume. Emphasis was placed on techniques of how to find the mass and volume of an object, how to read a graduated cylinder, how to use a vernier caliper, and how to determine the percentage error in student work. Students were given formulas for finding the volumes of regularly shaped objects.

The activities of this lab included having students find the density of water by massing an empty graduated cylinder, adding a measurable volume of water, subtracting the cylinder's mass from the water-filled cylinder's mass, and dividing the mass of the water by the volume of water in the cylinder. Students also used vernier calipers to measure the dimensions of a rectangular block, from which they calculated its volume using a formula. With the calculated volume, they determined the density of the rectangular block after determining its mass. Students repeated this procedure of finding the density of a material using two solid cylinders. Students compared their results to data provided in the manual.

Description of the Treatment Group's Density Lab

The Density elicitation activity was a modification of an activity described by Checkal and Whitsett (*96*). In this activity, students compared properties of cans of regular cola and diet cola in water and related these properties to density. This activity was chosen so students could see the different behaviors of objects having the same volume but different masses. This elicitation activity suggested to the students that mass and volume were important aspects of density.

The four development activities were designed so students could examine the relationship between mass and volume. The elicitation activity demonstrated that objects with the same volume but different masses would have different densities. The first development activity was adapted from Activity #2 from the Density unit of Operation Chemistry (*97*). It allowed students to observe that objects with different densities could have the same masses but would necessarily have different volumes.

The second development activity was adapted from Activity #25 from the Density unit of Operation Chemistry (*97*) and from Richardson and Teggins (*98*). This activity was designed to allow students to gather quantitative data using a graduated cylinder and a laboratory balance. It was also designed so the student could gain experience plotting the results on a graph and looking for patterns among the data. This development activity allowed students to recognize the proportional nature of mass and volume by noticing data points align on a graph and that the lines for different liquids had different slopes corresponding proportionally to different densities.

The third development activity had the students create a density tower. Similar activities have been reported in the literature using corn syrup, glycerin, Dawn® detergent, water, vegetable oil, isopropyl alcohol, and 10 W motor oil (*97*), water, syrup, vegetable oil, and salt water (*99*), and pancake syrup, automotive antifreeze, Dawn® detergent, Revlon Flex Balsam Shampoo®, water, and Oops Paint Remover® (*100*). The purpose was for students to observe that less dense liquids stack on top of more dense liquids.

The last development activity allowed the students to use their knowledge of the materials in the density tower. This activity was adapted from Activity #12: The Densitometer from Operation Chemistry (*97*) where objects' densities, previously unknown, were determined by dropping them into a column of liquids composed of corn syrup, glycerin, Dawn® detergent, water, vegetable oil, isopropyl alcohol, and 10 W motor oil, whose densities were known. In the guided learning development activity, however, an object's density was first calculated, and predictions were made about the final position the object would take in the density tower. Conducted this way, students used their knowledge to make and test their predictions rather than just perform an activity and determine the density from the place to which the object settled in the density tower.

Description of the Control Group's Kinetic Theory Lab

Before students began the activities of the control group lab, they read from the lab manual (*9*) about the fundamental concepts of the kinetic theory of matter. These concepts included: solids, liquids and gases are composed of tiny particles, they are in constant motion, a change in the heat content of the material made up of these particles either changes the temperature or phase of the entire object, and the collision of the particles with the surface of a container is responsible for pressure. Students also read about collision theory, which explains such aspects of chemical reactions as activation energy and rates of reaction. Students were encouraged to think of how the particles behaved as they conducted the activities of this lab.

The first activity involved heating a dry Erlenmeyer flask, which had a balloon affixed over its mouth. Students were urged to explain the expansion of the balloon in terms of moving molecules. The second activity involved heating a dry distilling flask which had a balloon affixed over its mouth and which had an open piece of rubber hose attached to the side arm of the flask. After the burner was removed from the distilling flask, the side tube was clamped, and students allowed the hot flask to cool. They were instructed to explain why the balloon went into the neck of the flask in terms of particles outside pushing in. Students were told that molecules in the air can not pull.

The third activity involved melting an unknown sample and comparing its melting point to the melting point values provided in the lab manual. The purpose was to assure students that solids can be identified by their melting point. The fourth activity instructed students to observe the rates of diffusion of drops of potassium permanganate solution which had been placed into beakers of hot and room-temperature water. The fifth activity involved monitoring the time for an iodide solution and a persulfate solution to react completely, varying the temperature of the reacting conditions. Students were encouraged to explain their observations in terms of the collision theory.

Description of the Treatment Group's Kinetic Theory Lab

There were three elicitation activities for this lab, each designed to help the student address specific concepts about the nature of matter. The idea for the first elicitation activity came from the Nature of Matter unit of the CPU Project (*101*). The purpose of this activity was to expose the misconception that gases have no mass and to provide evidence so these students conception would change to the scientific view of matter. This activity used a toy ball that could be massed before and after air was pumped into it so students could draw the conclusion that air has mass.

The second elicitation activity was designed to identify students' ideas about the relative particle spacing in solids, liquids and gases. This elicitation activity was also adapted from the Nature of Matter unit of the CPU Project (*101*). Using syringes filled with sand, water and air, this activity was intended to have students consider the existence of empty space between particles of a gas relative to the particles' sizes, but not between particles of a liquid or a solid.

The third elicitation activity led students to consider the concept of the existence of spaces between and within the bulk of a liquid medium. Taken from Density Activity #26: Nonadditive Volumes (*97*), students predicted the total volume if they poured 50.0

mL of ethanol into a 100-mL graduated cylinder containing 50.0 mL of water. Students compared their actual results with their predictions.

The first of the Kinetic Theory development activities used analogies of children standing, walking around, and running to illustrate the concept of particles' behavior at different temperatures. The use of analogies was chosen so students could visualize macroscopically what the scientific community accepts as the behavior of microscopic particles. The second development activity used a cardboard box top and golf balls to illustrate the concept of pressure. Students worked together in groups to roll golf balls into box tops varying the speed and number of golf balls, noting the distance the box top moved each time. This activity was designed so students could get a kinesthetic sense of how the pressure of a gas against a surface is affected by the temperature of the gas as well as by the number of gas molecules hitting the surface. The activity was designed to help students understand why objects respond as they do when equal or unequal pressures are applied to opposite sides of the object's surface simultaneously.

The third development activity was adapted from Todd's lab manual (*9*). This activity allowed students to apply the previous information they had gained in the lab to explain the expansion of a balloon over a heated flask. The fourth development activity used the melting point determination setup as described by Todd (*9*). In this activity, students were led to recognize that materials can be identified by the temperature at which they melt.

The fifth development activity helped the students understand that temperature plays a role in the rate of chemical reactions. Modifying an experiment by Conklin and Kessinger (*102*), this development activity involved decomposing a three-percent solution of hydrogen peroxide using a catalyst under conditions of three different temperatures. The three-percent hydrogen peroxide was purchased from a grocery store and the catalyst, manganese (IV) oxide was reagent grade purchased from a scientific supply company.

Description of the Control Group's Chemical Reactions Lab

Before conducting the control group lab, students read from the lab manual (*9*) about microscopic aspects of chemical reactions, noting the energy changes associated with chemical bonds that were broken or formed during chemical reactions. Students then read about macroscopic evidence of chemical reactions. These included the formation of a precipitate or a gas, a change in color or odor, or an energy change. Students then read about common types of chemical reactions, including combination, decomposition, combustion, single-replacement, double-replacement, and acid carbonate reactions.

In the activity portion of the lab, students performed 12 experiments. Students checked blanks provided in the data sheets for each experiment to check all macroscopic evidence of reactions. Based on their observations, students were asked to decide if the experiment represented a chemical reaction. Lastly, students were instructed to place a check mark in a blank preceding a description if it represented a chemical reaction.

Description of the Treatment Group's Chemical Reactions Lab

The Chemical Reactions lab began with an elicitation activity using a balloon containing baking soda and which covered a flask containing vinegar. This activity was adapted from the Journal of Chemical Education (*103*). A second elicitation activity, adapted from Space Shuttle Activity #5: Carbon Dioxide and Limewater (*97*), involved reacting carbon dioxide with limewater to form a precipitate. These activities were designed to show students that the production of a gas, the formation of a precipitate and changes in temperature are evidence of chemical reactions.

The development activities were designed to provide direct teaching about evidence scientists have observed that accompany chemical reactions. Since understanding chemistry relies on visualizing behavior of microscopic entities that explain macroscopic behavior, the guided learning lab on chemical reactions was designed to help the student develop mental ideas of what is happening at the particle level. In the first development activity, an analogy was used of people meeting and forming couples, couples separating, or couples changing partners. Fortman (*104*) reported the use of the analogy of men and women as couples to illustrate the formation of compounds.

In the second development activity, students were shown particle diagrams to illustrate the rearrangement of atoms in a chemical reaction. Another technique in the guided learning lab was to have student groups draw and display particle diagrams, similar to those used by Nakhleh (*45*), on dry-erase boards for three described chemical equations. The purposes for these activities was for students to develop mental pictures of microscopic behavior and for students to use a variety of learning modalities to strengthen understanding of concepts associated with chemical reactions.

The third development activity gave students hands-on experiences with chemical reactions. The ten chemical reaction experiments included: an iron nail in a copper (II) sulfate solution, an iron nail in a magnesium sulfate solution, the combination of a solution of lead (II) nitrate and a solution of potassium iodide, the combination of a solution of sodium chloride and a solution of potassium iodide, sulfur burning, a nail heated until it becomes red hot, magnesium burning, acidic water electrolyzed by a dry cell battery, the combination of a solution of hydrochloric acid and a solution of sodium hydroxide, and a combination of a solution of magnesium chloride and a solution of sodium hydroxide. The chemicals used in these experiments were all reagent grade and available at a chemical supply company.

In the fourth development activity, students examined the last five experiments of the third development activity. They checked blanks on their lab sheets if a precipitate formed, if a gas formed, if there was an odor, color or energy change, and/or if there was no reaction. If there was a reaction, students had to identify it as a composition, decomposition, single replacement or a double replacement reaction.

Measures to Avoid Scoring Bias

To prevent scoring bias, the assessments for this research were graded by two instructors having a combined total of 50 years of chemistry teaching experience, using a rubric designed for this research. The rubrics they used to score the pre-lab quizzes are found in Appendixes D, E and F. The rubrics used to score the post-lab quizzes are found in Appendixes G, H and I. The rubrics used to score the conceptual questions are found in Appendixes J, K and L. The scores they obtained were compared to the scores used in this research for inter-rater reliability using Pearson's correlation method. The closer the inter-rater reliability was to one, the more agreement the two graders had on the correctness of the answers to the questions being scored.

These two teachers, Grader One and Grader Two, graded all 168 pre-lab and post-lab quizzes for the Density Lab. These two teachers then graded every fifth paper of the Kinetic Theory lab and the Chemical Reactions lab, grading the same set of students' papers. A Pearson correlation was performed on the scores to see if these teachers' scores agreed with the scores already assigned to the students' answers. The results of that comparison will be discussed.

Statistical Analysis

All calculations for significance testing were conducted using a computer running Windows XP and SPSS, Statistical Package for the Social Sciences, Student Version 10.0 (*105*). Four statistical procedures, the t-test, the Pearson correlation method, analysis of covariance (ANCOVA), and linear regression were used to analyze data in this research. In determining statistical significance of the differences between scores, critical values of t were selected based on values of p less than or equal to 0.05, which Witte and Witte (*106*) remark is the customary level "reported in most professional journals."

Independent Samples t-Test

Independent samples t-tests were used to compare the means for the quizzes and for the conceptual questions. A t value (Equation 1) is generated when a t-test is performed (*107*). The t value is a ratio where the numerator is the difference between the means of the scores for the treatment (T) and control (C) groups. The denominator is the square root of two quotients. The quotients are the variance of the treatment group divided by the number of scores in the treatment group and the variance of the control group divided by the number of scores in the control group. Variance is the square of the standard deviation for a set of data.

$$t = \frac{\overline{X}_T - \overline{X}_C}{\sqrt{\frac{var_T}{n_T} + \frac{var_C}{n_C}}} \quad (1)$$

Formula for the t-test

Pearson Product Moment Correlation

The Pearson Product Moment Correlation, better known as the Pearson's correlation method, was used to investigate the relationship between two sets of data such as students' ACT Mathematics scores and their post-lab quiz scores. The strength of the relationship was represented by an "r" value, (Equation 2) (*108*). Values range from -1 to +1. For illustration purposes, "X" represents ACT Mathematics scores and "Y" represents post-lab quiz scores. A correlation coefficient of +1 means the paired values, X and Y, when plotted on a graph, formed a straight line having a positive slope. A positive correlation means that as the ACT Mathematics score increased, the post-lab quiz score also increased. Negative correlation coefficients mean that the post-lab quiz score decreased as the ACT Mathematics score increased. The absolute value of the correlation coefficient is a representation of how closely data values fit to a least-square line. Coefficients near one indicate a strong linear association while numbers near zero indicate there is almost no linear association of the two values. According to Lethen (*108*), correlation coefficients are considered to be strong if $|r| \geq 0.8$, moderate for $0.5 < |r| < 0.8$, and weak if $|r| \leq 0.5$. When an "r" value is reported in statistical research, a "p" value accompanies it. A p value represents the probability that the observed results could have occurred by chance without there being an underlying causal connection between the two data.

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{N}\right)\left(\sum Y^2 - \frac{(\sum Y)^2}{N}\right)}} \quad (2)$$

Formula for the Pearson correlation coefficient, r

Analysis of Covariance

A score on a test may have been influenced by one or more contributing factors called covariates. Analysis of covariance (ANCOVA) is a test that compares means of sets of data and adjusts the results to account for contributing factors. In this research, t tests were used to compare the pre-lab quizzes, and t tests were used to compare the post-lab quizzes using independent samples t tests. An ANCOVA was used to compare the means of the treatment and control groups on the post-lab quizzes by taking into consideration the difference in the means of pre-lab scores. These results were compared to determine if the scores were significantly different.

Linear Regression

Data that formed a pattern when plotted on a graph could be expressed by an equation, which could then be used to predict values not originally measured or to describe trends among the data. The simplest regression analysis, linear regression, expresses trends among data as if the data approximated a straight line with a formula of $Y = mX + b$.

Witte and Witte (*106*) pointed out that the slope of the line, m (Equation 3), was generated by multiplying the ratio of the standard deviation of the dependent variable, Y, and the standard deviation of the independent variable, X, by the Pearson correlation coefficient, r, shown in Equation 2.

$$m = \frac{S_Y}{S_X} r \tag{3}$$

The authors also pointed out that the constant value, b, can be calculated by finding the mean value of the dependent variable, $\overline{Y}$, and subtracting from it the product of the slope, m, and the mean value of the independent variable, $\overline{X}$ (Equation 4).

$$b = \overline{Y} - m\overline{X} \tag{4}$$

Microsoft Excel® was used to analyze numerical data and generate equations for that data. This software program was used to investigate trends among student scores on the post-course quiz as a function of time since students had taken the course PSCI 1030.

CHAPTER 4

RESULTS AND DISCUSSION

Comparison of the Participants

The treatment group and the control group were compared to determine if the demographics and academic abilities of the groups were statistically different. The numerical results of the participants' gender ratios, age distribution and descriptions of high school demographics are listed in Table 2. There were almost two females to every male in both groups. The student population taking PSCI 1030 was similar in age categories in both groups. Neither group had a student under age 18. The largest group of students taking the course was the 18-20 year-old category, typically first-year students or sophomores. Eighty-two percent of the treatment group and 91% of the control group attended a public high school. Both groups attended similar kinds of high schools, classifying the schools as being slightly more rural than urban.

Students were asked to identify mathematics and science courses that they had taken in high school. The data in Table 3 show that the two groups were similar with respect to the percentage who had taken Algebra I, Algebra II and geometry. Half of both groups took a pre-calculus / advanced mathematics course. There was a significant difference, $p \leq 0.01$, in the number of treatment group students who had taken trigonometry. There was also a significant difference, $p \leq 0.05$, in the number of treatment group students who had taken general mathematics. Just over 10% of both groups had taken Calculus.

Table 2. Comparison of Lab Groups' Demographics

	Treatment (N = 60)		Control (N = 116)	
Category	Frequency	(%)	Frequency	(%)
Age				
Under 18	0	0	0	0
18-20	21	35	53	46
21-23	27	45	37	32
24 – 27	6	10	11	9
Over 27	6	10	15	13
High School Type				
Public	49	82	105	91
Private	11	18	9	8
High School Size				
Up to 500	15	25	25	22
500 – 1000	14	23	31	27
More than 1000	31	52	60	52
High School Description				
Rural	32	53	65	56
Urban	28	47	49	42
Gender				
Female	43	72	75	65
Male	17	28	41	35

Table 3. Statistical Comparison of Lab Groups Based on Mathematics Courses Taken

Mathematics Course	Treatment (N = 60) Frequency	Treatment (%)	Control (N = 116) Frequency	Control (%)	t	df	p
General Mathematics	45	75	69	59	2.14	133[a]	0.03
Business Mathematics	4	7	16	14	-1.56	155[a]	0.12
Algebra I	56	93	112	97	-0.97	174	0.33
Algebra II	49	82	102	88	-1.07	103[a]	0.29
Geometry	50	83	103	89	-0.39	174	0.70
Pre-Calculus	19	32	39	34	-0.26	174	0.80
Advanced Mathematics	11	18	17	15	0.63	174	0.53
Trigonometry	22	37	19	16	2.83	96[a]	0.01
Calculus	8	13	14	12	0.24	174	0.81

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

The data for the high school science courses were likewise similar (Table 4). Thirty percent of the treatment group and 27% of the control group had taken earth science and 68% of the treatment group and 66% of the control group had taken physical science. Of the treatment group, 93% had taken one year of biology and 92% of the control group had taken one year of biology.

Two-thirds of both groups took one year of chemistry in high school. Twenty percent of the control group and 33 % of the treatment group took at least one year of physics. Students had exposure to geology, environmental science or ecology, astronomy, and anatomy and physiology as well. No attempt was made to determine how much or what content was covered in those courses. The groups were not significantly different, at $p \leq 0.05$, for any courses taken prior to the study (Table 4).

Table 4. Statistical Comparison of Lab Groups Based on Science Courses Taken

	Treatment (N = 60)		Control (N = 116)				
Science Course	Frequency	(%)	Frequency	(%)	t	df	p
Earth Science	18	30	31	27	0.46	174	0.65
Physical Science	41	68	76	66	0.37	174	0.71
Biology I	56	93	107	92	0.26	174	0.79
Biology II	11	18	27	23	-0.75	174	0.45
Chemistry I	41	68	78	67	0.15	174	0.88
Chemistry II	5	8	6	5	0.82	174	0.41
Physics I	18	30	22	19	1.58	104[a]	0.12
Physics II	2	3	1	1	0.99	75[a]	0.32
Astronomy	0	0	2	2	-1.42	115[a]	0.16
Geology	6	10	15	13	-0.57	174	0.57
Environmental Science / Ecology	6	10	13	11	-0.24	174	0.81
Anatomy and Physiology	11	18	20	17	0.18	174	0.86

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

Because physical science relies on a basic knowledge of science content and mathematics skills, students who have strong backgrounds in mathematics and science should succeed in PSCI 1030. Both groups received similar exposure to algebra, geometry, physical science and one year of chemistry in high school as shown in Tables 3 and 4. A high school chemistry course is where students would receive exposure to the same concepts covered in the three labs: Density, Kinetic Theory, and Chemical Reactions. An independent samples t-test was performed on the mean number of students taking each mathematics (Table 3) and each science (Table 4) course in high school. The groups were not statistically different at the 95% confidence level in both academic areas with the exception of the trigonometry class, $p \leq 0.01$, and the general mathematics class, $p \leq 0.05$. This result suggested the two groups were similar with respect to the students' exposure to mathematics and science core courses.

ACT scores were obtained for the treatment and control groups in the three subtest areas of Mathematics, Reading Comprehension, and Science Reasoning. These scores were examined to compare the academic aptitude of the two groups. The data were also used to correlate to student performance on the quizzes and the conceptual questions. The data for the statistical comparison of the means in those areas are displayed in Table 5. There was no statistical difference, $p > 0.05$, between the groups.

These results suggested that the two groups were similar in their mathematics and science aptitude as well as in their pre-college education experiences. This established that any differences in the groups' performances would not be due to differences in the level of preparedness for this course.

Students were asked to rate various statements concerning their attitudes about their science experiences in high school using a Likert scale of 1 to 5, ranging from "strongly disagree" to "strongly agree." This survey is found in Appendix C. The purpose of having students self-report was to get an ancillary view of students' personal evaluation

Table 5. Statistical Comparison of Lab Groups' Mean ACT Mathematics, Reading, and Science Reasoning Scores

	Treatment (N = 35)		Control (N = 77)		t-test for Equality of Means		
ACT test	Mean score	SD	Mean score	SD	t	df	p
Mathematics	20.74	4.39	20.34	4.17	0.47	110	0.64
Reading Comprehension	23.17	5.63	21.65	4.79	1.47	110	0.14
Science Reasoning	21.74	4.87	21.32	3.84	0.49	110	0.63

of their academic preparation and their confidence about success in college. The self-assessment summary is in Table 6.

Table 6. Comparison of Lab Groups' Self-Assessment

	Treatment (N = 60)		Control (N = 116)	
Statement	Mean	SD	Mean	SD
I considered myself to be a good science student.	3.33	1.35	3.18	1.04
I found science courses interesting.	3.53	1.29	3.39	1.05
I was well prepared in high school for science in college.	3.20	1.42	2.89	1.18
I was encouraged to take all the science and mathematics courses I could.	3.20	1.23	2.90	1.25
Grades were important to me.	4.20	1.12	4.28	0.98

Scale: 1 = Strongly Disagree, 2 = Moderately Disagree, 3 = Neutral,
4 = Moderately Agree, 5 = Strongly Agree

Both groups were more positive than neutral in believing that they were good students and that studying science was interesting. Students in the control group did not rate personal preparation for college as highly as the treatment group, nor did the control group students sense as much encouragement to take all the science and mathematics courses they could. Both groups agreed that grades were important. The data in Table 6 indicate that both groups were similar in their self-assessment.

Experiences or topics that students found enjoyable in high school science are listed in Table 7. Both groups favored life sciences in high school as shown by 42% of the treatment group and 46% of the control group. Fewer students in both groups favored the physical sciences in high school as shown by 27% of the treatment group and 25% of the control group. These data show parallel sentiments among the students in this study with regard to their science interest. In view of these data, any conclusion drawn from this research could not be interpreted in light of an inherent interest for physical science of one group over the other. Twelve percent of the treatment group and 13% of the control group favored the active nature of labs. Students in both groups recalled the influence of a teacher, and they reported enjoyment from learning subject matter.

After comparing demographic data, number of high school mathematics and science courses taken, ACT scores and self-assessments, it was determined that the two lab groups were not significantly different ($p > 0.05$) except in the number of general mathematics and trigonometry courses the students in each group had taken. This established credibility to the claim that differences in scores on the assessments were not due to any inherent differences in the populations of students in this study.

Table 7. Responses to: Name One Thing (or Science Topic) You Enjoyed about High School Science

Main Category (total number of responses)	Subcategory	Treatment (N = 60)		Control (N = 116)	
		Responses	%	Responses	%
Life Sciences: (78)	Biology	6	10	16	14
	Dissection	4	7	15	13
	Anatomy	4	7	8	7
	Genetics	4	7	2	2
	Zoology	2	3	3	3
	Reproduction	0	0	4	3
	Ecology / Environmental Science	3	5	1	1
	Evolution	0	0	3	3
	Botany	1	2	1	1
	Agricultural Science	1	2	0	0
Physical Sciences: (45)	Chemistry	5	8	11	9
	Physics	7	12	7	6
	Astronomy	3	5	8	7
	Earth Science / Geology	1	2	2	2
	Physical Science	0	0	1	1
Non-specific Comments: (36)	Experiments, labs, activities, ...	7	12	15	13
	Influential teacher	4	7	5	4
	Academic gains: Learn about scientific method, have discussions, solve problems, gain knowledge, make observations	2	3	3	3
Neutral: (8)	Nothing, Can't Think of Anything	3	5	5	4
Total: (167)[a]		57	95[a]	110	95[a]

[a] All students did not answer this question

Results and Discussion: Density

The first lab covered the topic of density. Density is a topic typically covered early in a physical science or chemistry course because many concepts and skills can be addressed through the study of density. For example, density is an intrinsic physical property of matter that is obvious to everyone who picks up an iron bar and an aluminum bar of the same size. The study of density has been used to teach the concept of proportionality (*92*). It has given students an opportunity to use lab equipment, practice association of a formula with its practical usefulness, and investigate floating and Archimedes' Principle.

Density: Rubric and Responses for Each Question on the Pre-lab Quiz

There were 56 treatment group students and 91 control group students who responded to the pre-lab quiz. The Density pre-lab quiz is found in Appendix D. Each question of the pre-lab quiz is bold printed. The rubric used to assign a value to the students' answers is shown in the table associated with each question. Table footnotes elaborate on the criteria for the points assigned to the responses. The tables contain the frequencies for each answer and the percentage of the students providing that response.

Pre-lab Question 1:

Density (to you) is BEST described as...

A. Heaviness or weight	**B. Thickness or compactness**	**C. Hardness**	**D. __________ (Other)**

The response data for this question are given in Table 8. Forty-one percent of each group associated density with heaviness or weight. Density was thought of as thickness or compactness by 23% of the treatment group and 48% of the control group. Twenty-three percent of the treatment and 48% of the control groups believed density was the product rather than the quotient of mass and volume. Twenty-five percent of the treatment group and two percent of the control group held the correct concept of density. These students either expressed density as "Mass/Volume" or they correctly noted that density is the amount of mass in a given volume of any material.

Table 8. Density: Rubric and Responses for Pre-lab Question 1

Response (points)	Treatment (N = 56)	Control (N = 91)
A. Heaviness (1)	23[a](41)[b]	37 (41)
B. Thickness (2)[c]	13 (23)	44 (48)
C. Hardness (1)	1 (2)	3 (3)
D. Other (1)[d]	5 (9)	5 (6)
D. Other (3)[e]	14 (25)	2 (2)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Mass density is directly proportional to particle density, an interpretation of "thickness," but this would not necessarily be true for viscosity if it were defined as "thickness".
[d] Included mass times volume, volume, size, dimensions, or moisture.
[e] Either "m/V" or similar rendering is correct.

This question's mean score was 1.73 / 3 for the treatment group and 1.53 / 3 for the control group. The difference between these means was not significant ($t = 1.62$, $df = 84$, $p > 0.05$). These results that the groups were not significantly different. These results indicated that both groups thought of density in terms of particle compactness or weight. Some students indicated a knowledge of the formula, $D = m/V$, to calculate density while others only considered the size of the object as being density. Students began this lab with a variety of ideas about density.

Pre-lab Question 2:

[CHOOSE only ONE] Compare the density of an iron horseshoe and an iron nail.
A. The horseshoe and the nail have the same density because
B. The horseshoe has more density than the nail because
C. The horseshoe has less density than the nail because
D. It depends. It could be

Pre-lab Question 2 asked students to compare the density of an iron horseshoe and an iron nail. Student response data is summarized in Table 9. Students in both groups were almost evenly split in their decision of whether the items had the same density or whether the horseshoe had greater density. Five percent of the treatment group and two percent of the control group believed the horseshoe was less dense than the nail. Students who said the horseshoe was denser based their claim on the fact that a horseshoe was heavier and larger.

Table 9. Density: Rubric and Responses for Pre-lab Question 2

Response (points)	Treatment (N = 56)	Control (N = 91)
No work (0)	0[a] (0)[b]	1 (1)
A. Correct choice and logical reason given (3)	24 (43)	40 (44)
A. Correct choice, illogical or no reason given (2)	1 (2)	3 (3)
B. Gave effort with illogical reason (1)	26 (46)	40 (44)
C. Gave effort with illogical reason (1)	3 (5)	2 (2)
D. Gave effort with illogical reason (1)	2 (4)	5 (6)

[a] Number of times this item was chosen
[b] Percentage of students

Those who correctly said that the nail and horseshoe had the same density justified their answer by saying that the two objects were made of the same material. The treatment group had a mean score of 1.88 / 3 and the control group had a mean score of 1.90 / 3. The difference between these means was not significant ($t = -0.15$, $df = 145$, $p > 0.05$).

Pre-lab Question 3:

Which has the LESSER density - a 2 g mass which takes up 0.50 mL or a 3 g mass which takes up 3.00 mL? SHOW YOUR WORK.

This question was a calculation question. Students had to make the comparison between both sets of figures. Student responses are cataloged in Table 10.

Table 10. Density: Rubric and Responses for Pre-lab Question 3

Response (points)	Treatment (N = 56)	Control (N = 91)
No Work (0)	4[a] (7)[b]	10 (11)
Incomplete Effort (1)[c]	1 (2)	1 (1)
3 g / 3 mL, guessed or no reason given (2)	3 (5)	4 (4)
3 g / 3 mL, right work shown with units (3)	25 (45)	46 (51)
2 g / 0.5 mL, found product not quotient (1)	17 (30)	20 (22)
2 g / 0.5 mL, reciprocated work (1)	0 (0)	2 (2)
2 g / 0.5 mL, said this was greater (2)	6 (11)	8 (9)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Student started solving the problem but did not complete the work to get an answer

Forty-five percent of the treatment group and 51% of the control group selected the correct answer for the right reason. Seven percent of the treatment group and 11% of the control group did not attempt the problem. An examination of student work revealed that students were careless in answering questions. These errors were identified: students did not know what to do with the numbers, they inverted division or used multiplication instead of division, and they identified the object of greater density rather than the object of lesser density as was requested. The treatment group had a mean score of 1.98 / 3 and the control group had a mean score of 2.03 / 3. The difference between these means was not significant ($t = -0.28$, $df = 145$, $p > 0.05$).

Pre-lab Question 4:

A ball has a density of 1.86 g / mL and it is dropped into a liquid that has a density of 2.54 g / mL. Will it float or sink, or do you have to know more information before you can decide? (If so, what other information do you need?) EXPLAIN HOW YOU DECIDED.

Students were to compare how objects of different densities behave when two substances of different densities were put in the same environment. Their responses are summarized in Table 11. Seventy-seven percent of the treatment and 64% of the control group believed that objects of lesser density float in a liquid of greater density. Students who needed more information wanted to know the composition of the ball or liquid before making a judgment. Others ignored the densities given in the problem. The treatment group had a mean score of 2.39 / 3 and the control group had a mean score of 2.08 / 3. The difference between these means was not significant ($t = 1.79$, $df = 145$, $p > 0.05$).

Table 11. Density: Rubric and Responses for Pre-lab Question 4

Response (points)	Treatment (N = 56)	Control (N = 91)
No work (0)	4[a] (7)[b]	7 (8)
Incomplete Effort (1)[c]	0 (0)	1 (1)
Float, guessed or gave no reason (2)	4 (7)	11 (12)
Float, correct with logical reason given (3)	39 (70)	47 (52)
Sink, no reason given (1)	2 (4)	4 (4)
Need more information (1)	7 (13)	21 (23)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Student started solving the problem but did not complete the work to get an answer

Pre-lab Question 5:

You have a rectangular wooden block with a mass of 300 g. It is 2.0 cm wide, 1.5 cm high and 11.5 cm long. What is its density? (The formula for volume of this object is: V = L x W x H.)

The object's volume had to be calculated in this problem. The data for students' responses are given in Table 12. Seventy-five percent of the treatment group and 58% of the control group calculated the correct value but did not always include units. Four percent of the treatment group and three percent of the control group set up the problem correctly but calculated the wrong answer. Two percent of the control group inverted the mathematical operations. Thirteen percent of the treatment group and 28% of the control group only calculated the volume of the block but did not finish the problem. Six percent of the treatment group and eight percent of control group either did not attempt or complete the problem.

Table 12. Density: Rubric and Responses for Pre-lab Question 5

Response (points)	Treatment (N = 56)	Control (N = 91)
No work (0)	3[a] (6)[b]	7 (8)
Incomplete Effort (1)[c]	2 (4)	2 (2)
Only volume calculated (1)	7 (13)	25 (28)
Problem correct with units (3)	27 (48)	35 (39)
Obtained reciprocal answer or product (1)	0 (0)	2 (2)
Problem set up correctly but mathematics was wrong (1)	2 (4)	3 (3)
Problem correct but no units (2)	15 (27)	17 (19)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Student started solving the problem but did not complete the work to get an answer.

The treatment group had a mean score of 2.21 / 3 and the control group had a mean score of 1.91 / 3. The difference between these means was not significant ($t = 1.83$, $df = 145$, $p > 0.05$).

A statistical comparison for each pre-lab question is summarized in Table 13. On the whole, there were no statistical differences between the mean quiz scores of the two groups.

Table 13. Density: Statistical Comparison of Lab Groups' Means on Each Pre-lab Question

Question Number	Treatment (N = 56) Mean score	SD	Control (N = 91) Mean score	SD	t	df	p
1	1.73	0.84	1.53	0.54	1.62	84[a]	0.11
2	1.88	0.99	1.90	1.00	-0.15	145	0.88
3	1.98	1.04	2.03	1.10	-0.28	145	0.78
4	2.39	1.00	2.08	1.06	1.79	145	0.08
5	2.21	0.91	1.91	1.01	1.83	145	0.07

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

The Treatment Group's Density Lab

Following the Density pre-lab quiz, the instructor conducted the elicitation activity involving cola cans in an aquarium of water. Students who said the two cans would sink mentioned that both cans were heavier than the water. Both would float, according to one student, because they both had pressure or carbonation in them. Students who thought the regular cola would sink claimed it was denser because it had more sugar, syrup or calories in it. Those who said the diet cola would float believed that it had less sodium in it or that its artificial sweetener would somehow make it lighter. After the activity, the cans were massed and students noted that the regular cola can had more mass than the diet cola can. The instructions asked the students then to consider whether the mass of an object had anything to do with sinking and floating. The elicitation period was where students encountered their misconceptions and where students raised questions to be answered. Students learned from the elicitation activity that objects can have the same volume but different masses.

The purpose of the first development activity was to encourage students to see the relationship between mass and volume. This was accomplished by requiring students to measure 5.00 g of four materials. Students commented that the four materials having the same mass occupied different volumes.

The purpose for the second development activity was for students to see patterns based on data. When students measured the volumes of two different quantities of liquids and noted their respective masses, they learned that the same volume of two different liquids can have different masses. Students also learned that points on a graph generated from the masses of different volumes of liquids lined up with each other. Even though the directions for finding the slope were in the lab write-up, students requested assistance for this. The slope of the line for each liquid represented the density of the liquid.

The third development activity had the students pour four different liquids into one graduated cylinder in a particular order, stopping after each addition to use their density data to explain why the liquids stacked the way they did. After the liquids had been carefully poured into the same cylinder, students saw and learned that the liquids formed layers based on densities.

The fourth development activity involved the class finding the density of a small block of paraffin. Students successfully applied their density knowledge developed in the first three development activities to predict where the paraffin block would settle when it was dropped into the graduated cylinder of the four colored liquids.

Density Lab: Rubric and Responses for Each Question on the Post-lab Quiz

After the lab, students answered questions on a post-lab quiz (Appendix G).

Post-lab Question 1:
Density (to you) is BEST described as:

Student responses to this question are found in Table 14. The percentage of students who correctly recognized that density is the ratio of the mass of an object to its volume improved. The treatment group improved from 25% to 75% and the control group improved from 2% to 53%. The percentage of students who incorrectly referred to density as "thickness or compactness" dropped from 23% to 9% for the treatment group and from 48% to 13% for the control group.

Table 14. Density: Rubric and Responses for Post-lab Question 1

Response (points)	Treatment (N = 56)	Control (N = 91)
Ratio of mass to volume (3)	42[a] (75)[b]	48 (53)
Thickness or compactness (2)	5 (9)	12 (13)
Heaviness or weight (1)	1 (2)	21 (23)
Volume or size (1)	8 (14)	9 (10)
No work (0)	0 (0)	1 (1)

[a] Number of times this item was chosen
[b] Percentage of students

Forty-one percent of both the treatment and control groups described density as "heaviness or weight" prior to performing the density lab. Two percent of the treatment group maintained that conception while 23% of the control group still believed that an object's density is proportional to an object's weight alone. This suggested that the treatment lab was more successful in changing students' misconception that density is equal to weight or mass -- a result that was not reflected in the control group. It also suggested that students are reluctant to change conceptions in spite of instruction. The percentage of students who incorrectly said that density was proportional to the volume, size or dimensions of an object increased in both groups. The treatment group percentage increased from 9% to 14% and the control group percentage increased from 6% to 10%. Students focused more attention on volume and size after the doing the lab activity than they did before doing the activity. Further study would need to be conducted to determine what aspects of the treatment and control density labs correctly caused students to realize that density is not proportional to an object's weight but erroneously conclude that density is proportional to the volume of an object.

Both lab groups improved their score on this question compared to pre-lab question one. This suggested that both lab methodologies helped students increase their understanding of the meaning of density. The mean score on this question for the treatment group was 2.59 / 3 while the mean score for the control group was 2.18 / 3. The difference between these means was significant ($t = 2.93$, $df = 135$, $p \leq 0.01$), suggesting that students taught by the guided learning pedagogy outperformed students taught by the traditional lab methodology.

Post-lab Question 2:

[CHOOSE only ONE] Compare the density of a big brick and a broken piece of the brick.

A. The whole brick and the piece of brick have the same density because ...
B. The whole brick has more density than piece of the brick because ...
C. The whole brick has less density than the piece of brick because ...
D. It depends. It could be ...

Student response data to this question is recorded in Table 15. The treatment group improved its percentage of correct responses from the pre-lab to the post-lab quiz for this question from 43% to 66% while the control group improved from 44% to 50%. As in post-lab question one, these data also show that students improved their understanding that density is not dependent solely upon an object's mass or size. The response that density is in proportion to mass decreased from 46% on the pre-lab quiz to 27% on the post-lab quiz for the treatment group while the control group responses decreased from 44% to 36%. The percentages on the post-lab quiz still indicated the tenacious nature of the misconception. Those who thought the smaller object had the greater density explained that the big brick or the horseshoe took up more space than did the piece of brick or the nail. The percentages of students who believed that a larger item had less density remained at 5% for the treatment group while the control group percentages increased from 2% to 7%.

These results indicated that students do not have a clear grasp of what they believe density to be. The first question on the post-lab quiz asked students to describe density, but the second question asked the students to apply the meaning of density. Students were more capable of describing density than they were able to apply its meaning.

Table 15. Density: Rubric and Responses for Post-lab Question 2

Response (points)	Treatment (N = 56)	Control (N = 91)
No work (0)	0[a] (0)[b]	0 (0)
A, Correct choice and logical reason given (3)	37 (66)	45 (50)
A, Correct choice, illogical or no reason given (2)	1 (2)	3 (3)
B, Gave effort with illogical reason (1)	15 (27)	33 (36)
C, Gave effort with illogical reason (1)	3 (5)	6 (7)
D, Gave effort with illogical reason (1)	0 (0)	4 (4)

[a] Number of times this item was chosen
[b] Percentage of students

The treatment group had a mean score of 2.34 / 3 and the control group had a mean score of 2.02 / 3. The difference between these means was not significant ($t = 1.95$, $df = 121$, $p \leq 0.05$), suggesting that students taught by the guided learning pedagogy outperformed students taught by the traditional lab methodology.

Post-lab Question 3:

Which has the <u>LESSER</u> density - a 1 g mass which takes up 0.50 mL or a 5 g mass which takes up 3.00 mL? SHOW YOUR WORK.

The values for the masses and volumes in this question were changed from the pre-lab quiz question, but the order and nature of the question did not change. Student responses to this question are summarized in Table 16. The percentage of students in the treatment group who got the answer correct improved from 45% to 66% and the control group improved from 51% to 68%. Of students who answered in terms of the more dense material instead of the less dense material, the number of the students in the treatment group increased from 11% to 18%, and the number of students in the control group decreased from nine percent to six percent. Taking together the "1g / 0.5 mL is more dense" and the "5g / 3 mL is less dense" responses, the treatment group's correct responses increased from 55% on the pre-lab quiz to 84% on the post-lab quiz. The control group's correct responses increased from 59% to 74%.

Table 16. Density: Rubric and Responses for Post-lab Question 3

Response (points)	Treatment (N = 56)	Control (N = 91)
No Work (0)	0[a] (0)[b]	4 (4)
Incomplete Effort (1)[c]	1 (2)	3 (3)
5 g / 3 mL, said "guess" or gave no reason (2)	3 (5)	6 (7)
5 g / 3 mL, right work shown with units (3)	37 (66)	62 (68)
1 g / 0.5 mL, found product not quotient (1)	5 (9)	7 (8)
1 g / 0.5 mL, reciprocated work (1)	0 (0)	4 (4)
1 g / 0.5 mL, said this was greater (2)	10 (18)	5 (6)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Student started solving the problem but did not complete the work to get an answer

After the lab, students made fewer incorrect choices due to mathematical errors. The incorrect answers for the treatment group decreased from 30% on the pre-lab quiz to 9% on the post-lab quiz and the incorrect answers for the control group decreased from 24% to 12%. Students who missed these problems had difficulties with understanding the logic and mechanics of mathematics. They multiplied the mass and volume instead of dividing them. They divided correctly on one part of the problem and divided incorrectly on another part of the problem. They inverted their division. Until students develop better mathematics skills, using mathematics to solve science problems will remain difficult.

The portion of students who either did not provide an explanation or admitted their answer was a guess remained at five percent for the treatment group and increased from four percent to seven percent for the control group. The treatment group improved its mean score to 2.55 / 3 while the control group's mean score increased to 2.44 / 3. The difference between these means was not significant ($t = 0.86$, $df = 139$, $p > 0.05$). These results suggest that both lab methodologies equally helped students calculate density.

Post-lab Question 4:

A ball has a density of 3.86 g/mL and it is dropped into a liquid that has a density of 1.54 g/mL. Will it float or sink, or do you have to know more information before you can decide? (If so, what other information do you need?) EXPLAIN HOW YOU DECIDED.

Student responses to this question are summarized in Table 17. Both the treatment group and the control group improved their ability to recognize different densities based on objects' ability to sink or float. The treatment group's percentages improved from 77% to 88% and the control group's percentages improved from 64% to 74%. Before the lab, 13% of the treatment group and 23% of the control group said they needed more information. Those percentages decreased to seven percent for the treatment group and to nine percent for the control group. Both groups recognized that if an object floats, it must have a density less than the medium in which it is placed.

Both groups improved their mean scores from the pre-lab to the post-lab quiz on this question. The treatment group had a mean score of 2.70 / 3 and the control group had a mean score of 2.31 / 3. The difference between these means was significant

($t = 2.53$, $df = 141$, $p \leq 0.05$), suggesting that students who are taught by the guided learning pedagogy about objects floating or sinking given the density of the object and the fluid outperformed students taught by the traditional lab methodology.

Table 17. Density: Rubric and Responses for Post-lab Question 4

Response (points)	Treatment (N = 56)	Control (N = 91)
No work (0)	2[a] (4)[b]	9 (10)
Incomplete Effort (1)[c]	0 (0)	0 (0)
Sink, guessed or gave no reason (2)	1 (2)	6 (7)
Sink, correct with logical reason given (3)	48 (86)	61 (67)
Float, no reason given (1)	1 (2)	7 (8)
Need more information (1)	4 (7)	8 (9)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Student started solving the problem but did not complete the work to get an answer

Post-lab Question 5

You have a rectangular wooden block with a mass of 250 g. It is 2.5 cm wide, 1.5 cm high and 10.5 cm long. What is its density? (The formula for volume of this object is: V = L x W x H.)

Student responses to this question are cataloged in Table 18. This calculation problem was answered correctly by 89% of the treatment group and by 79% of the control group compared to 75% of the treatment group and 58% of the control group on the pre-lab quiz. On pre-lab quiz question five, 10% in both the treatment and the control group did not answer this question, only rewrote the numbers in the problem, or set up the problem without calculating an answer. After completing the lab, all students in the treatment group attempted the problem, and 98% of the control group attempted the problem. This suggested that both lab methodologies gave the students increased confidence to solve problems.

Table 18. Density: Rubric and Responses for Post-lab Question 5

Response (points)	Treatment (N = 56)	Control (N = 91)
No work (0)	0[a] (0)[b]	2 (2)
Incomplete Effort (1)[c]	0 (0)	0 (0)
Only volume calculated (1)	3 (5)	15 (16)
Problem correct with units (3)	35 (63)	50 (55)
Obtained reciprocal answer or product (1)	2 (4)	1 (1)
Problem set up correctly but mathematics was wrong (1)	1 (2)	1 (1)
Problem correct but no units (2)	15 (27)	22 (24)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Student started solving the problem but did not complete the work to get an answer.

The Density lab conducted by the control group focused on measurement and calculations to determine density while the treatment group focused on the concept that density is a ratio of an object's mass to its volume. The treatment group had a mean total score of 2.54 / 3 and the control group had a mean total score of 2.33 / 3. The difference between these means was not significant ($t = 1.65$, $df = 137$, $p > 0.05$), suggesting that both lab methodologies helped students correctly perform density calculations using a given mass and the dimensions of a rectangular block.

Density: Comparison of Pre- and Post-lab Quiz Means

The data in Table 19 shows a statistical comparison of each post-lab question. There was a statistical difference ($p \leq 0.05$) between the two groups, in favor of the treatment group, for question one. This question was conceptual in nature and asked students to originate the meaning of density. When students were given a more-specific situation, as in question two where they had to consider the relative densities of a brick and a piece of the same brick, both groups performed without distinction ($p > 0.05$).

Table 19. Density: Statistical Comparison of Lab Groups' Means on Each Post-lab Question

	Treatment (N = 56)		Control (N = 91)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1	2.59	0.76	2.18	0.94	2.93	135[a]	0.00
2	2.34	0.94	2.02	0.99	1.95	121[a]	0.05
3	2.55	0.69	2.44	0.91	0.86	139[a]	0.39
4	2.70	0.78	2.31	1.07	2.53	141[a]	0.01
5	2.54	0.66	2.33	0.84	1.65	137[a]	0.10

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

Questions three and five were calculation questions, and there was no significant difference ($p > 0.05$) between the two groups' performance on these two questions. These results suggest that students who study the topic of density with the guided learning pedagogy are able to understand the calculations as well as the control group and perform significantly better on conceptual questions than the control group.

There was a statistical difference ($p \leq 0.05$) favoring the treatment group on question four, which addressed the issue of sinking and floating. These results should be interpreted in light of the fact that the treatment group explicitly performed an additional activity demonstrating properties of floating based on differences in densities.

The bar graphs in Figure 1 compares the two groups' pre-lab and post-lab mean total scores. A comparison of total scores for the pre-lab and post-lab quizzes (Table 20) revealed that both the treatment and control groups improved their scores. The pre-lab means for the two groups were not significantly different ($p > 0.05$), but the treatment group had a significantly higher mean than the control group ($p \leq 0.01$), on the post-lab quiz.

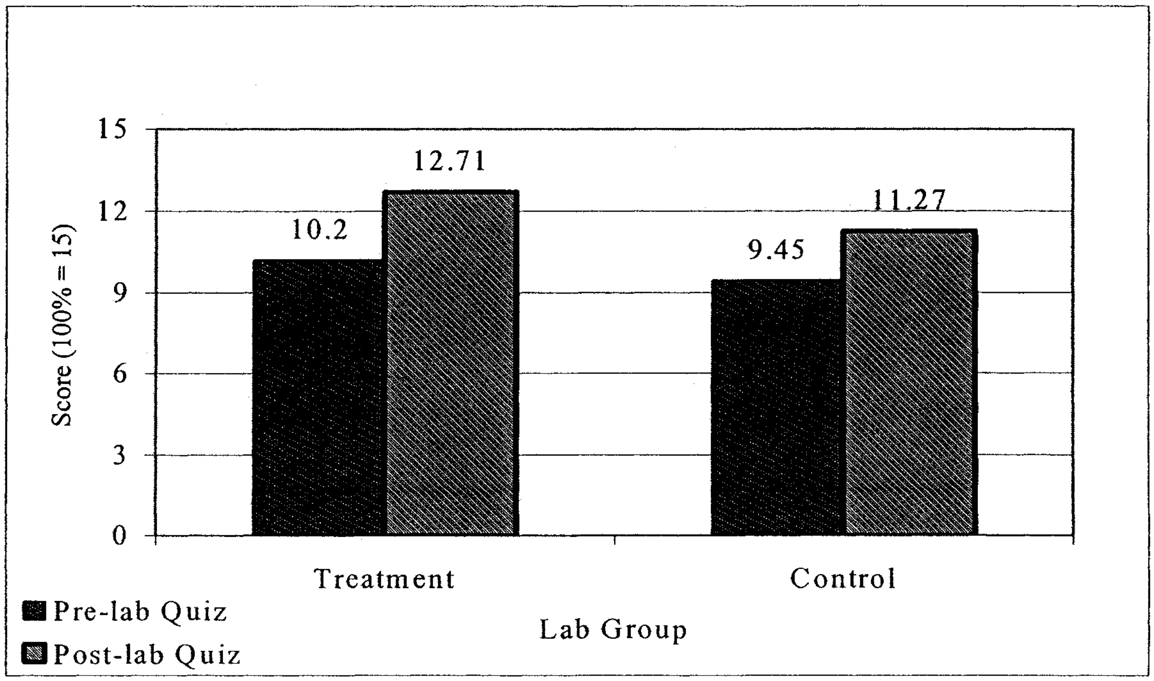


Figure 1. Comparison of Density pre-lab and post-lab quizzes by lab groups

The treatment group improved their mean score by 2.52 points from the pre-lab to the post-lab quiz while the control group improved their mean score by 1.82 points. This suggested that students who study density in a lab setting and who use the guided learning lab pedagogy were able to conceptualize density concepts more than those who were instructed using the traditional lab method.

The data in Table 20 indicate that the treatment and control groups' pre-lab quiz mean total scores were not significantly different ($t = 1.38$, $df = 145$, $p > 0.05$). The data in Table 20 also shows that the post-lab quiz mean total scores were significantly different ($t = 3.46$, $df = 141$, $p < 0.01$). This suggested that the treatment group outperformed the control group on the post-lab quiz.

Table 20. Density: Statistical Comparison of Each Lab Groups' Mean Total Score on the Pre-lab and Post-lab Quizzes

Data Sources for Scores	Treatment (N = 56) Mean score	Treatment (N = 56) SD	Control (N = 91) Mean score	Control (N = 91) SD	t	df	p
Pre-lab quiz	10.20	2.95	9.45	3.30	1.38	145	0.17
Post-lab quiz	12.71	2.12	11.27	2.90	3.46	141[a]	0.00

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

An analysis of covariance, ANCOVA, was conducted to determine if the post-lab quiz score for the treatment group remained significant after considering the groups' performances on the Density pre-lab quiz. The two groups' mean total scores on the post-lab quiz were compared with the results of the ANCOVA which adjusted for differences in the groups' mean total score on the pre-lab quiz. The results of the ANCOVA indicated that the two groups' post-lab quiz means remained significantly different ($F = 34$, $p \leq 0.01$), after controlling for differences in the pre-lab quiz, favoring the treatment group. This strengthened the claim that students who study density using a guided learning approach outperform students who study density using the traditional lab format.

Density: Rubric and Responses for Conceptual Questions

The following conceptual questions identified students' ability to apply the concepts learned in the Density lab. Fifty-eight treatment group students and 45 control group students responded to the questions. The number of students in the tables will vary because student participation was voluntary. In the control group, one whole class did not respond to the conceptual questions.

Conceptual Question 1:

A table of densities (all in g/cm^3) of some metals gives the following data: Magnesium (1.74), Aluminum (2.70), Osmium (22.48), and Iron (7.86). If you have 1.00 g of each of these metals in the shape of a cylinder, all with the same diameter, which would be the tallest cylinder? How did you arrive at your answer?

This question examined a student's understanding of the relationship between density and the role mass and volume play in density's determination. The majority of students in both groups recognized that the less dense metal would be taller when the diameter and mass of all cylinders were the same. An examination of student responses (Table 21) revealed that 64% of the treatment group and 50% of the control group correctly chose magnesium. The students in both groups who chose magnesium either displayed calculations to justify their response or justified their response by reasoning that the less dense material would have the larger volume. Two control group students chose magnesium and said that volume and density were inversely proportional to each other.

Table 21: Density: Rubric and Responses for Conceptual Question 1

Response (points)	Treatment (N = 58)	Control (N = 45)
Magnesium (1)[a]	34[b] (59)[c]	19 (42)
Magnesium (0.7)[d]	3 (5)	2 (4)
Magnesium (0.5)[e]	0 (0)	2 (4)
Aluminum (0.4)[f]	3 (5)	3 (7)
Osmium (0.4)[f]	13 (22)	12 (27)
Iron (0.4)[f]	3 (5)	0 (0)
Other (0.2)[g]	1 (2)	3 (7)
No answer	1 (2)	4 (9)

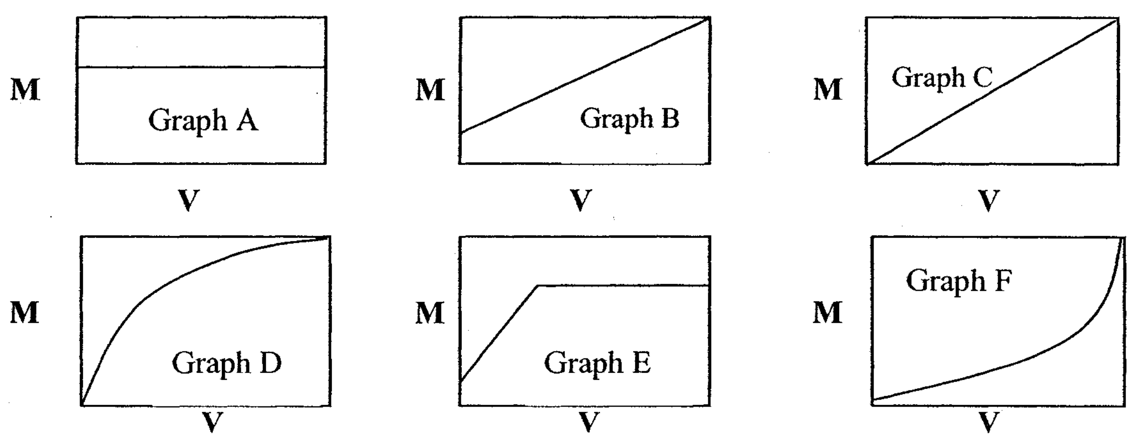
[a] Correct response, logical reason
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct response, illogical reason
[e] Correct response, no reason
[f] Incorrect response, illogical reason
[g] No response, illogical reason

The incorrect answer chosen most often was osmium. Twenty-two percent of the treatment group and 27% of the control group chose osmium. These students believed that the metal with the greatest density would have the tallest cylinder. One member of the treatment group did not answer this question, and four of the control group failed to answer the question. One of the treatment group's students said the heights would all be the same. Three of the control group's students said the metals would be the same height, mentioning that they had used the "same height" metal cylinders in another lab.

The treatment group's mean of 0.76 / 1 was higher than the control group's mean of 0.62 / 1. The difference between these means was significant ($t = 206$, $df = 101$, $p \leq 0.05$), suggesting that the guided learning methodology with emphasis on concepts helped the students relate density of an object to its volume more effectively than the control lab methodology.

Conceptual Question 2:

Suppose you have a supply of little aluminum cubes, all being about the size of dice. You have a 1000 mL graduated cylinder on a balance with 200 mL of water in it. You record the mass of the cylinder with just water but no aluminum cubes in the water. Then you add one cube at a time to the cylinder of water and record both the volume and the mass on the scale. Which, if any, of graphs A - F (M = mass, V = volume) do you think would represent this situation? If you do not believe any of them represent this situation, create your own that depicts how the graph would look. EXPLAIN your answer.



Student responses to this question are reported in Table 22. Seven students in the treatment group and four students in the control group selected Graph A, which shows a constant mass with increasing volume. One student said that the mass of the water remains the same no matter how many cubes of aluminum were placed in it. One student said the graph represented a direct proportion, stating that as the volume increased, so did the mass. Graph B or Graph C was clearly being described though that student circled Graph A.

Table 22: Density: Rubric and Responses for Conceptual Question 2

Response (points)	Treatment (N = 58)	Control (N = 45)
Graphs B or C (1)[a]	33[b] (57)[c]	11 (24)
Graphs B or C (0.7)[d]	0 (0)	3 (7)
Graphs B or C (0.5)[e]	7 (12)	10 (22)
Graphs A, D, E, or F (0.7)[f]	0 (0)	2 (4)
Graphs A, D, E, or F (0.4)[g]	5 (9)	6 (13)
Graphs A, D, E, or F (0.2)[h]	5 (9)	7 (16)
No response (0)	4 (7)	6 (13)

[a] Correct response, logical reason
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct response, illogical reason
[e] Correct response, no reason
[f] Incorrect response, logical reason or true statement of fact
[g] Attempt, illogical reason
[h] Attempt, no reason

Students offered correct explanations but chose wrong graphs and made illogical explanations. Such was the case when one student said that mass would increase more than volume. Another student said, "the volume of the water would rise as function of time." Other responses indicated that while many students are able to identify a graph that matched a scenario, others had difficulty with that skill. One student chose Graph E and indicated that after the aluminum cubes extend out of the water, the water level would not rise. This was a case where a student's initial answer was correct, but the misunderstanding became apparent the more he or she wrote. This student believed the graph profile represented the water level as a function of time. Four treatment group students and five control group students chose Graph D. One student said that the graph was correct because the mass would increase more than the volume. This was in spite of the fact that the graph represented the opposite trend. A control group student said Graph D was correct because "a solid is more dense than a liquid which would make the mass and volume rise." Two treatment group students and four control group students selected Graph F. One student said that if the graph were "tilted slightly," it would represent a "solid submerged in water in a graduated cylinder." These types of answers revealed that students have difficulty interpreting graphs.

The treatment group had a mean score of 0.71 / 1 and the control group had a mean score of 0.53 / 1. The difference between these means was significant ($t = 2.53$, $df = 101$, $p \leq 0.01$). These results should be interpreted in light of the fact that the treatment group performed a graphing activity that the control group did not perform. This may have influenced the results in favor of the treatment group. This graphing activity involved students observing and recording mass measurements of a graduated cylinder containing two volumes of four different liquids. The treatment group students then calculated the density of the liquids. The question under consideration here was similar in that there was an increasing mass that had an accompanying volume, but the material was solid aluminum cubes instead of liquids and the students were not asked to calculate the density of the aluminum cubes. The results suggested that the guided-learning pedagogy helped students understand the concept of density as represented by graphs.

Conceptual Question 3:

Suppose you have a piece of metal in a rectangular solid shape with dimensions 3.40 cm x 2.56 cm x 1.78 cm having a mass of 61.97 g. Which one of the metals in question 1 is it most likely to be, if any? Justify your answer.

Students responses are recorded in Table 23. This question posed a challenge because none of the choices given in conceptual question one matched the answer. This question tested the student's understanding of how to determine the density of a substance. Students were invited to disagree with the given choices if they believed their answer was correct.

Table 23: Density: Rubric and Responses for Conceptual Question 3

Response (points)	Treatment (N = 58)	Control (N = 45)
None of them (1)[a]	24[b] (41)[c]	10 (22)
Aluminum (0.8)[d]	0 (0)	3 (7)
Aluminum (0.5)[e]	15 (26)	18 (40)
Aluminum (0.3)[f]	3 (5)	3 (7)
Magnesium, Osmium or Iron (0.4)[g]	10 (17)	2 (4)
Magnesium, Osmium or Iron (0.2)[h]	4 (7)	6 (13)
No response (0)	2 (3)	3 (7)

[a] Correct response, logical reason
[b] Number of times this item was chosen
[c] Percentage of students
[d] Student stated that aluminum was closer than others but there really was no match
[e] Calculated answer was closer to Aluminum's density than any other metal in list
[f] Chose aluminum but gave no reason
[g] Incorrect response, but attempted an explanation
[h] Incorrect response, no explanation

Twenty-six percent of the treatment group and 40% of the control group said the metal was probably aluminum because their calculated density (4.00 g/cm^3) was closest to aluminum's density of 2.70 g/cm^3. This line of reasoning indicated students did not recognize the importance of precision of measurements. They did the calculation and recognized that their answer was not a match to the densities given in the table, but they chose a metal with a density closer, albeit 48.1% higher, to their calculated answer. This suggested that students who rounded their answer to the closest value in a list have limited regard for the precision of measurements. It also suggested that students believed that the correct answer must be in a list. Students must learn to trust their understanding rather than just exercise question-answering strategies.

The treatment group had a mean score of 0.64 / 1 and the control group had a mean score was 0.54 / 1 for this question. The difference between these means was not significant ($t = 1.62$, $df = 101$, $p > 0.05$), suggesting that both lab methodologies were equally, but only moderately, capable of helping students calculate the density of an object when given data and then select a material from a list that matched that calculated density.

Conceptual Question 4:

Calculate the density of a 17.52 g block of wood that has the dimensions 3.59 cm x 1.94 cm x 2.65 cm. Recall that V = L x W x H. Show your work, and express your answer with 3 digits.

Student responses are categorized and recorded in Table 24. Students were asked to calculate the density of an object given its dimensions and mass. Seventy-two percent of the treatment group and 60% of the control group calculated the correct answer.

Student responses revealed calculation errors such as performing inverted division, adding instead of multiplying dimensions to get volume, and misplacing the decimal point.

Table 24: Density: Rubric and Responses for Conceptual Question 4

Response (points)	Treatment (N = 58)	Control (N = 45)
Correct answer (1)	42[a] (72)[b]	27 (60)
Correct procedure, but decimal error (0.9)	9 (16)	9 (20)
Set up problem correctly; only calculated volume (0.7)	6 (10)	0 (0)
Set up problem correctly; calculated volume incorrectly (0.5)	0 (0)	2 (4)
Only calculated volume (0.4)	0 (0)	2 (4)
Attempted; calculated volume incorrectly (0.2)	1 (2)	4 (9)
No response (0)	0 (0)	1 (2)

[a] Number of times this item was chosen
[b] Percentage of students

An examination of the lab instructions for both the treatment (Appendix N) and control (9) groups reveals that both groups practiced calculating density. The treatment lab emphasized the conceptual relationship of the slope of a mass versus volume graph to density. The treatment lab applied the concept that liquids of different densities, if not mixed, will stack themselves in a density column from top to bottom in increasing densities. The lab sheet for the control group overtly stressed mathematical calculations, including finding the density of liquids, rectangular solids and cylindrical solids and finding the percent error.

In spite of the emphasis in the control lab on calculations, the treatment group performed better than the control group on this question. The treatment groups' mean of 0.94 / 1 versus 0.84 / 1 for the control group. The difference between these means was significant ($t = 2.21$, $df = 59$, $p \leq 0.05$) suggesting that students who study density from a conceptual perspective are just as capable, or are more capable, of working density calculations when compared to students who study density by a method of lab instruction that emphasized the mechanics of calculations.

Conceptual Question 5:

Calculate the density of a 25.71 g cylinder of wood that has a length of 9.33 cm and a diameter of 1.92 cm. Recall that $V = 3.14 \times R^2 \times L$. Show your work, and express your answer with 3 digits.

Categories of student responses are recorded in Table 25. This question was also a calculation problem, but the object was a cylinder instead of a rectangular solid. This

Table 25: Density: Rubric and Responses for Conceptual Question 5

Response (points)	Treatment (N = 58)	Control (N = 45)
Correct answer (1)	29[a] (50)[b]	17 (38)
Correct procedure, but decimal error (0.9)	5 (9)	8 (18)
Set up problem correctly; only calculated volume (0.7)	9 (16)	6 (13)
Set up problem correctly; calculated volume incorrectly (0.5)	11 (19)	2 (4)
Only calculated volume (0.4)	1 (2)	0 (0)
Attempted; calculated volume incorrectly (0.2)	3 (5)	11 (24)
No response (0)	0 (0)	1 (2)

[a] Number of times this item was chosen
[b] Percentage of students

question involved the use of exponents, multiplication, and division while the previous question only involved multiplication and division. The lower mean scores for the two questions suggested that the additional mathematical operations constituted greater difficulty for students.

The mean score for the treatment group on this question was 0.82 / 1 while the mean score for the control group was 0.73 / 1. The difference between these means was not significant ($t = 1.54$, $df = 78$, $p > 0.05$), suggesting that both lab methodologies were equally successful at helping students calculate the density of a cylindrical object when given its mass and dimensions. The lower scores on this question compared to those on question four suggest that additional mathematical operations increased the difficulty for both group.

Conceptual Question 6:

Which has the greater density, 6.89 g of cream which fills 8.11 cm^3 or 5.92 g of milk with a volume of 6.23 mL? (Recall that 1 mL takes up the same amount of space as 1 cm^3.) Justify your answer.

This question was a calculation problem. Categories of student responses to this question are recorded in Table 26. Eighty-one percent of the treatment group and 91% of the control group correctly indicated that milk was more dense than cream based on a correct calculation. Students supported their answer with calculations. Students also offered invalid or incomplete reasons such as: “Milk is more compact,” “Milk is purer,” and “Cream has more air in it.” Three percent of the treatment group performed calculations that pointed to milk as being more dense, but their answer said that cream was more dense. Fourteen percent of the treatment group and four percent of the control group said cream was denser than milk. Students arrived at this conclusion by noting that both the mass and the volume of the cream was more than milk. Two students inverted the division and got the wrong answer.

Table 26: Density: Rubric and Responses for Conceptual Question 6

Response (points)	Treatment (N = 58)	Control (N = 45)
Milk, correct work (1)	44 (76)[a]	35 (78)
Cream, but student work indicated milk (0.9)	2 (3)	0 (0)
Milk, guess or showed incorrect work (0.7)	1 (2)	2 (4)
Milk, no reason given (0.5)	2 (3)	4 (9)
Cream, illogical reason or reciprocal work (0.4)	4 (7)	1 (2)
Cream, no reason (0.2)	4 (7)	1 (2)
No response (0)	1 (2)	2 (4)

[a] Number of times this item was chosen
[b] Percentage of students

The treatment group's mean score was 0.86 / 1, and the control group's mean score was 0.87 / 1. The difference between these means was not significant ($t = -0.11$, $df = 101$, $p > 0.05$. These results suggested that students using both lab pedagogies were equally able to calculate the density of two liquids and determine the one that was more dense.

Conceptual Question 7:

A barge is fully loaded with corn and is moving down the Mississippi River from Iowa to be off-loaded at a port on the Gulf of Mexico. How will the barge's depth in the water change (if at all) as it moves from the fresh water of the Mississippi to the salt water of the Gulf? Note that the Gulf of Mexico water has a density of 1.05 g/cm^3 and the Mississippi River's water has a density of 1.01 g/cm^3. Explain your reasoning to the best of your ability.

This problem addressed the issue of an object floating in liquids of different densities. This question was included to see if students would transfer the concept of density to floating. Student responses are cataloged and recorded in Table 27.

Table 27: Density: Rubric and Responses for Conceptual Question 7

Response (points)	Treatment (N = 58)	Control (N = 45)
Higher in water, correct reason (1)	46[a] (79)[b]	21 (47)
Higher in water, incorrect reason or guess (0.7)	2 (3)	5 (11)
Higher in water, no reason (0.5)	5 (9)	5 (11)
Lower in water, incorrect reason or guess (0.4)	1 (2)	0 (0)
Lower in water, no reason (0.2)	2 (3)	5 (11)
No response or unclear response (0)	2 (3)	9 (20)

[a] Number of times this item was chosen
[b] Percentage of students

Ninety-one percent of the treatment group and 69% of the control group correctly noted that the barge would rise in the Gulf. Twelve percent of the treatment group and 22% of the control group either did not correctly explain their reasoning or they did not offer a reason at all. Two treatment group students and one control group student indicated they did not believe there would be a noticeable change in the depth. One student said the Gulf water would slow the barge down and another said that the barge would weigh less in the Gulf of Mexico. One student mentioned that no matter how deep the water, the barge would still float. Another student needed to know the density of the barge before the question could be answered.

The treatment group had a mean score of 0.88 / 1, and the control group had a mean score of 0.62 / 1. The difference between these means was significant ($t = 3.58$, $df = 72$, $p \leq 0.01$). The elicitation activity which used a can of diet cola and a can of regular cola involved the concept of sinking and floating. However, the treatment lab did not emphasize relative degrees to which a floating object sank into the water. Nevertheless, these results should be interpreted, keeping in mind the differences in the two groups observations of objects floating. These data suggested that students in the treatment group were better able to recognize the relationship between differences in density of objects and the ability of objects to float than was the control group.

Conceptual Question 8:

Suppose you do not have a reference book, ruler or laboratory balance available, but you wish to decide which of 2 objects has the greater density. Describe an experiment you could perform to find out. Give as much detail as possible.

Question eight was an open-ended question which elicited several unique answers, many of which were scientifically sound. Both lab groups used typical lab equipment such as balances or graduated cylinders in finding density. However, this problem told the students that such equipment was not at their disposal. Creativity was required. Responses are shown in Table 28.

Table 28: Density: Rubric and Responses for Conceptual Question 8

Response (points)	Treatment (N = 58)	Control (N = 45)
Method proposed could determine the greater density for all situations (1)	17[a] (29)[b]	8 (18)
Method proposed would work for some, but not all, situations (0.8)	27 (47)	9 (20)
Described a means of finding mass or volume of object, but not both (0.5)	6 (10)	15 (33)
Effort was made, but the answer was unintelligible or did not address the question (0.2)	5 (9)	5 (11)
No response (0)	3 (5)	8 (18)

[a] Number of times this item was chosen
[b] Percentage of students

Students who received full credit offered methods that would consistently determine which object of a set had the greater density. One student recalled the treatment group's development activity where a density tower was made of liquids of known densities. This student suggested placing objects into the tower and noting the level to which it would sink. Nine percent of the treatment group and seven percent of the control group suggested estimating the mass and volume of the objects and then calculating the density. Four percent of the control group suggested estimating the mass but determining the relative volumes of the objects by using water displacement. Ten percent of the treatment group suggested continuing to lower the two objects into different liquids until one sank and the other floated. These students assumed there existed a liquid that could provide that distinction. Five percent of the treatment group and four percent of the control group suggested finding objects that were the same size or making them the same size. Two percent of students in each lab group suggested that if both objects were placed in water, relative density could be determined if one sank while the other floated. Two percent of the treatment group also suggested that if both floated, then each could be submerged and the less dense would rise to the surface faster than the more dense object.

Students also provided methods which would determine the more dense object for some, but not all, sets of objects. The treatment group recalled the elicitation activity involving cans of cola in an aquarium. Thirty-four percent of the treatment group and seven percent of the control group suggested floating the two objects in water. Nine percent of the treatment group and two percent of the control group said that if the two objects both sank, the more dense object would sink faster, or if they both were floating, the more dense object would float deeper in the water. Two percent of the treatment group said that if the two objects were the same size, the one which displaced more water would be less dense. Seven percent of the control group suggested that if the two objects were the same size and both floated in water, the one that makes water rise most is more dense because it would sink deeper and displace more water. The only problem with such a response was that an explanation was not provided for the possibility of both sinking. Three treatment group students considered that the objects might be liquids. Their perception was that the less dense liquid would lie on top of the more dense liquid.

Students received partial credit if they described a means of finding mass or volume of object, but not both. Students suggested that the more dense object could be found by observing which of two objects displaced the most water. These students confused density with volume. Students also suggested holding the objects in one's hand to see which was heavier. These students did not say the objects appeared to have the same volume. One student said to "take into account size and weight," but that student did not say what to do with that information.

Student answers were considered incomplete if they attempted to answer the question but their suggestions were unintelligible or if they ignored the question as they gave a response. Three students provided incomplete responses because they ignored the premise that laboratory tools were not available. These students suggested that the mass and volume be determined in a laboratory setting and then use a formula to find the density. One person suggested, "feeling each one and forming a hypothesis" but that student did not elaborate. Another student suggested that if one were to apply a force to break each object, the one that broke first would be less dense. Another incomplete response was to drop them in the air. The more dense object would fall faster according to that student. One student suggested tying each end of a string to both and hanging the two objects over a stick. The method suggested was "to pull the string back 38 cm and let go." According to that student, the object that "pushes the other back" is more dense. Three other students answered the question by making up problems or scenarios, but they did not explain how the object with greater density could be determined.

Students in the treatment group recalled from their experiences in the lab that relative density could be determined without making actual measurements of mass and volume. Sixty-four percent of the treatment group and 20% of the control group made use of the fact that differences in density could be determined by an object's ability to float or sink in a liquid of a known density. Aside from the ability of an object to float or sink, 28% of the treatment group and 62% of the control group stated the need to use some method to determine the mass and/or volume of an object. Students made it clear that they needed to know these two fundamental qualities of an object in order to describe relative densities.

This question provided students with an opportunity to apply what they had learned from the lab. Sixty-four percent of the treatment group relied on the procedures of the lab they had performed to give them a way to determine relative densities. Twenty percent of the control group were also capable of originating the same idea though they had not performed the activities in the lab.

The treatment group had a mean score of 0.74 / 1 while the control group had a mean score of 0.50 / 1. The difference between these means was significant ($t = 3.62$, $df = 82$, $p \leq 0.01$), suggesting that students more successfully describe methods to compare densities of objects when taught using a conceptual approach to density using the guided learning lab pedagogy scored than students who studied density in a traditional lab format.

Conceptual Question 9:

Without having any numerical data available, tell all you can about why a steel ship floats.

Student responses to this question are cataloged in Table 29. Both labs addressed the relationship between density differences and floating. Full credit was awarded if the student supported their correct answer with logical statements explaining why a steel ship floats. Students commented on the overall lower density of the ship compared to the water in which it floated. They mentioned that the weight of the ship was distributed over a large volume which caused its density to be less than the density of the displaced water. Students also attributed the lower density of the ship to its shape, stating that this caused displacement of water equal to the mass of the ship. Students who associated a ship's density and its shape accounted for the overall lower density of a steel ship by adding that the hull of the ship was hollow and/or was filled with air that is less dense than water. One treatment group student recalled from the lab that less dense objects float on more dense objects. Students gave correct responses by noting that the ship had an overall lower density than the water it displaced, but these students did not support their statement with any evidence. Students also claimed that the ship floated because it was hollow. These students claimed that this "hollow-ness" acted like a floatation device that "allowed" the ship to float.

Table 29: Density: Rubric and Responses for Conceptual Question 9

Response (points)	Treatment (N = 58)	Control (N = 45)
Method proposed could determine the greater density for all situations (1)	19[a] (33)[b]	8 (18)
Method proposed would work for some, but not all, situations (0.8)	20 (34)	10 (22)
Described a means of finding mass or volume of object, but not both (0.5)	10 (17)	7 (16)
Effort was made, but the answer was unintelligible or did not address the question (0.2)	8 (14)	9 (20)
No response (0)	1 (2)	11 (24)

[a] Number of times this item was chosen
[b] Percentage of students

Other statements by students contained correct answers which included some misstatements. For example, one treatment group student said that the design of the hull caused more water weight to be displaced than ship's weight. This student further stated that a ship designed for water would sink in a sea of motor oil, but if it were designed to float in a sea of motor oil, it would tip over in water. This student stated "density is not all that important." Another treatment group student said that ship's hull shape displaced less weight than its own weight of water. A control group student remarked that the ship's hull shape displaced water to offset the weight of the ship.

Students provided responses, which involved correct vocabulary in their explanations, but they did not give a clear reason for the cause of the ship floating. Five students said that the ship experienced a buoyant force or surface tension. These students said that the buoyant force was equal to the water displaced and that a buoyant force was needed for the ship to stay afloat. Nine students indicated that since steel ships float, steel is less dense than water. One treatment group student said that steel is denser than water but that the density is distributed over a larger area. This gives the ship buoyancy "which displaces less water than a solid block of steel." One treatment group student said that equal displacement of water on both sides of a ship keeps it afloat.

Students also gave responses which were unintelligible or did not address the question. Five students said that a ship stayed afloat because it was built with its particular shape. Six control group students offered these reasons why a ship floats in water: "steel is less dense than other metals," "because of the mass of the ship," "sturdy ships float because of the science of making objects float," and "atoms in the steel are so close they allow the floating process". Six treatment group students offered these reasons: "because of water displacement," "steel allows ship ease of floating," "floating has something to do with the density of the ship and water's molecules," "the ship and water have same mass but water takes up more volume so ship floats," and "steel is more dense than water."

The treatment group had a mean score of 0.82 / 1, and the control group had a mean score of 0.53 / 1. The difference between these means was significant ($t = 3.91$, $df = 73$, $p \leq 0.01$), suggesting that students knew that floating objects had less density than the liquid in which it was floating. Students accounted for the lower density of the ship by noting the ship's shape and the fact that its hull contained air. These results also indicated that students were able to use appropriate vocabulary, but their logic when using that vocabulary did not always make sense. These results should be interpreted in light of the fact that the treatment group explicitly performed an additional activity demonstrating properties of floating based on differences in densities.

Conceptual Question 10:

We all know that ice floats. Soft crunchy ice is white and has air trapped in it. Clear ice does not have much air in it, yet it also floats in water. What can you say about why ice floats in water?

Students' answers to this question have been condensed into Table 30. This conceptual question also dealt with floating and was designed to eliminate the effect air has on floating. Twelve students correctly remarked that molecules are spaced farther apart when water is frozen than when it is in the liquid state. These students pointed out that molecules spread apart increases the volume, which in turn decreases the density of ice to a value below the density of water. The question left open the possibility that there was still some residual air trapped in clear ice. Answers that included air as an answer to lower density of ice than water were accepted, even though students should have reasoned that the air would have also been in the water before freezing. One treatment

Table 30: Density: Rubric and Responses for Conceptual Question 10

Response (points)	Treatment (N = 58)	Control (N = 45)
Method proposed could determine the greater density for all situations (1)	19[a] (33)[b]	6 (13)
Method proposed would work for some, but not all, situations (0.8)	31 (53)	22 (49)
Described a means of finding mass or volume of object, but not both (0.5)	3 (5)	2 (4)
Effort was made, but the answer was unintelligible or did not address the question (0.2)	3 (5)	10 (22)
No response (0)	2 (3)	5 (11)

[a] Number of times this item was chosen
[b] Percentage of students

group student reasoned that ice's density was less than water because it floated. This student commented that there was either a decrease in the mass or an increase in volume to cause that density difference. Two treatment group students said, "ice is less dense because it is frozen," and "ice is less dense because its volume and mass have changed."

Students also offered partially logical responses which included: "Ice has the same density as water but the air helps it float," "As a solid its particles are closer together and cause its density to change," "It doesn't have much volume, so when you calculate the m/V, the density is less and the ice will float," and "Ice is more dense than water because it expands as it freezes, making it able to float."

Students offered incomplete answers that included: "No matter what, its mass is the same," "Ice varies from top to bottom, from greatest to least," "Water in solid form cannot sink," and "Frozen molecules in ice make it denser than water and this makes ice buoyant." Students also said, "Solid ice has a higher density than crunchy ice," "Air still rises, frozen or not, especially when the density is as low as it is," and "Ice has the same density which causes it to float." One student said, "It is still water though the form has changed," and another student said, "It (ice) is not denser than water." Lastly, one student said, "I see know (sic) reason for it to not float." One control group student admitted, "now that I think about it, I have no idea why it floats instead of sinks."

The treatment group had a 0.88 / 1 mean score and the control group students had a mean score of 0.72 / 1. The difference between these means was significant ($t = 2.39$, $df = 85$, $p \leq 0.01$), suggesting that students taught using the guided learning pedagogy were able to outperform students taught using a traditional lab method in explaining why ice floats in water. This conclusion, however, must be interpreted in light of the fact that the treatment group performed an additional activity demonstrating properties of floating based on differences in densities

The data in Table 31 summarizes the comparison of the two laboratory groups' mean scores on the conceptual questions. Four of the questions, numbers three, four, five, and six could be solved using calculations and making application of knowledge of mass and volume. The control group's lab emphasized calculations of density using formulas more than the treatment group's lab, yet there was no significant difference ($p > 0.05$) on these two groups' performance on questions three, five and six. Question six was the least demanding cognitively because students had to calculate the density of two liquids when given mass and volume. For question three, students calculated density from mass and dimensions, and then select the substance from a list. Question five involved the student calculating the density of a material given the mass and the formula for a cylinder. Question four was also a density calculation question, when given mass and the dimensions for a rectangular solid. The treatment group's mean was statistically higher ($p \leq 0.05$) than the control group's mean on that question.

Table 31. Density: Statistical Comparison of Each Lab Groups' Mean Score on Each Conceptual Question

	Treatment (N = 58)		Control (N = 45)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1	0.76	0.31	0.62	0.36	2.06	101	0.04
2	0.71	0.36	0.53	0.35	2.53	101	0.01
3	0.64	0.32	0.54	0.31	1.62	101	0.11
4	0.94	0.13	0.84	0.28	2.21	59[a]	0.03
5	0.82	0.23	0.73	0.32	1.54	78[a]	0.13
6	0.86	0.28	0.87	0.28	-0.11	101	0.91
7	0.88	0.27	0.62	0.41	3.58	72[a]	0.00
8	0.74	0.30	0.50	0.37	3.62	82[a]	0.00
9	0.82	0.29	0.53	0.43	3.91	73[a]	0.00
10	0.88	0.26	0.72	0.39	2.39	85[a]	0.00

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

Questions seven, nine and ten concerned the concept of floating. The mean scores were significantly different ($p \leq 0.01$) for the two groups. The treatment group distinctively exceeded the control group on those questions, but the fact that the treatment group explicitly performed additional lab activities dealing with the concept of floating may have unduly influenced the results in favor of the treatment group. Students best answered question one by contemplating the volume of 1.00 gram of each of several metal samples and considering the one that would be the tallest. They also used their understanding of mass and volume to suggest an experiment one could conduct to determine the material having a greater density. Question two provided students with a scenario and asked them to select a graph, from a list, that best described scenario. The distinctive results in favor of the treatment group could have been unduly influenced by the fact that the treatment group gathered and graphed data while the control group did not. There was a significant difference ($p \leq 0.05$) on questions one, two, four, seven, eight, nine and ten. This suggests that students who study density using the guided learning lab outperform students using the traditional lab on density as measured by those questions.

Density: Comparison of Conceptual Questions' Total Scores

The groups' mean total scores on the conceptual questions are displayed in Figure 2. A statistical analysis was performed on the mean total scores of the conceptual questions for the two lab groups. The treatment group had a mean total score of 8.05 / 10 and the control group had a mean total score of 6.50 / 10. The difference between these means was significant ($t = 4.28$, $df = 101$, $p \leq 0.01$). This suggested that students taught in labs using guided learning techniques score statistically higher than those taught in a traditional manner.

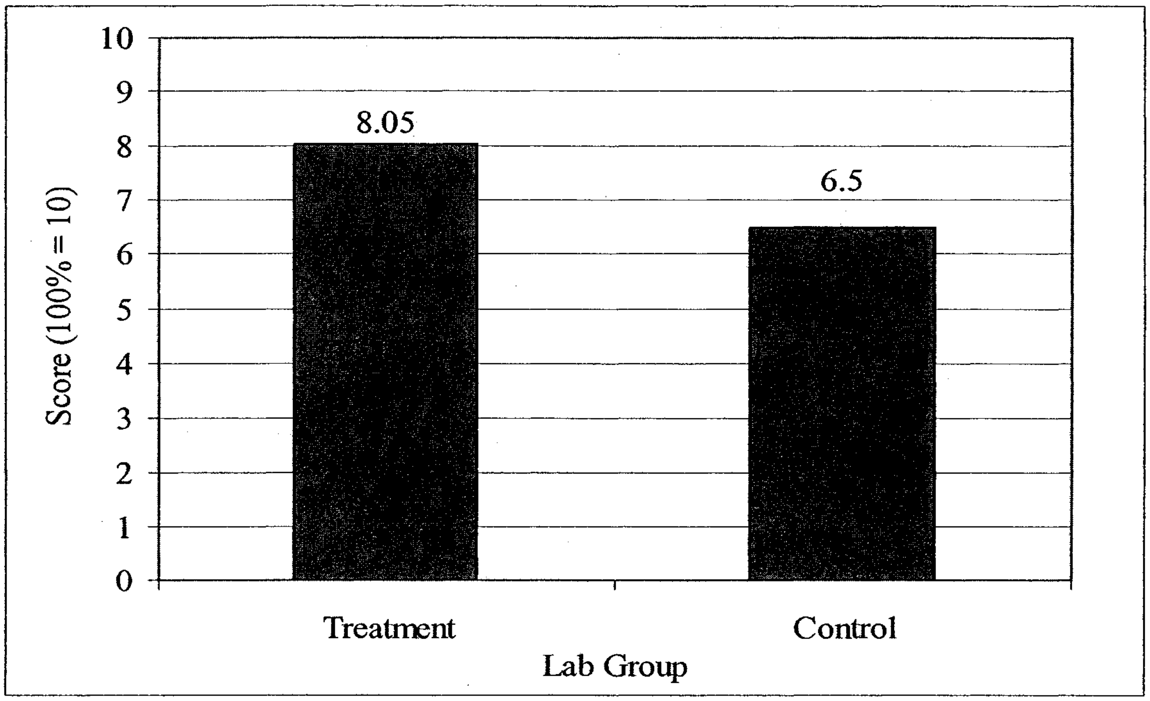


Figure 2. Group comparisons of Density lab conceptual questions

Results and Discussion: Kinetic Theory

The second lab covered the topic of the kinetic theory of matter, which is used to explain behavior of matter in all physical sciences. It has an integral connection to chemistry. The kinetic theory, (*26*) maintains that matter is composed of tiny particles in constant motion. These particles have attractions to other particles. The kinetic theory explains states of matter and the changes made between states of matter. The gas laws can be understood if one grasps the concepts of the kinetic theory. Chemical reactions can be explained as one thinks of particles interacting and rearranging. The kinetic theory of matter is also called the small particle model of matter or the particulate nature of matter.

Kinetic Theory: Rubric and Responses for Each Question on the Pre-lab Quiz

There were 53 treatment group students and 63 control group students who responded to the Kinetic Theory pre-lab quiz. Following each pre-lab quiz question, there is a statistical comparison of each question.

Pre-lab Question 1:

If you put air into car tires, the pressure goes up, but which of these would you say also happens? The tire actually: A. Gets heavier B. Stays the same C. Gets lighter Why?

Student responses to this question are summarized in Table 32. Thirty-six percent of the treatment group and 22% of the control group correctly explained that a tire gets heavier when air is added to it because the added air has mass. One treatment group student referred to air as "particles which have mass," and another treatment group student offered justification by noting that a propane tank is heavier when it has been refilled. The predominant incorrect reason given by nine percent of the treatment group and 14% of the control group students was that weight increased because the pressure increased. Other reasons included "air occupies space," "particles are compressed or are expanded," "molecules move faster," or "more particles can withstand gravity." Fifteen percent of the treatment group and 21% of the control group believed the tire would be heavier, but these students did not offer an explanation, or they did not give a correct reason.

Thirty-two percent of the treatment group and 43% of the control group believed that a tire which had air pumped into it would not change its weight. Fifteen percent of the treatment group and 22% of the control group said that air is weightless. Two percent of the treatment group and six percent of the control group said that the tire would inflate but not be heavier. Eight percent of the treatment group and five percent of the control group correctly believed that the weight of the tire is not inherently associated with the tire's pressure, so they believed the weight would not change. Four percent of the treatment group and eight percent of the control group offered no reason for their belief that the weight would not change.

Table 32. Kinetic Theory: Rubric and Responses for Pre-lab Question 1

Response (points)	Treatment (N = 53)	Control (N = 63)
A, Correct choice, logical reason given (2)	19[a] (36)[b]	14 (22)
A, Correct choice, (1)[c]	8 (15)	13 (21)
B, Incorrect choice, logical reason given (1)	4 (8)	3 (5)
B, Incorrect choice (0.5)[d]	1 (2)	1 (2)
B, Incorrect choice (0)[c]	12 (23)	23 (37)
C, Incorrect choice, logical reason given (1)	1 (2)	1 (2)
C, Incorrect choice (0)[c]	8 (15)	8 (13)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Illogical or no reason given
[d] Used a true statement which did not adequately answer the question

Seventeen percent of the treatment group and 14% of the control group said that the tire would get lighter. Four percent of the treatment group and six percent of the control group expressed the idea that the tire was being filled with a "light" material and thus the tire would become lighter. Four percent of the treatment group and five percent of the control group believed the tire would become lighter because the pressure of the added air would make the tire expand, and the tire would be lighter to hold up the car. The treatment group had a mean score of 0.97 / 2 while the control group had a mean score of 0.72 / 2. The difference between these means was not significant ($t = 1.60$, $df = 114$, $p > 0.05$), suggesting that the two groups had equal means on this pre-lab quiz question.

These results provided a list of misconceptions students hold. Students in both groups attributed a tire's weight to pressure. This revealed students' lack of understanding about pressure. They also held the concept that air has no mass which indicated that they have little concept of what air is. These results also indicated that students believed that air, when added to containers, give the containers "lightness."

Pre-lab Question 2:

Suppose you have a straw in a soft drink cup. Explain as best you can how the soft drink gets into your mouth.

Student responses to this question are summarized in Table 33. The majority of the students, 64% of the treatment group and 81% of the control group, described the way a liquid gets into one's mouth through a straw by only saying that a person sucks on the straw. Twenty-one percent of the treatment group and 18% of the control group recognized that a pressure differential was created when one sucked on a straw. Nine percent of the treatment group and five percent of the control group recognized that the pressure inside the straw was decreased and the relatively higher atmospheric pressure pushed the drink into one's mouth. One of the treatment group students and five of the control group students thought that sucking on the straw increased the pressure in the straw, making the drink go into the mouth. Five of the treatment group students and three of the control group students said that sucking decreased the pressure in the straw, allowing the drink to go up through the mouth without explaining how that occurred.

Table 33. Kinetic Theory: Rubric and Responses for Pre-lab Question 2

Response (points)	Treatment (N = 53)	Control (N = 63)
Pressure Difference (1)[a]	5[b] (9)[c]	3 (5)
Pressure Difference (0.5)[d]	6 (11)	8 (13)
Suction (0)	34 (64)	51 (81)
Other (0)	7 (13)	1 (2)

[a] Correct terms and logical explanation given
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct terms but illogical or no explanation given

The data in Table 33 suggested that students do not think in terms of particle behavior to explain what they observe. One student considered the phenomenon of sucking on a straw in terms of particles. That student said, "collisions of the molecules inside the surface of the soft drink cup causes pressure, and the pressure rises up through the straw into your mouth." Students in the study did not display an understanding that particles of gases do not pull but only push on the surfaces. Of the 116 students who offered replies on the pre-lab quiz, only two percent of the treatment group and two percent of the control group used the word "push" in describing what the air was doing. In contrast, nine percent of the treatment group and 18% of the control group used the word "pull" to describe the behavior of air. Other students responded in a variety of non-scientific ways. Two percent of the treatment group stated that the liquid was attracted to the vacuum. Two percent of the treatment group focused on the fact that the air or drink flows through the straw without any further comment. Six percent of the treatment group did not answer the question.

The mean score was 0.15 / 1 for the treatment group and 0.11 / 1 for the control group. The difference between these means was not significant ($t = 0.74$, $df = 114$, $p > 0.05$). These results support the idea that students held multiple misconceptions about how liquids move through a straw when a person puts the straw in his/her mouth.

Pre-lab Question 3:

What is it about air that makes the leaves move when the wind blows?

Student responses to this question are cataloged in Table 34. Fifty-seven percent of the treatment group and 46% of the control group explained the movement of leaves in the wind in terms of a force or pressure. Twenty-six percent of treatment group and 30% of the control group said that air or wind exerted a force on the light leaves making them move. Seventeen percent of the treatment group and six percent of the control group said that though air particles were light in mass, they hit the leaves with enough force to move the leaves. These students explained that leaves move because air has mass and exerts a force on the leaves. Thirteen percent of the treatment group and ten percent of the control group mentioned only the existence of a force. These students did not mention the involvement of particles that make up the air or the leaves which exert forces on one another. Fifteen percent of the treatment group and 21% of the control group included the idea that the leaves move when there is wind. However, only six percent of the control group justified their answer by commenting on the relative masses of leaves and air as the leaves moved in the wind.

Table 34. Kinetic Theory: Rubric and Responses for Pre-lab Question 3

Response (points)	Treatment (N = 53)	Control (N = 63)
Force or pressure (1)[a]	23[b] (43)[c]	23 (37)
Force or pressure (0.5)[d]	7 (13)	6 (10)
Mass or impact (1)[a]	0 (0)	4 (6)
Mass or impact (0.5)[d]	8 (15)	9 (14)
Other (0)	15 (28)	21 (33)

[a] Correct terms and logical explanation given
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct terms but illogical or no explanation given

Twenty-eight percent of the treatment group and 33% of the control group either offered ideas that were merely descriptions or these students did not offer a reason. Seventeen percent of the treatment group and 21% of the control group described the situation by saying that the air circulates and blows the leaves into the air. Six percent of the treatment group and eight percent of the control group did not answer the question.

The treatment group had a mean score of 0.58 / 1 and the control group had a mean score of 0.55 / 1 on this question. The difference between these means was not significant ($t = 0.35$, $df = 114$, $p > 0.05$). These results indicated that students have a variety of ideas to explain the movement of leaves in the wind. Students, as a group did not think of air as being composed of particles with a given mass. Explanations were vague as they mentioned the presence of a force or pressure. Other students just described the movement of leaves because the air was moving.

Pre-lab Question 4:

Suppose you had 2 cups - one with marbles and the other one had the same level of sand. Describe what would happen if you pour the sand in on top of the marbles and why?

Answers to this question by students in both groups are summarized in Table 35. This question challenged students to consider that particles have different sizes. The question also identified whether or not students recognized that small particles would fit into the spaces between the larger particles.

Table 35. Kinetic Theory: Rubric and Responses for Pre-lab Question 4

Response (points)	Treatment (N = 53)	Control (N = 63)
Total equals less than volume sums (2)[a]	37[b] (70)[c]	39 (62)
Total equals less than volume sums (1)[d]	8 (15)	21 (33)
Total equals volume sums (1)[e]	2 (4)	0 (0)
Total equals volume sums (0)[f]	3 (6)	0 (0)
Total equals more than volume sums (0)[f]	2 (4)	0 (0)
No response (0)	1 (2)	3 (5)

[a] Correct answer and logical explanation given
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct answer but illogical or no explanation given
[e] Incorrect answer but logical explanation given
[f] Incorrect answer and illogical or no explanation given

Sixty-six percent of the treatment group and sixty-five percent of the control group recognized that sand grains are small enough to fit into the spaces left between the marbles. Once some of the grains of sand fell into the void between the marbles, the resulting volume would be less than the sum of the volumes of the marbles and sand alone. The responses by both groups on this pre-lab quiz question indicated that students recognized that there would be spaces between particles, and the amount of space would depend, in part, on the size of the particles.

Six percent of the treatment group and six percent of the control group offered alternate explanations as to why the combined volume would be less than the sum of the two materials individually. These students thought that the total volume would be less than the sum of the two separate materials because the sand grains had a lower mass than the marbles or that the sand and marbles had different textures. Eight percent of the treatment group and 18% of the control group did not offer a reason for the final volume being less than the initial volume.

Nine percent of the treatment group and six percent of the control group believed that the sand would stay on the top of the marbles, but two of these treatment group students contradicted themselves by saying that the sand would fall into the spaces between the marbles. Two control group students said that the sand would stay on top of the marbles because the marbles were heavier. These students were not considering the size of the particles and the spaces that exist between the marbles. Three treatment group students and two control group students did not attempt an answer Eight percent of the treatment group thought that the sand would not only stay on top of the marbles but the combined volume of the sand and marbles would be greater than the sum of the individual volumes. Four percent of the treatment group and five percent of the control group did not give a reason for believing the total would be greater than the sum of the individual amounts of sand and marbles.

The treatment group had a mean score of 1.49 / 2 and the control group had a mean score of 1.57 / 2 on this question. The difference between these means was not significant ($t = -0.62$, $df = 114$, $p > 0.05$), suggesting that the two groups were equal in their ability to answer this question before they performed the kinetic theory lab. Students in both groups held the correct conception that particles have different sizes, and there would be void spaces between them. Students also held misconceptions such as the combined volumes would be less because the grains of sand had less mass or had a different texture than marbles. An examination of student papers also indicated that students are inconsistent in their logic. They argued that the particles of sand were smaller than the marbles, but the sand would remain on top of the marbles without falling into the void spaces between the marbles. This question provided students an opportunity to reveal their initial understanding of particle sizes.

Pre-lab Question 5:

Explain what is happening when ice melts.

Table 36 contains the summary of students' responses to this question. Students were to answer this question based on how particles of matter behave. Thirteen percent of the treatment group and 22% of the control group remarked that, during the melting process, molecules begin to move apart from one another and their movement increased relative to each other. Twenty-five percent of the treatment group and 22% of the control group focused their attention on the phenomenon of a phase change rather than describing what happens specifically to the particles. These students' answers were correct, but incomplete.

Table 36. Kinetic Theory: Rubric and Responses for Pre-lab Question 5

Response (points)	Treatment (N = 53)	Control (N = 63)
Particles (1)[a]	15[b] (28)[c]	8 (13)
Structure breaks down (1)[a]	1 (2)	4 (6)
Phase change (0.5)[d]	16 (30)	16 (25)
Heat or temperature (0.5)[d]	7 (13)	14 (22)
Heat or temperature (0)[e]	12 (23)	17 (27)
No response or other (0)	2 (4)	4 (6)

[a] Logical explanation given
[b] Number of times this answer was given
[c] Percentage of students
[d] True statement but does not explain what happens when ice melts
[e] Incorrect explanation given

Most incorrect answers centered on either a temperature change or a discussion of heat's effect on melting. Fifteen percent of the treatment group and 25% of the students in the control group held the conception that water warms as it changes from ice to water. Two percent of the control group said, "heat is taking away the coldness." Two percent of the control group said that during freezing, water gets heavier. Two percent of the control group also said that as water freezes, the temperature increases which causes the water to freeze.

Nineteen percent of the treatment group and ten percent of the control group pointed out that the ice was absorbing heat, but none of these students explained what that absorbed heat was doing to the particles. Seventeen percent of the treatment group and three percent of the control group commented that the multi-particle structure was breaking down as heat was added. Students offered other ideas that were neither scientific nor revealed insight into student understanding. These ideas included that during melting, there is a temperature drop, there is a loss of mass, and molecules shrink. Six percent of the treatment group and five percent of the control group failed to provide an answer.

The treatment group had a mean score of 0.52 / 1 and the control group had a mean score of 0.41 / 1 for this question. The difference between these means was not significant ($t = 1.44$, $df = 114$, $p > 0.05$). Prior to instruction, both groups posted results that corresponded to a macroscopic description of what students see rather than an explanation based on the behavior of particles making up the ice. Other students associated a temperature increase with the phenomenon of ice melting. These results suggested that students had a variety of incomplete or incorrect ideas regarding the melting of ice.

Table 37 summarizes the statistical comparisons of the means for the two groups on the kinetic theory pre-lab quiz. The differences in the mean scores for all five questions on the pre-lab quiz were not statistically significant ($p > 0.05$). The students in both groups were able to answer Question 1 without much difficulty. This question asked students to consider that mass changes as air is placed in to a car tire. Students in both groups were unable to explain how gases are involved in moving a liquid through a straw. The third question invited the students to consider that air has mass and exerts a force on leaves when the wind hits them. The fourth question asked the students to think of particles as having actual sizes with empty space between them. The last question required students to consider how particles behave relative to one another during a phase change.

Table 37. Kinetic Theory: Statistical Comparison of Lab Groups' Means on Each Pre-lab Question

	Treatment (N = 53)		Control (N = 63)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1	0.97	0.87	0.72	0.81	1.60	114	0.11
2	0.15	0.32	0.11	0.26	0.74	114	0.46
3	0.58	0.42	0.55	0.44	0.35	114	0.73
4	1.49	0.78	1.57	0.64	-0.62	114	0.54
5	0.52	0.38	0.41	0.41	1.44	114	0.15

The Treatment Group's Kinetic Theory Lab

In the elicitation activity, students offered various possibilities regarding the change of mass of a ball when it was inflated with air. Students who offered the possibility that the ball's mass would increase supported their idea by saying that particles which have mass were introduced into the ball. Students who said the ball's mass would not change said that air does not have mass or that the air was simply moved inside the ball which would not make it more massive. Those who said the ball's mass would decrease concluded that air is "light," and when air was placed inside the ball, the ball became light also. After the ball was inflated and remassed, the class arrived at the conclusion that gases have mass.

In the second elicitation activity, students squeezed the plungers of three 60-cc syringes. One syringe contained sand, another contained water, and the third contained air. After a class discussion, students arrived at the conclusion that gases are compressible because there is empty space between particles while solids and liquids do not have appreciable vacant space between their particles.

The third elicitation activity helped students recognize that liquids have space between their particles. Students predicted what the final volume would be if they poured equal volumes of water and ethanol together. They observed that the volume of the mixture was less than the sum of the two individual volumes. They observed air bubbles rising to the top of the liquid mixture. In a class discussion, students explained the presence of the gas bubbles by saying that the smaller molecules of one liquid were able to fit in between the larger molecules of the other liquid. The students offered the idea that the dissolved air between the larger molecules was squeezed out by the smaller molecules. Students commented that this activity resembled the sand-and-marbles question on the pre-lab quiz.

The control group did not perform these elicitation activities. These activities were included in the treatment group's kinetic theory lab so students would have hands-on, concrete experiences with which to accompany the theory. It is acknowledged that the inclusion of these activities may have affected the results of a comparison of the two groups' understanding of the material.

The purpose of the first development activity was to encourage students to imagine molecules as people. The activity urged students to visualize watching children play soccer and associate their relative spacing on the soccer field with the physical states of matter. The speed and spacing of the student players relative to each other was analogous to the temperature of particles. This analogy was adapted from that used by Fortman (*104*).

In the second development activity, students predicted what would happen to a box top when golf balls were rolled into it. The students tested their predictions and concluded that it moved proportionally farther as more golf balls were rolled. Students also predicted what effect the speed of the golf balls would have on how far the box top would move. After testing their predictions, they concluded that faster golf balls would move the box top farther because they exerted a greater force on the box top wall. After discussion, the students concluded that independent gas molecules push but never pull on a surface and that pressure depends on the speed and number of particles striking a surface.

The third development activity used a balloon stretched over the mouth of a dry flask. The flask was then heated and the balloon was allowed to expand. The instructor asked the students to explain this observation based on the kinetic theory of matter. They pointed out that the heated molecules moved faster and hit the interior surface of the balloon with more force. A side arm of the flask was opened and the balloon collapsed. When prompted, the students explained that the opening allowed air molecules to escape, leaving less pressure on the inside of the balloon. This allowed the balloon to deflate. The side arm of the flask was then closed, and the flask was allowed to cool to room temperature. Students observed the balloon move into the neck of the flask. Students at first said that the cool flask sucked the balloon in, but a class discussion helped these students realize that air pressure on the outside pushed the balloon into the flask.

The fourth development activity was an application of the kinetic theory of matter. Solids were placed in a capillary tube and attached to a thermometer. The thermometer was lowered into a beaker of water which was subsequently heated. Students noted the temperature at which the solid melted and compared it to a table of known melting points. The last development activity related the kinetic theory to chemical reactions. Students decomposed warmed, room temperature, and chilled hydrogen peroxide, H_2O_2, solutions using a catalyst. Students noticed that the warm H_2O_2 tended to liberate oxygen bubbles much faster than the other two solutions. The chilled H_2O_2 solution was the slowest at generating oxygen bubbles. The students commented that since they saw fewer bubbles when the temperature of the H_2O_2 was colder, chemical reactions are temperature dependent.

Kinetic Theory Lab: Rubric and Responses for Each Question on the Post-lab Quiz

After the lab, students answered questions on a post-lab quiz. The two groups' responses are discussed below.

Post-lab Question 1:

If you pump air into bicycle tire until it is firm, which of these would you say happens? The tire actually ... A. Gets lighter. B. Stays the same weight. C. Gets heavier. Why?

Student responses to this question are summarized in Table 38. The percentage of students who correctly recognized that the tire would become heavier for logical reasons increased from 36% to 92% for the treatment group but decreased from 22% to 16% for the control group. The logical reasons given were that "air has mass" and "more particles

Table 38. Kinetic Theory: Rubric and Responses for Post-lab Question 1

Response (points)	Treatment (N = 53)	Control (N = 63)
C, Correct choice, logical reason given (2)	49[a] (92)[b]	10 (16)
C, Correct choice, (1)[c]	3 (6)	15 (24)
B, Incorrect choice, logical reason given (1)	0 (0)	5 (8)
B, Incorrect choice (0.5)[d]	0 (0)	1 (2)
B, Incorrect choice (0)[c]	1 (2)	21 (33)
A, Incorrect choice (0)[c]	0 (0)	11 (17)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Illogical or no reason given
[d] Used a true statement which did not adequately answer the question

are placed in the tire." The percentage who said the tire would become heavier because it had an increased pressure went down from 10% to four percent for the treatment group but increased from eight percent to 14% for the control group. The percentage of students who believed the tire would become heavier but gave an illogical reason or no reason dropped from five percent to two percent for the treatment group but rose from five percent to ten percent for the control group. The percentage of students who believed that a tire's weight would stay the same decreased from 33% to two percent for the treatment group and from 44% to 43% for the control group. The most common reason given was that air does not have mass and thus it does not have weight. This misconception dropped from 15% to zero percent for the treatment group and from 22% to 16% for the control group. Eight percent of the control group continued to argue correctly that the weight of the tire would not change simply due to an increase in air pressure, but that reasoning was misapplied for this question.

The percentage of students who thought the tire would get lighter decreased from 17% to 0% for the treatment group but increased from 15% to 17% for the control group. The most common misconceptions still held by the control group were that mass spreads out as the tire expands, the tire gains "lightness" because it is filled with air, and increased molecular motion increases pressure and thus decreases weight. These results suggested that students who participated in the treatment group lab recognized that gases have mass and objects, which have gases pumped into them, weigh more. Students in the control group remained convinced that air does not have mass, or air makes objects lighter.

The treatment group had a mean score of 1.91 / 2 while the control groups' mean score was 0.63 / 2 for this question. The difference between these means was significant ($t = 12.37$, $df = 93$, $p \leq 0.01$). The treatment group improved their score 0.94 points over their pre-lab quiz score while the control group decreased 0.09 points.

The treatment lab emphasized the fact that gases have mass. The control lab pointed out that molecules are made of atoms, that they collide with each other and with the walls of a container, and that they have kinetic energy which can be calculated using the formula, $E = \frac{1}{2} mv^2$ (*9*), but it was not explicitly emphasized in the control lab that solids, liquids and gases have mass. It is acknowledged that the difference in emphasis on this topic in the two lab manuals may have influenced the outcome of this statistical examination. The results by the control group on this question indicated that its students did not internalize the mass nature of particles, a concept that would help students understand pressure, collisions and differences in diffusion rates. This question differentiated the treatment group from the control group among those who correlated pressure and weight. The treatment lab helped students abandon the idea that weight increased because the pressure of a gas increased. The control group continued to hold that view.

Post-lab Question 2:

Suppose you have a soda straw down in a cup of your favorite cola. Explain as best you can (based on the kinetic theory) how the cola gets into your mouth.

Student responses to this question are summarized in Table 39. The percentage of students who attributed the movement of a soda through a straw into one's mouth to pressure increased from 20% to 59% for the treatment group and from 18% to 19% for the control group. Students in both labs continued to describe the mechanics of the process rather than explain the phenomenon at the particle level. The percentage of

Table 39. Kinetic Theory: Rubric and Responses for Post-lab Question 2

Response (points)	Treatment (N = 53)	Control (N = 63)
Pressure or Force (1)[a]	28[b] (53)[c]	12 (19)
Pressure or Force (0.5)[d]	3 (6)	0 (0)
Pressure or Force (0)[e]	2 (4)	1 (2)
Suction (0)	17 (32)	39 (62)
Other (0.5)[f]	1 (2)	5 (8)
No response (0)	2 (4)	6 (10)

[a] Correct terms and logical explanation given
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct terms but no explanation given
[e] Correct terms but illogical explanation given
[f] True statement which does not adequately answer the question

students who attributed the movement of soda through a straw due to suction decreased from 64% to 32% for the treatment group and from 81% to 62% for the control group. The tenacity of deep-seated concepts is evident in this case. The results of this lab suggested that student involvement in a lab activity designed to teach certain concepts does not guarantee conceptual change.

Students in the treatment group displayed a better understanding of the particle nature of matter than did students in the control group. By their answers, treatment group students demonstrated an understanding that gaseous particles push rather than pull on a surface. Control group students as a whole did not display that understanding, though their manual (*9*) explicitly encouraged students to consider the effect of outside particles which push on a surface. The treatment group had a mean score of 0.62 / 1 and the control group had a mean score of 0.20 / 1 on this post-lab question. The difference between these means was significant ($t = 5.77$, $df = 114$, $p \leq 0.01$), suggesting that the guided learning lab on the kinetic theory helps students consider the effect of pressure differences on movement of liquids through a straw better than the traditional lab. When comparing the pre-lab to the post-lab quiz, the treatment group improved its mean score 0.47 points while the control group's mean score improved 0.09 points.

Post-lab Question 3:

On the basis of the kinetic theory, why do clothes hanging on the clothesline wave about when the wind blows?

Table 40 contains students' summarized responses to this question. Students attributed the movement of clothes on a clothesline when the wind blows to pressure or force. Students in both lab groups were instructed that gaseous particles are constantly hitting surfaces, and that movement of an object occurs if the forces on one side of the object are greater than on the other. The percentage of students who explained the movement of clothes moving on a clothesline due to force or pressure improved for the treatment group from 43% to 85% and from 37% to 57% for the control group. Those who included the terms "force" or "pressure" but who did not elaborate upon their answer declined in the treatment group from 13% to 4% and increased from ten percent to 11% for the control group. These results suggested that both labs helped students understand the role particles play in causing motion.

Table 40. Kinetic Theory: Rubric and Responses for Post-lab Question 3

Response (points)	Treatment (N = 53)	Control (N = 63)
Force or pressure (1)[a]	45[b] (85)[c]	36 (57)
Force or pressure (0.5)[d]	2 (4)	7 (11)
Other (0)	4 (8)	14 (22)
No response (0)	2 (4)	6 (10)

[a] Correct terms and logical explanation given
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct terms but illogical or no explanation given

Students continued to describe the phenomenon of clothes waving in the wind rather than explaining why they were moving. These ideas included: "air has currents and circulates around the clothes," "the wind causes the clothes to move around," "air pulls on the clothes," "air is lighter than the wind," "some molecules are moving fast while others are moving slow," and "energy increases and decreases in all directions." Two percent of the control group suggested that "evaporating water from wet clothes diffuses into the air and moves them."

The percentage of these students who offered nondescript answers or who did not answer the question declined from 28% to 12% for the treatment group and from 33% to 32% for the control group. The treatment group used the kinetic theory of matter to explain movement of clothes by wind more than the control group. The treatment group had a mean score of 0.87 / 1 while the control group had a mean score of 0.63 / 1. The difference between these means was significant ($t = 3.30$, $df = 111$, $p \leq 0.01$), suggesting that the guided learning Kinetic Theory lab was more effective than the traditional lab in helping students recognize the effect of particles in motion and their collisions with surfaces of objects.

Post-lab Question 4:

Suppose you had a cylinder with BBs up to the 50 mL mark, and you had another one up to the 50 mL mark with marbles. If you pour the BBs in on top of the marbles, how will the final volume compare to the sum of the two materials' volumes (more than 100 mL, equal to 100 mL, or less than 100 mL)? Why did you say that?

The responses to this question by students in both groups are summarized in Table 41. When marbles are placed in a container, even though they are touching, there are cavities between them. This question asked students to remark about the final volume of a mixture when 50 mL of BBs were poured on top of 50 mL of marbles in a graduated cylinder. The percentage of students who correctly concluded that the final volume of the mixture would be less than the sum of the two individual volumes decreased from

85% to 79% for the treatment group and from 95% to 51% for the control group. Fifteen percent of the treatment group and ten percent of the control group did not give a reason

Table 41. Kinetic Theory: Rubric and Responses for Post-lab Question 4

Response (points)	Treatment (N = 53)	Control (N = 63)
Total equals less than volume sums (2)[a]	34[b] (64)[c]	26 (41)
Total equals less than volume sums (1)[d]	8 (15)	6 (10)
Total equals volume sums (1)[e]	1 (2)	4 (6)
Total equals volume sums (0)[f]	5 (9)	11 (17)
Total equals more than volume sums (1)[e]	3 (6)	1 (2)
Total equals more than volume sums (0)[f]	2 (4)	3 (5)
No response (0)	0 (0)	12 (19)

[a] Correct answer and logical explanation given
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct answer but illogical or no explanation given
[e] Incorrect answer but logical explanation given
[f] Incorrect answer and illogical or no explanation given

for this choice. Students who gave improper reasons stated, "the BBs are lighter" and "BBs do not have as much volume as the marbles." The percentage of students who believed the final mixture volume would equal the sum of the individual volumes of marbles and BBs increased from 10% to 11% for the treatment group and from 0% to 23% for the control group. Two percent of the treatment group and six percent of the control group correctly stated that the BBs would fall into the cavities between the marbles. This statement was true, but it logically should have led these students to realize the sum of the volumes would be less than, not equal to 100 mL. The rest of the students who said the volume of the mixture was equal to the sum of the individual volumes offered inconsequential reasons such as "the volumes do not change since BBs and marbles are solids," "the mass of each does not change," and "the BBs will just sit on top of the marbles."

The percentage of students who said the total volume would be more than the sum of the two volumes rose from 4% to 10% for the treatment group and from 0% to 7% for the control group. The number of students who did not respond to the question decreased from 2% to 0% for the treatment group but rose from 5% to 19% for the control group.

For this question, the treatment group's mean score was 1.51 / 2, and the control group's mean score was 0.94 / 2. The difference between these means was significant ($t = 3.63$, $df = 114$, $p \leq 0.01$). This suggested that students who studied the kinetic theory using the guided learning pedagogy were more capable than the control group of recognizing the results when particles of different sizes were mixed together. The treatment group improved its score over the pre-lab quiz by 0.02 points, but the control group's mean score dropped by 0.63 points. A follow-up study would be required to determine the reason the control group's mean score declined by such a large amount. It is acknowledged that the elicitation activity involving the addition of water and alcohol into the same cylinder may have unduly favored the treatment group being able to answer this question correctly.

Post-lab Question 5:

How can you explain what is happening when water freezes?

Student responses to this question are summarized in Table 42. This question was concerned with the topic of phase changes of matter. The treatment group improved from 28% to 79% and the control group improved from 13% to 52%. These students included the idea that particles slow down or create a packed arrangement.

Table 42. Kinetic Theory: Rubric and Responses for Post-lab Question 5

Response (points)	Treatment (N = 53)	Control (N = 63)
Particles (1)[a]	42[b] (79)[c]	33 (52)
Phase change (0.5)[d]	1 (2)	8 (13)
Heat or temperature (0)[e]	5 (9)	15 (24)
Other (0.5)[d]	2 (4)	3 (5)
Other (0)	1 (2)	2 (3)
No response (0)	2 (4)	2 (3)

[a] Logical explanation given
[b] Number of times this answer was given
[c] Percentage of students
[d] True statement but does not explain what happens when ice melts
[e] Correct terms but explanation revealed misconceptions

Students who described water freezing as a phase change without addressing the particle nature of the phenomenon declined from 30% to 2% for the treatment group and from 25% to 13% for the control group.

Nine percent of the treatment group and 24% of the control group included a reference to temperature or heat in their explanations. Students in these groups indicated an understanding that heat transferred from the water, but they did not comment on the effect this heat loss had on the particles. Comments included, "heat gets sucked out by the cold air" and "cold takes the heat out." Students also expressed the idea that water changed to a lower temperature when it became ice. During this conversion to ice, some students said that molecules "cool off," "the molecules expand and become harder," and "the cold overtakes the warm molecules." Four percent of the treatment group and five percent of the control group said that water expanded as it froze. No student tried to explain why that was the case. Two percent of the treatment group and three percent of the control group reasoned that water molecules form uniform ice crystals. According to the sequence of labs in PSCI 1030, students had not studied latent heat of fusion at the time of this Kinetic Theory lab. This could explain why nine percent of the treatment group and 24% of the control group associated a temperature change with a phase change.

The treatment group had a mean score of 0.78 / 1 while the control group had a mean score of 0.66 / 1 on this question. The difference between these means was not significant ($t = 1.63$, $df = 114$, $p > 0.05$). When compared to the pre-lab quiz, the treatment group improved 0.26 points while the control group improved 0.25 points. Both labs were effective in helping students understand the concept of freezing as measured by this question.

Kinetic Theory: Comparison of Pre- and Post-lab Quiz Means

The two groups' mean scores were not significantly different (Table 37) on any of the pre-lab quiz questions ($p > 0.05$). However, four of the five post-lab quiz questions indicated a significant difference ($p \leq 0.01$) between the two groups' means (Table 43).

Table 43. Kinetic Theory: Statistical Comparison of Lab Groups' Means on Each Post-lab Question

	Treatment (N = 53)		Control (N = 63)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1	1.91	0.35	0.63	0.72	12.37	93[a]	0.00
2	0.62	0.42	0.20	0.38	5.77	114	0.00
3	0.87	0.33	0.63	0.46	3.30	111	0.00
4	1.51	0.75	0.94	0.95	3.63	114	0.00
5	0.78	0.41	0.66	0.41	1.63	114	0.11

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

The two groups' pre-lab and post-lab mean total scores were compared (Figure 3). Students' total scores on the Kinetic Theory pre-lab quiz and post-lab quiz were

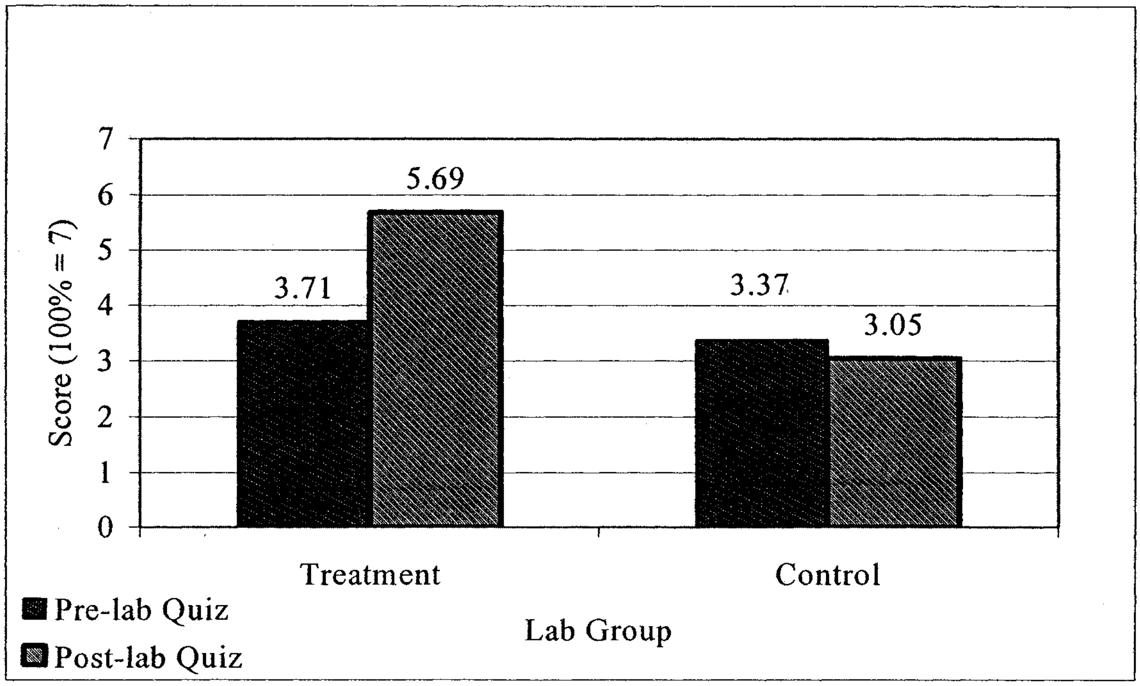


Figure 3. Comparison of Kinetic Theory pre-lab and post-lab quizzes by lab groups

determined and are reported in Table 44. The treatment group improved their mean score by 1.98 points from the pre-lab to the post-lab quiz while the control groups' score declined by 0.32 points. On the pre-lab quiz, the lab groups' means were not statistically different ($t = 1.21$, $df = 114$, $p > 0.05$). On the post-lab quiz, the groups' means were significantly different ($t = 9.52$, $df = 114$, $p \leq 0.01$). These data suggested that the guided learning lab instructional methodology produce significantly higher mean scores than the traditional laboratory pedagogy for questions like those found in the pre-lab and post-lab quiz.

Table 44. Kinetic Theory: Statistical Comparison of Each Lab Groups' Mean Total Scores on the Pre-lab and Post-lab Quizzes

	Treatment (N = 53)		Control (N = 63)				
Data Sources for Scores	Mean score	SD	Mean score	SD	t	df	p
Pre-lab quiz total	3.71	1.61	3.37	1.43	1.21	114	0.23
Post-lab quiz total	5.69	1.36	3.05	1.59	9.52	114	0.00

Given these measures of significance for the Kinetic Theory pre-lab and post-lab quizzes, an analysis of covariance, ANCOVA, was conducted to determine if the post-lab mean total quiz score for the treatment group remained significantly different from that of the control group after considering the groups' performances on the Kinetic Theory pre-lab quiz. The results of the ANCOVA indicated that the two groups' post-lab quiz means remained significantly different ($F = 89$, $p \leq 0.01$), after controlling for differences in the pre-lab quiz. This suggested that students who studied the kinetic theory using a guided learning approach outperformed students who studied the kinetic theory using the traditional lab format.

Kinetic Theory: Rubric and Responses for Conceptual Questions

The following conceptual questions identified students' ability to apply the kinetic theory of matter to new situations. The drawings in questions two and four were reproduced, with permission (Appendix Q), from the CPU Project (*48*). Fifty-two treatment group students and 29 control group students responded to the questions.

Conceptual Question 1:

An aluminum rod was found in a chemical stockroom. It measured 1.0 cm in diameter and was 50.0 cm long. Some students decided to take it and heat it with a laboratory burner to see what would happen. One thing they did was to check its length while hot. Do you think it was longer, the same length, or shorter? Based on your studies, tell why you chose that answer.

Students' responses to this question are summarized in Table 45. The predominant response indicated that students correctly associated movement of particles with temperature. Sixty-nine percent of the treatment group and 75% of the control group said the rod would get longer, but only 42% of the treatment group and 31% of the control group included the idea that the particles had increased vibration and that this increased motion caused particles to occupy greater space. Forty-six percent of the treatment group and 58% of the control group mentioned either the particles were vibrating faster or that the particles were moving apart from one another.

Students also said that the aluminum rod would get longer because its atoms or "molecules" would expand. These students did not explain whether the term "expand" meant that the particles literally increased in size or if the particles moved apart making the bulk material expand. Sixteen percent of the treatment group and ten percent of the control group thought the rod would stay the same length. Twelve percent of the treatment group and ten percent of the control group said that the rod would become shorter. Students also offered illogical reasons such as: "because it is aluminum," "heat can not change the length," and "it would start to melt."

Table 45. Kinetic Theory: Rubric and Responses for Conceptual Question 1

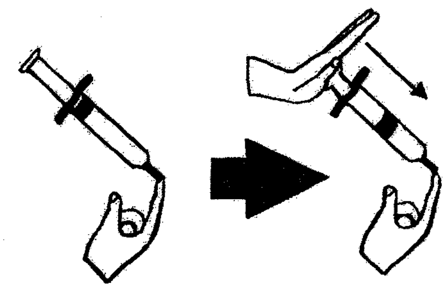
Response (points)	Treatment (N = 52)	Control (N = 29)
Longer (2)[a]	22[b] (42)[c]	9 (31)
Longer (1.5)[d]	12 (23)	12 (41)
Longer (1)[e]	2 (4)	1 (3)
Same length (0.5)[f]	2 (4)	0 (0)
Same length (0)[g]	6 (12)	3 (10)
Shorter (0.5)[f]	2 (4)	0 (0)
Shorter (0)[g]	4 (8)	3 (10)
No response (0)	2 (4)	1 (3)

[a] Correct response, logical reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, incomplete reason
[e] Correct response, illogical or no reason
[f] Incorrect response, incomplete reason
[g] Incorrect response, illogical or no reason

The treatment group had a mean score of 1.27 / 2 and the control group had a mean score of 1.28 / 2 on this question. The difference between these means was not significant ($t = -0.04$, $df = 79$, $p > 0.05$). This suggested that students in both groups applied their understanding that heated materials expand and explained their answer in terms of particle motion.

Conceptual Question 2:

Based on the kinetic theory, explain what happens to the pressure as you push in the plunger of a syringe while the small end is stopped up as in the picture here. (Figure, courtesy of the CPU Project, Appendix Q, (*101*))



Student response to this question are summarized in Table 46. The data show that 13% of the treatment group and 31% of the control group thought that the pressure increased inside the syringe, and they gave logical reasons for their responses. These students focused their attention on how the particles in the syringe would be affected. These students cited several events that would occur such as, "there will be a decreased surface area inside the syringe," "the force per unit area would increase," or "there would be more collisions per unit area of surface inside the syringe."

Twenty-one percent of the treatment group and 28% of the control group indicated that the pressure would increase, but their explanations did not reveal a complete or correct understanding to support their belief. Students gave these responses, "the molecules have nowhere to go," "there is a force," "an explosion is created," or "something is in the way."

Four percent of the treatment group and six percent of the control group said that the pressure would decrease inside the syringe. Four percent of the treatment group and three percent of the control group did not explain their answer. Three percent of the control group said that the pressure would decrease because the particles got closer together. Six percent of the treatment group and three percent of the control group said that the pressure would remain the same because the molecules could not go anywhere. Even though these students gave a true statement, the consequence of that statement had no bearing on why the pressure would remain the same. These students' responses indicated the conception that pressure was a property of the particles inside the syringe. Their reasoning supported the idea that if the number of particles could not change, the pressure would not change either.

Table 46. Kinetic Theory: Rubric and Responses for Conceptual Question 2

Response (points)	Treatment (N = 52)	Control (N = 29)
Pressure increases (1)[a]	7[b] (13)[c]	9 (31)
Pressure increases (0.5)[d]	11 (21)	8 (28)
Pressure decreases (0.5)[e]	0 (0)	1 (3)
Pressure decreases (0)[f]	2 (4)	1 (3)
Pressure does not change (0.5)[e]	3 (6)	1 (3)
Other (0.5)[d]	17 (33)	2 (7)
Other (0)[f]	9 (17)	5 (17)
No response (0)	3 (6)	2 (7)

[a] Correct response, logical reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, illogical or no reason
[e] Incorrect response, logical reason
[f] Incorrect response, illogical or no reason

Thirty-three percent of the treatment group and seven percent of the control group based their answers solely on what happens to the molecules without alluding to pressure.

These students made statements such as, “the molecules are forced closer together,” “molecules have nowhere to go,” “the molecules collide more,” or “molecules are compressed.” The students did not explain how the pressure of the gas would be affected. Seventeen percent of the treatment group and seventeen percent of the control group who did not comment on the pressure made the statement, “air can not get out,” “the volume decreases,” or their response was unclear.

The treatment group had a mean score of 0.43 / 1 and the control group had a mean score of 0.52 / 1 on this question. The difference between these means was not significant ($t = -1.07$, $df = 79$, $p > 0.05$). Neither lab methodology overwhelmingly helped students associate pressure changes and decreased surface area as measured by this question. The results on this question revealed that while students were able to conceptualize particles being packed more closely, it was harder for students to extend that increased compactness to their understanding of how pressure was increased. Students had a difficult time expressing a logical effect for a cause. Student answers suggested they equated pressure with volume by saying that a decreased volume would mean a decreased pressure. Other students’ answers showed they equated pressure with the total number of particles by saying that the pressure did not change because the number of particles could not change when the plunger was pushed into the syringe. Collectively, these observations indicated that students did not have a clear understanding of pressure.

Conceptual Question 3:

Suppose you were able to isolate one molecule of water at room temperature. How would you classify it? Is it a solid, a liquid, a gas, or would it be something else? Explain your answer.

Table 47 contains summaries of students' responses to this question. The data show that 29% of the treatment group and 14% of the control group correctly indicated that one molecule of water would have to be something else besides a solid, liquid or a gas. They said, "it is a thing of its own kind" and "you need other particles to have solids, liquids or gases." Students who said that a water molecule was something else but who gave illogical reasons said, "it has a definite shape and volume," "it depends on what the particle is," and "it is water and made of hydrogen and oxygen." Eight percent of the

Table 47. Kinetic Theory: Rubric and Responses for Conceptual Question 3

Response (points)	Treatment (N = 52)	Control (N = 29)
Solid (0)[a]	4[b] (8)[c]	7 (24)
Liquid (0)[a]	13 (25)	12 (41)
Gas (1)[d]	8 (15)	1 (3)
Gas (0)[a]	3 (6)	2 (7)
Something else (2)[e]	15 (29)	4 (14)
Something else (1)[f]	3 (6)	1 (3)
No response (0)	6 (12)	2 (7)

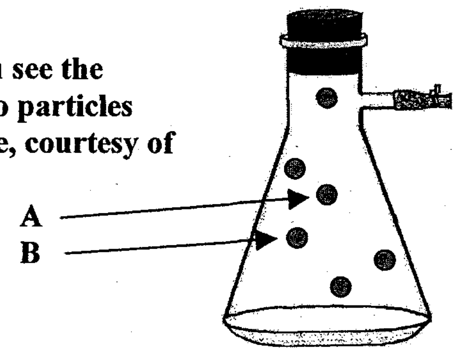
[a] Incorrect response, illogical or no reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Incorrect response, logical reason
[e] Correct response, logical reason
[f] Correct response, illogical or no reason

treatment group and 24% of the control group said the molecule was a solid. They illogically stated, "particles are solids at room temperature" and "it would be a solid if the temperature was below the freezing point." Twenty-five percent of the treatment group and 41% of the control group said that one molecule of water must be a liquid. They gave illogical reasons such as, "because it is water," "it is a bunch of molecules sliding around each other," and "if the temperature is at room temperature." Twenty-one percent of the treatment group and ten percent of the control group indicated that a single molecule was a gas. Logical statements given were, "gas particles are essentially alone," and "hydrogen and oxygen are both gases." Illogical statements were, "it would have to be cooled to be a solid or liquid," and "it would be a gas if the temperature was above the boiling point."

The treatment group had a mean score of 0.77 / 2 and the control group had a mean score of 0.34 / 2 on this question. The difference between these means was significant ($t = 2.35$, $df = 68$, $p \leq 0.05$). These results indicated that students who studied the kinetic theory of matter using the guided learning pedagogy developed a higher degree of concept mastery regarding individual particles of matter compared to students in the traditional lab studying the same material. An examination of students' papers indicates that 33% of the treatment group and 65% of the control group considered one molecule of water to be a solid or a liquid. These students revealed that they did not understand that phases of matter require many particles in proximity to each other. Students who said that one molecule of water was a gas recognized the independent nature of molecules in a gas, though there must be many particles acting in concert to display macroscopic properties of gases such as temperature and compressibility.

Conceptual Question 4:

Suppose you had a sample of air magnified so you see the particles. What would you say is between any two particles (such as A & B in the figure to the right)? (Figure, courtesy of the CPU Project, Appendix Q, (*101*))



Student responses to this question are summarized in Table 48. The most common response was that empty space existed between particles because there had to be room for compression to occur. Sixty percent of the treatment group and 34% of the control group expressed this view. One treatment group student reasoned that if there was something in the way, gases could not be compressed.

Table 48. Kinetic Theory: Rubric and Responses for Conceptual Question 4

Response (points)	Treatment (N = 52)	Control (N = 29)
Nothing or space (1)[a]	31[b] (60)[c]	10 (34)
Air or unidentified gas (0)[d]	13 (25)	6 (21)
Solid, liquid or identified gas (0)[d]	5 (10)	10 (34)
Pressure or forces (0)[d]	3 (6)	3 (10)

[a] Correct response
[b] Number of times this answer was given
[c] Percentage of students
[d] Incorrect response

Students believed that there exists the presence of more air or some unnamed gas between the particles of air. This view was expressed by 25% of the treatment group and

21% of the control group. Ten percent of the treatment group and 34% of the control group mentioned items such as "dust," "carbon," "smaller particles," "nitrogen," "oxygen," "suspended liquid drops," or "other molecules." Six percent of the treatment group and ten percent of the control group mentioned nonmaterial items such as "pressure," "repulsive forces," "kinetic energy," and "gravity."

The treatment group had a mean score of 0.60 / 1 while the control group's mean score was 0.34 / 1 on this question. The difference between these means was significant ($t = 2.21$, $df = 79$, $p \leq 0.05$). This suggested that the treatment lab was better able to help students recognize there was empty space between particles than the control lab did.

Conceptual Question 5:

If you spill a bucket of marbles, would you categorize the mass of marbles as a solid, a liquid or a gas? Why?

Table 49 contains the summarized responses by students to this question. Twenty-seven percent of the treatment group and 45% of the control group identified the mass as a solid and correctly stated that each marble is a solid. Nineteen percent of the treatment group and 24% of the control group said that the marbles represented a liquid. They stated, "some would still be together," "they had a definite mass but an indefinite shape," and "they separated slightly." Forty-four percent of the treatment group and 14% of the control group said the marbles represented a gas. They justified their responses by saying that the marbles "moved freely" or that the marbles were "not close together."

This question was open to interpretation, but it was the justification of an answer that determined if students received full credit. The treatment group predominantly envisioned the spilled bucket of marbles as a gas, 44% versus 29% and 23% for solids and liquids respectively. The control group predominantly saw the spilled mass of marbles as a solid, 45% versus 38% and 14% for liquids and gases.

Table 49. Kinetic Theory: Rubric and Responses for Conceptual Question 5

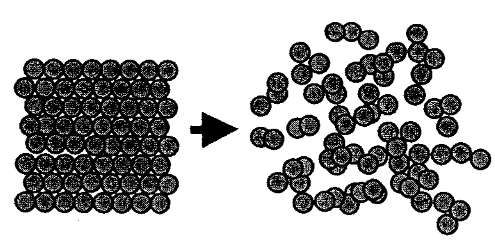
Response (points)	Treatment (N = 52)	Control (N = 29)
Solid (2)[a]	14[b] (27)[c]	13 (45)
Solid (1)[d]	1 (2)	0 (0)
Liquid (2)[a]	10 (19)	7 (24)
Liquid (1)[d]	2 (4)	4 (14)
Gas (2)[a]	23 (44)	4 (14)
No response (0)	2 (4)	1 (3)

[a] Correct response, logical reason given
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, no reason given

The treatment group had a mean score of 1.85 / 2 while the control group's mean score was 1.79 / 2. The difference between these means was not significant ($t = 0.46$, $df = 79$, $p > 0.05$). Both lab groups were able to justify their answers about the spilled bucket of marbles.

Conceptual Question 6:

What is shown in the picture at the right?
- **A. Melting**
- **B. Dissolving**
- **C. Decomposing**
- **D. Evaporating**
- **E. Other: ________**



Student responses to this question are summarized in Table 50.

Table 50. Kinetic Theory: Rubric and Responses for Conceptual Question 6

Response (points)	Treatment (N = 52)	Control (N = 29)
A. Melting (1)[a]	34[b] (65)[c]	13 (45)
B. Dissolving (0)	3 (6)	3 (10)
C. Decomposing (0)	6 (12)	4 (14)
D. Evaporating (1)[a]	4 (8)	8 (28)
E. Other (0)	1 (2)	0 (0)
No response (0)	1 (2)	0 (0)

[a] Correct response
[b] Number of times this answer was given
[c] Percentage of students

Sixty-five percent of the treatment group and 45% of the control group correctly said that the picture represented melting because it showed a tightly-packed and orderly arrangement of particles becoming slightly separated. Twenty treatment group students received copies that looked like the intact block of particles above. The rest of the treatment group and the entire control group received a question set on which the block was separated into two pieces by a prominent crack. This gave the appearance that the solid had begun to melt. From that, students reasoned that the liquid was becoming a gas. Student answers were scored based on whether the printing flaw existed on their paper. Eight percent of the treatment group and 28% of the control group said this represented evaporation. Nineteen percent of the treatment group and 24% of the control group gave incorrect responses of dissolving, decomposing, and other. Those who said "other" used the terms "diffusion," "expanding," "temperature," or "all of the above."

The treatment group had a mean score of 0.73 / 1 and the control group had a mean score of 0.72 / 1 on this question. The difference between these means was not significant ($t = 0.06$, $df = 79$, $p > 0.05$). While these results suggest that students understood melting or evaporating, the most common incorrect answer, decomposing, was given by 12% of the treatment group and by 14% of the control group. The makeup of each particle was not changing, but the particles were separating from each other. Students in neither group had engaged in the Chemical Reactions lab prior to this activity, so it is conceivable students did not know what decomposition meant.

Conceptual Question 7:

Suppose you find the mass of a 2-L bottle of cola then loosen the cap for 4 hours so much of the gas comes out. Would the mass of the cola (including the cap as before) be more, less or the same? Why?

Students' responses to this question are summarized in Table 51. Seventy-seven percent of the treatment group and 48% of the control group recognized that the escaping gas has mass and its absence would affect the overall mass of the cola. Eight percent of the treatment group and 21% of the control group associated the mass of the cola with its internal pressure. These students reasoned that a decrease in pressure was responsible for a decrease in mass.

Ten percent of the control group reasoned that since a gas, which has no weight or mass, was escaping, there would be no change in the overall mass of the bottle of cola. Two percent of the treatment group reasoned that the mass did not change because air went back into the bottle after the gas has escaped. Two percent of the treatment group said that capping the bottle forced air back into the bottle. Ten percent of the control group said that the mass of the opened cola bottle would have a greater mass. Two of these students justified their answer by saying that a light gas was now gone from the cola.

Table 51. Kinetic Theory: Rubric and Responses for Conceptual Question 7

Response (points)	Treatment (N = 52)	Control (N = 29)
Less mass (2)[a]	40[b] (77)[c]	14 (48)
Less mass (1)[d]	5 (10)	6 (21)
Same mass (0.5)[e]	1 (2)	0 (0)
Same mass (0)[f]	3 (6)	4 (14)
More mass (0)[f]	0 (0)	3 (10)
No response (0)	3 (6)	2 (7)

[a] Correct response, logical reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, illogical or no reason
[e] Incorrect response, incomplete reason
[f] Incorrect response, illogical or no reason

The treatment group had a mean score of 1.64 / 2 and the control group had a mean score of 1.17 / 2. The difference between these means was significant ($t = 2.47$, $df = 47$, $p \leq 0.05$), suggesting that students who studied the kinetic theory using the guided learning lab format achieved significantly higher scores than the control group. However, these results must be interpreted in light of the fact that the treatment group performed an activity comparing the mass of an uninflated ball and then it's mass after being inflated. This activity may have unduly influenced the outcome of this statistical comparison.

Conceptual Question 8:

You have 2 cups of 100 mL of water; one is cold and the other is warm. You put 1 drop of red food coloring into the middle of each cup. Will the food coloring mix with the water at the same rate, and why? If not, which would mix faster, and why?

Students' responses to this question are summarized in Table 52. Sixty-nine percent of the treatment group and 34% of the control group believed that mixing of the food coloring and the water occurred faster in warm water than in cold water. Their reasoning was that the molecules of warm water were moving at a higher rate of speed. This provided a higher rate of mixing with the food coloring. Both the treatment and the control labs emphasized the association between molecular activity and a substance's temperature.

Table 52. Kinetic Theory: Rubric and Responses for Conceptual Question 8

Response (points)	Treatment (N = 52)	Control (N = 29)
Hot faster (2)[a]	36[b] (69)[c]	10 (34)
Hot faster (1.5)[d]	9 (17)	9 (31)
Hot faster (1)[e]	3 (6)	6 (21)
Cold faster (0)[e]	2 (4)	2 (7)
No response (0)	2 (4)	2 (7)

[a] Correct response, logical reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, incomplete reason
[e] Correct response, no reason given

Seventeen percent of the treatment group and 31% of the control group offered responses that were true statements, but their reasons were more descriptive than explanative. For example, "diffusion is faster in hot water," "molecules react faster in hot water," and "more heat or energy is present." Other students did not offer a reason for stating that food coloring mixes faster in warm water than in cold. Twenty-one percent of the control group believed that the food coloring would mix in hot water faster for these unclear reasons: "electrons are moving faster," "there is more friction between the particles," and "because of the kinetic theory." Four percent of the treatment group and seven percent of the control group said that the food coloring would mix faster in cold water. Their reasons were that "molecules move faster and join faster" or "diffusion occurs better in cold water." Two percent of the treatment group and seven percent of the control group did not look on the back of their paper to answer this question.

The treatment group had a mean score of 1.70 / 2 and control group had a mean score of 1.36 / 2 on this question. The difference between these means was significant ($t = 2.42$, $df = 79$, $p \leq 0.05$), suggesting that students in the treatment group associated greater particle motion with higher temperatures than did the control group. Students continued to have difficulty with providing a causal explanation, preferring to give true, but inconsequential, statements as explanations.

Conceptual Question 9:

A pan of water is allowed to boil on a camp stove for 5 minutes. What is the makeup of the bubbles that rise from the bottom to the top? Explain (use drawings as needed). Note: hydrogen is a gas that can explode if ignited in the presence of oxygen.

Students' responses to this question are summarized in Table 53. Only 15% of the treatment group and 17% of the control group knew that the bubbles were water vapor and correctly understood that the molecules separated from one another to make steam. Seven percent of the treatment group indicated they believed the bubbles were water vapor, but they gave no reason. Forty-eight percent of the treatment group and 34% of the control group thought the bubbles were air or oxygen which was trapped or which was dissolved in the water. Two percent of the treatment group and ten percent of the control group thought the oxygen came from the breakup of water, but they did not account for the hydrogen that would also be present if water decomposed.

Table 53. Kinetic Theory: Rubric and Responses for Conceptual Question 9

Response (points)	Treatment (N = 52)	Control (N = 29)
Water vapor (2)[a]	8[b] (15)[c]	5 (17)
Water vapor (1)[d]	2 (7)	0 (0)
Air or oxygen (0)[e]	25 (48)	10 (34)
Hydrogen and Oxygen (0)[e]	6 (12)	4 (14)
Other gases or substances (0)[e]	5 (10)	6 (21)
No response (0)	6 (12)	4 (14)

[a] Correct response, logical reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, no reason
[e] Incorrect response, illogical or no reason

Twelve percent of the treatment group and 14% of the control group believed that the bubbles were hydrogen and oxygen gas liberated from the water. Ten percent of the treatment group and 21% of the control group said the bubbles were made of hydrogen, carbon dioxide, unidentified gases or "heat particles.".

The mean score for the treatment group was 0.35 / 2 and the control group's mean was 0.34 / 2 on this question. The difference between these means was not significant ($t = 0.01$, $df = 79$, $p > 0.05$). Neither lab methodology overwhelmingly helped students understand the nature of boiling.

These results reiterated the continued misunderstanding about the nature of gas bubbles in boiling water that has been reported in the literature. Students call bubbles in boiling water, air or oxygen, without considering that the added heat causes water molecules to separate from one another. Students do not understand at the particle level what is happening when a liquid changes to a gas. Students also do not read or understand the question. There were those who said the bubbles were a mixture of hydrogen and oxygen, but the question pointed out that such a mixture was capable of exploding if ignited. Students should have known the bubbles were not a mixture of hydrogen and oxygen because pans of boiling water do not explode. It was noted that 12% of the treatment group and 14% of the control group did not answer this question. The control group had their questions printed on both sides of one sheet of paper, and two students did not answer any questions on the back side of their paper. On all of the other student papers, questions were attempted on the second page. One could only speculate why students do not attempt to answer all questions.

Conceptual Question 10:

Does air weigh anything? Explain your thinking.

Table 54 contains students' responses to this question. Eighty-seven percent of the treatment group and 54% of the control group reasoned that air has weight. Students arrived at that conclusion by saying that air is made of atoms, which have mass and weight and by noting that containers weigh more when filled with air than when empty. One student in the control lab group wrote, "Air must weigh something because it has mass, and gravity is acting on it because it remains in our atmosphere." The treatment lab group justified their responses by noting the lab activity in which a child's ball was massed before and after air had been pumped into it. Although students witnessed this event, at least one student was still skeptical about air having mass. This student remarked, "Apparently, air has more mass" when referring to the inflated ball activity. This suggested that the student was experiencing a personal conception that differed from empirical evidence. This student's response indicated concepts are difficult to change even when there is evidence to support the change.

Table 54. Kinetic Theory: Rubric and Responses for Conceptual Question 10

Response (points)	Treatment (N = 52)	Control (N = 29)
Yes (2)[a]	43[b] (83)[c]	12 (41)
Yes (1.5)[d]	0 (0)	3 (10)
Yes (1)[e]	2 (4)	1 (3)
No (0)[f]	4 (8)	9 (31)
No response (0)	3 (6)	4 (14)

[a] Correct response, logical reason
[b] Number of times this answer was given
[c] Percentage of students
[d] Correct response, incomplete reason
[e] Correct response, illogical or no reason
[f] Incorrect response, illogical or no reason

The lab activity on the kinetic theory of matter was designed to convince students that matter is composed of particles possessing mass. Fourteen percent of the treatment lab group and 45% of the control lab group did not express a belief that air has mass. One student in the control lab expressed the belief that air was weightless, claiming, "otherwise, it would weigh us down." One treatment group student remarked, "Particles of air apply a force to other objects to give them a weight, but air has no weight of its own." Another treatment group student said, "Air has mass but it is unaffected by gravity. It can have a force but not weight." Students demonstrated by these responses that they were trying to assimilate the experiences of the lab into existing frameworks of understanding.

The treatment group's mean score was 1.69 / 2 and the control group's mean score was 1.02 / 2 for this question. The difference between these means was significant ($t = 3.33$, $df = 45$, $p \leq 0.01$). This suggests that the guided learning lab activity was more effective in helping students master the concept that all matter, even gases, have mass as measured by this question. However, it is acknowledged that the activity relating the mass of the uninflated and inflated ball performed by the treatment group may have unduly influenced the outcome of this statistical comparison.

Conceptual Question 11:

Place a check mark in the blank preceding all the statement(s) with which you agree.

A _____ Molecules get larger or smaller when they are heated or cooled.
B _____ Particles of solids, liquids or gases are in constant motion, even when nothing is pushing them.
C _____ If a liquid's temperature increases, the particles move faster.
D _____ Solid aluminum has air in between its atoms so it is less dense than iron.

Table 55 contains the data of students' responses to this question. Students were credited for each statement they selected which agreed with the scientific view of the kinetic theory of matter.

Table 55. Kinetic Theory: Rubric and Responses for Conceptual Question 11

Response (points)	Treatment (N = 52)	Control (N = 29)
A. Molecules get larger or smaller when they are heated or cooled. (0)[a]	15[b] (29)[c]	16 (55)
B. Particles of solids, liquids or gases are in constant motion, even when nothing is pushing them. (1)[d]	40 (77)	15 (52)
C. If a liquid's temperature increases, the particles move faster. (1)[d]	49 (94)	26 (90)
D. Solid aluminum has air in between its atoms so it is less dense than iron. (0)[a]	28 (54)	12 (41)

[a] Incorrect response
[b] Number of times this answer was selected
[c] Percentage of students
[d] Correct response

For Statement A, 29% of the treatment group and 55% control group incorrectly believed that individual particles of a material become larger as the temperature of the material increases. It is true that as temperature increases, intermolecular bond distances increase, but the atoms do not swell with increased temperature. These results suggested that students who performed the control group's kinetic theory lab were more likely than the treatment group to believe that heated solids expand because their individual atoms or molecules expand. For Statement A, the treatment group had a mean score of 0.71 / 1 and the control group had a mean score of 0.45 / 1. The difference between these means was significant ($t = 2.32$, $df = 53$, $p \leq 0.05$). Students who studied the kinetic theory using the guided learning methodology were better able to recognize that particles did not swell when heated than students in the traditional lab.

Statement B examined students' understanding about moving particles. Seventy-seven percent of the treatment group and 52% of the control group agreed with the idea that particles are in constant motion. For Statement B, the treatment group had a mean of 0.77 / 1 and the control group had a mean of 0.52 / 1. The difference between these means was significant ($t = 2.26$, $df = 50$, $p \leq 0.05$). These data pointed to the conclusion that students who engaged in the guided learning lab on the kinetic theory developed a better understanding about the concept of particle movement than those who participated in the control group's lab.

Statement C suggested that particle movement was directly proportional to the temperature of the object. Ninety-four percent of the treatment group and 90% of the control group recognized the kinetic theory concept that greater particle movement was associated with higher temperatures. For Statement C, the treatment group had a mean of 0.94 / 1 and the control group had a mean of 0.90 / 1. The difference between these means was not significant ($t = 0.75$, $df = 79$, $p > 0.05$), suggesting that both groups were aware that particle movement increased with an increase in the object's temperature.

In Statement D, 54% of the treatment group and 41% of the control group thought that aluminum had a low density due to the presence of air between its atoms. Students believed there to be an association between air and aluminum's density. The treatment group had a mean of 0.46 /1 and the control group had a mean of 0.59 / 1. The difference between these means was not significant (t = -1.07, df = 79, p > 0.05). These results suggested that both groups were not significantly different, and they incorrectly explained the density of aluminum by stating that a sample of the metal contained air.

The data in Table 56 shows the mean scores by each group for each question. It also contains a statistical comparison of the means using an independent samples t test.

Table 56. Kinetic Theory: Statistical Comparison of Each Lab Groups' Mean Score on Each Conceptual Question

	Treatment (N = 52)		Control (N = 29)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1	1.27	0.82	1.28	0.77	-0.04	79	0.97
2	0.43	0.31	0.52	0.39	-1.07	79	0.29
3	0.77	0.88	0.34	0.72	2.35	68[a]	0.02
4	0.60	0.50	0.34	0.48	2.21	79	0.03
5	1.85	0.50	1.79	0.49	0.46	79	0.65
6	0.73	0.45	0.72	0.46	0.06	79	0.95
7	1.64	0.70	1.17	0.89	2.47	47[a]	0.02
8	1.70	0.57	1.36	0.67	2.42	79	0.02
9	0.35	0.74	0.34	0.77	0.01	79	0.99
10	1.69	0.70	1.02	0.96	3.33	45[a]	0.00
11A	0.71	0.46	0.45	0.51	2.32	53[a]	0.02
11B	0.77	0.43	0.52	0.51	2.26	50[a]	0.03
11C	0.94	0.24	0.90	0.31	0.75	79	0.46
11D	0.46	0.50	0.59	0.50	-1.07	79	0.29

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

Question 1 and Question 11A both address the concept of swelling or contracting as a function of temperature. There was no distinction among the groups' means on Question 1, but there was a distinction on question 11A. Students in both groups had no difficulty recognizing the macroscopic changes in the object's size as a function of temperature (Question 1), but the treatment group significantly outscored the control group on Question 11A which addressed the possibility of size changes for individual particles as the temperature changed.

Neither group demonstrated a clear understanding of what gaseous pressure is or how it is created as evidenced by Question 2. There were four questions that probed students' association of particles with phases of matter. Students showed a distinction between lab methodologies only with Question 3. The treatment group more readily recognized that one molecule of water could not be a solid, liquid or a gas, but it had to be an entity all its own. Questions 5 and 6 dealt with representations of phase changes. Without distinction, students in both groups showed an understanding of this concept. Question 9 was equally, but poorly, understood by both groups. Neither lab methodology superiorly helped students understand that the bubbles in boiling water were pockets of water vapor. Students responded with better explanations to drawings that depicted particles separating during phase change than they did to macroscopic, non-particle like observations such as boiling water.

Questions 4, 8, 11B, and 11C addressed fundamental concepts of the kinetic theory. Question 4 dealt with matter being composed of particles, which are separated by empty space. There was a distinction between the two groups on that question in favor of the treatment group. This distinction should be interpreted in light of the fact that a syringe activity was performed by the treatment group that was not performed by the control group. That activity addressed the independence of particles and led students to consider the possibility there is empty space between particles. It is acknowledged that this activity may have unduly influenced the outcome of the statistical comparison of the groups' means on this question. Though both groups did an activity that addressed diffusion as a function of the temperature of the medium, the treatment group had a distinctively-higher mean on Question 8 than did the control group. There was a distinction between the two groups in favor of the treatment group on Question 11B. Both labs addressed the concept of constant motion of particles, but the treatment group's mean score was different from the control group for this question. On Question 11C, both groups had equal means. That is, both groups understood the concept that particle speed is related to temperature. This point is only technically true only if the particles' masses are identical. Nothing was mentioned about the mass of the particles in this problem, and no student identified that distinction as a necessary condition for that relationship to be true.

Questions 7, 10, and 11D involved knowing gases have mass. Questions 7 and 10 probed for that understanding directly. The treatment group had a distinctly higher score on those two questions, but these results should be interpreted in light of the fact that the treatment group performed an activity indicating that gases have mass, while the control group did not. This may have unduly influenced the results on this question. Question 11D made use of the relatively low density of a gas to assert that the "lightness" of an aluminum bar is due to air present within the bar of aluminum itself. Student scores on that question were not statistically different. The mean scores indicate that this reasoning was used by 46% of the treatment group and by 59% of the control group.

Kinetic Theory: Comparison of Conceptual Questions' Total Scores

A group comparison was made of the students' total scores on the Kinetic Theory conceptual questions (Figure 4). The treatment group's mean total score was 14.84 / 21 and the control group had a mean score of 12.17 / 21. The difference between these means was significant ($t = 3.01$, $df = 79$, $p \leq 0.01$), suggesting that students who studied the kinetic theory of matter using the guided learning pedagogy scored higher than those who used the traditional laboratory method as measured by these conceptual questions.

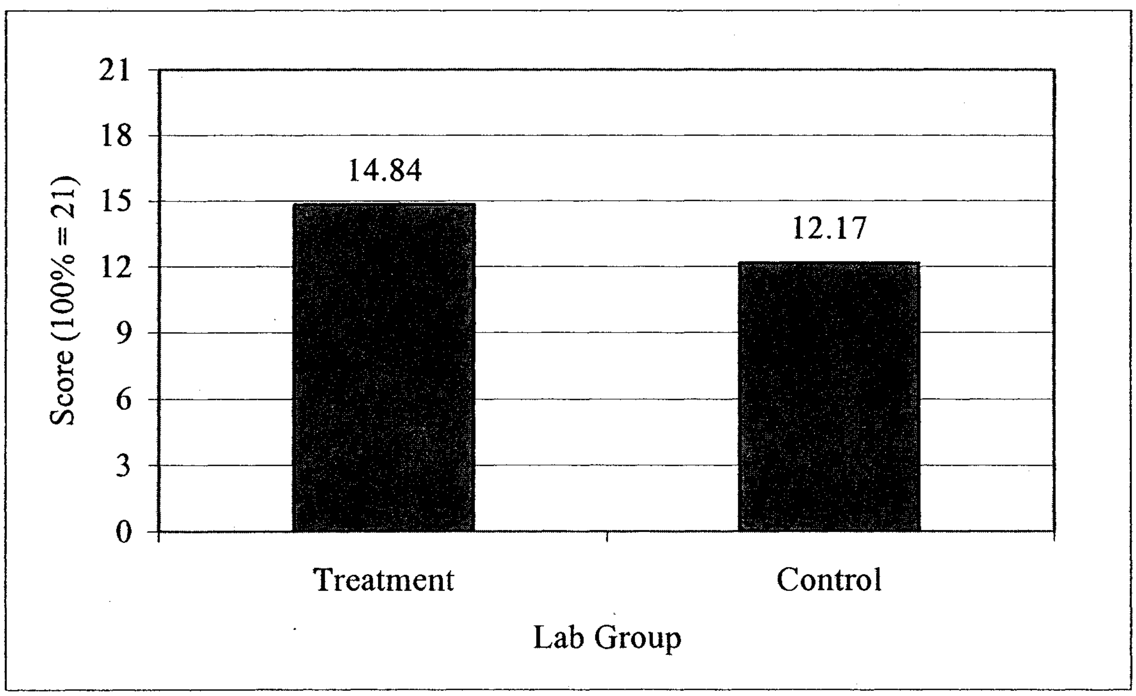


Figure 4. Group comparisons of Kinetic Theory lab conceptual questions

Results and Discussion: Chemical Reactions

In the third lab, students were introduced to the concepts that chemical reactions result from interactions of particles and that the number of particles remains constant during the reaction. Students were led to recognize evidence of chemical reactions and they were instructed on how to categorize chemical reactions into four broad types.

Chemical Reactions Lab: Rubric and Responses for Each Question on the Pre-lab Quiz

There were 56 treatment group students and 57 control group students who responded to the Chemical Reactions pre-lab quiz.

Pre-lab Question 1

Label these reactions with these possibilities:
Composition (C), Decomposition (D), Single Replacement (SR),
Double Replacement (DR), or Something Else (SE).

Tables 57 – 60 contain the data of student response summaries for Question 1A – 1D

1A: _____ A + B → AB

Table 57. Chemical Reactions: Rubric and Responses for Pre-lab Question 1A

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (1)[a]	54[b] (96)[c]	50 (88)
D (0)	1 (2)	1 (2)
SR (0)	1 (2)	3 (5)
DR (0)	0 (0)	2 (4)
SE (0)	0 (0)	1 (2)

[a] Correct answer
[b] Number of times this item was chosen
[c] Percentage of students

1B: _____ AB + C → AC + B

Table 58. Chemical Reactions: Rubric and Responses for Pre-lab Question 1B

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (0)	1[a] (2)[b]	4 (7)
D (0)	9 (16)	4 (7)
SR (1)[c]	45 (80)	45 (79)
DR (0)	1 (2)	3 (5)
SE (0)	0 (0)	1 (2)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct answer

1C: _____ PQ + RS → PS + RQ

Table 59. Chemical Reactions: Rubric and Responses for Pre-lab Question 1C

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (0)	1[a] (2)[b]	0 (0)
D (0)	0 (0)	0 (0)
SR (0)	2 (4)	4 (7)
DR (1)[c]	53 (95)	53 (93)
SE (0)	0 (0)	0 (0)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct answer

1D: ____ DE → D + E

Table 60. Chemical Reactions: Rubric and Responses for Pre-lab Question 1D

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (0)	3[a] (5)[b]	4 (7)
D (1)[c]	48 (86)	46 (81)
SR (0)	4 (7)	4 (7)
DR (0)	1 (2)	2 (4)
SE (0)	0 (0)	1 (2)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct answer

. The data show that students in both groups were able to identify reaction types based on generic alphabetic equations. The terms composition, decomposition, single replacement, and double replacement were self-explanatory. The total score of question one for the treatment group was 3.54 / 4 and for the control group was 3.33 / 4. The difference between these means was not significant ($t = 0.96$, $df = 111$, $p > 0.05$), suggesting that the two groups' were not significantly different on this question.

Pre-lab Question 2

Name at least 3 things that indicate a chemical reaction has happened.

Table 61 summarizes students' responses to this question. These data provided evidence that students have a variety of ideas about indicators of chemical reactions. Students' responses were consolidated into 37 categories. The most common responses included color change, the liberation of a gas, odor change, energy change in the form of

Table 61. Chemical Reactions: Rubric and Responses for Pre-lab Question 2

Response (points)	Treatment (N = 56)	Control (N = 57)
Change Color (1)[a]	28[b] (50)[c]	29 (51)
Gas formed (1)[a]	13 (23)	19 (33)
New substances appear / old substances disappear (1)[a]	13 (23)	12 (21)
Change substance (0.5)[d]	12 (21)	0 (0)
Odor change (1)[a]	12 (21)	14 (25)
Change Form/phase (0)	11 (20)	12 (21)
Energy change (1)[a]	10 (18)	7 (12)
Temperature / heat change (1)[a]	10 (18)	21 (37)
Precipitate / smoke (1)[a]	8 (14)	9 (16)
Physical change (0)	7 (13)	4 (7)
Chemical swapped / change (0.5)[d]	6 (11)	7 (12)
Decomposition (0)	5 (9)	8 (14)
Molecules change structure (0.5)[d]	4 (7)	4 (7)
Burning (1)[a]	4 (7)	1 (2)
Dissolve / Form solution (0)	3 (5)	1 (2)
Single Replacement (0)	3 (5)	1 (2)
Rust (1)[a]	3 (5)	1 (2)
Sound given off / explosion (1)[a]	2 (4)	7 (12)
Composition (0)	2 (4)	4 (7)
Density change (0)	2 (4)	2 (4)
Boiling (0)	2 (4)	0 (0)
Movement (0)	2 (4)	1 (2)
Double Replacement (0)	1 (2)	3 (5)
Mass change (0)	1 (2)	2 (4)

[a] Correct response
[b] Number of times this item was mentioned
[c] Percentage of students
[d] True statement which does not adequately indicate a chemical reaction

Table 61 (cont.)

Response (points)	Treatment	Control
Transfer of molecules (0)	1 (2)	0 (0)
Ionization (0)	1 (2)	0 (0)
Melt (0)	1 (2)	0 (0)
Light given off (1)[a]	1 (2)	0 (0)
Chemical properties stay same (0)	1 (2)	0 (0)
Water produced (1)[a]	1 (2)	0 (0)
Oxidation (0.5)[d]	0 (0)	2 (4)
Combustion (0.5)[d]	0 (0)	1 (2)
Gain / Lose electrons (0.5)[d]	0 (0)	2 (4)
Size / Volume change (0)	0 (0)	2 (4)
Texture (0)	0 (0)	1 (2)
Crystallization (0)	0 (0)	1 (2)

[a] Correct response
[b] Number of times this item was mentioned
[c] Percentage of students
[d] True statement which does not adequately indicate a chemical reaction

a temperature change or emission of light or sound, or production of smoke or precipitate. Twenty percent of the treatment group and 21% of the control group stated that a phase change indicated a chemical change. Students also included true statements that were not evidence of a chemical reaction. Student comments like "molecules change structure," "oxidation," and "gain/loss of electrons" were all specific features associated with chemical reactions, but not always readily observable. Students also offered less specific comments like "a change in substance" or "combustion."

Students listed terms such as "composition" and "double replacement" as evidence of chemical reactions. While these terms are types of chemical reactions, they are not indicators of chemical reactions. It was not clear if students believed that "composition" and "double replacement" were actually evidence for chemical reactions or if it was a term they had recently heard or read and knew it belonged in a discussion of chemical reactions.

The treatment group had a mean score of 1.78 / 3 and the control group had a mean score of 1.53 / 3 on this question. The difference between these means was not significant $t = 1.33$, $df = 111$, $p > 0.05$). This question established that both groups were able to recognize evidence of chemical reactions.

Pre-lab Question 3

In each of these, indicate if this represents a chemical reaction and tell why you think so.

The data in Table 62 – 64 summarize student responses to Questions 3A – 3C.

3A:

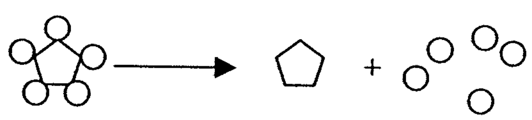


Table 62. Chemical Reactions: Rubric and Responses for Pre-lab Question 3A

Response (points)	Treatment (N = 56)	Control (N = 57)
Yes (1)[a]	47[b] (84)[c]	42 (74)
Yes (0.5)[d]	6 (11)	9 (16)
No (0)	2 (4)	5 (9)
Left blank (0)	1 (2)	1 (2)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical reason

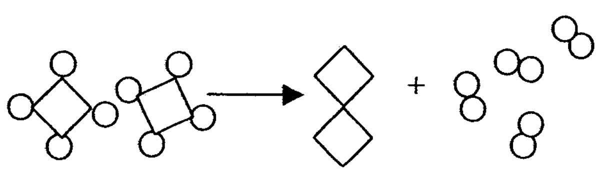
This particle diagram represented a decomposition chemical reaction. Ninety-five percent of the treatment group and 90% of the control group recognized that this diagram represented a chemical reaction. The reasons given were varied and not always correct.

Students justified their choice by making comments such as "the original form has been broken down," "it became something new," and "items separated" were common. Four students in each group mentioned that bonds had been broken. This response indicated that these students were already aware of the role chemical bonds play in chemical reactions.

Two percent of the treatment group and two percent of the control group said that the diagram represented a chemical reaction, but they added that it also represented a physical change. One control group student wrote that it was a "physical change and chemical change."

The treatment group had a mean score of 0.88 / 1 and the control group had a mean score of 0.81 / 1. The difference between the two groups was not significant ($t = 1.34$, $df = 110$, $p > 0.05$). These results indicated that students in both groups were able to recognize reaction types by looking at particle diagrams.

3B:



This particle diagram also represented a decomposition reaction. Unlike the previous particle diagram, this one generated products that were multi-atom units. This behavior indicated that new bonds were formed. Students responded with statements that were not completely explicable. Their responses included, "particles attached to each other," "chemicals exchanged elements," "the reaction has been altered," and "a new system has been formed." These explanations showed that students did not have clear terminology for what they were trying to discuss.

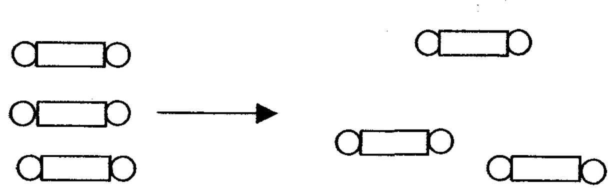
Table 63. Chemical Reactions: Rubric and Responses for Pre-lab Question 3B

Response (points)	Treatment (N = 56)	Control (N = 57)
Yes (1)[a]	34[b] (61)[c]	31 (54)
Yes (0.5)[d]	16 (29)	21 (37)
No (0)	5 (9)	3 (5)
Left blank (0)	1 (2)	2 (4)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical reason

The treatment group had a mean score of 0.78 / 1 and the control group had a mean score of 0.70 / 1 on this question. The difference between the two groups was not significant ($t = 1.37$, $df = 111$, $p > 0.05$). These results indicated that students in both groups were able to recognize reaction types by looking at particle diagrams.

3C:



Seventy-seven percent of the treatment group and 80% of the control group recognized that the particle diagram did not represent a chemical reaction. These students reasoned that the particles had rearranged, but they still had the same composition. Four percent of the control group included the term physical change in their explanation. Nine percent of the treatment group and five percent of the control group did not provide an explanation for their response.

Table 64. Chemical Reactions: Rubric and Responses for Pre-lab Question 3C

Response (points)	Treatment (N = 56)	Control (N = 57)
Yes (0.5)[a]	0[b] (0)[c]	1 (1)
Yes (0)	9 (16)	6 (11)
No (1)[d]	37 (66)	43 (75)
No (0.5)[e]	6 (11)	3 (5)
Unsure if bonds were broken (0)	0 (0)	1 (2)
Left blank (0)	4 (7)	3 (5)

[a] Incorrect answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, logical reason
[e] Correct answer, illogical or no reason

Sixteen percent of the treatment group and 11% of the control group believed that this particle diagram represented a chemical reaction. They said the diagram represented decomposition and replacement reactions. They also said "the makeup was different," "the chemicals spread in different directions," and "they combine." The treatment group's mean score was 0.77 / 1 and the control group's mean score was 0.80 / 1. The difference between these means was not significant ($t = -0.44$, $df = 111$, $p > 0.05$). These results indicate that students in both groups were able to recognize reaction types by looking at particle diagrams.

Pre-lab Question 4

How would you define a "chemical reaction"?

The data in Table 66 summarize student responses to this question.

Table 65. Chemical Reactions: Rubric and Responses for Pre-lab Question 4

Response (points)	Treatment (N = 56)	Control (N = 57)
New / changed composition (1)[a]	36[b] (64)[c]	20 (35)
Result of change (bonds broken or formed) (1)[a]	2 (4)	4 (7)
Cause of change (heat, energy, etc.) (0.5)[d]	0 (0)	3 (5)
An unspecified "change" is observed (0.5)[d]	5 (9)	7 (12)
Both sides equal (0.5)[d]	0 (0)	3 (5)
Listed a type of chemical reaction (0.5)[d]	0 (0)	3 (5)
The name for the phenomenon (0)	8 (14)	9 (16)
Change in shape, size or form or quantity (0)	2 (4)	4 (7)
No response (0)	3 (5)	4 (7)

[a] Correct response
[b] Number of times this item was mentioned
[c] Percentage of students
[d] Comment which does not adequately define a chemical reaction

Sixty-four percent of the treatment group and 35% of the control group explained a chemical reaction in terms of a new composition of the products or the composition of original material had changed. Four percent of the treatment group and seven percent of the control group focused on the making and breaking of bonds that occurs during a chemical reaction. One student said that a chemical reaction was "a reaction that takes place in which a new product is formed and energy is released or absorbed." Another student said that in addition to changes in a molecule's composition, there can also be "physical changes as well."

Other students were less specific. Nine percent of the treatment group and 27% of the control group made less specific statements where they focused on the cause of the change rather than what change has occurred within the material. Students comments included: "when some things change and become another thing," "a reaction when combining two or more elements," "when you add two chemicals together," "a reaction that changes the nature of the particles involved," and "change of a chemical due to heat." Such explanations were more descriptive of a process than an explanation of how the identity of the particles changes. This question had a mean score of 0.72 / 1 for the treatment group and 0.56 / 1 for the control group. The difference between the two groups was significant ($t = 2.03$, $df = 111$, $p \leq 0.05$). The treatment group was significantly different than the control group.

Pre-lab Question 5:

Which of these are chemical reactions? Check all that are chemical reactions.
A. ______ Firecracker exploding
B. ______ Ice melting
C. ______ Nail rusting
D. ______ Water evaporating
E. ______ Paper burning

Table 66 contains the summarized student data for this question. Both the treatment and control groups recognized chemical reactions. Eighty-nine percent of the treatment group and 88% of the control group recognized that an exploding firecracker represented a chemical reaction. Eighty-nine percent of the treatment group and 90% of the control group knew that rust forming on a nail represented a chemical reaction. Eighty-nine percent of the treatment and 97% of the control group knew that burning paper represented a chemical reaction.

Table 66. Chemical Reactions: Rubric and Responses for Pre-lab Question 5

Response (points)	Treatment (N = 56)	Control (N = 57)
Firecracker exploding (1)[a]	50[b] (89)[c]	50 (88)
Ice melting (1)[d]	45 (80)	43 (75)
Nail rusting, (1)[a]	50 (89)	51 (89)
Water evaporating (1)[d]	40 (71)	37 (65)
Paper burning (1)[a]	50 (89)	55 (96)

[a] Correct if this item was checked
[b] Number of times this answer was identified correctly
[c] Percentage of students
[d] Correct if this item was unchecked.

These data also showed that fewer students were prepared to identify changes that were not chemical reactions. Eighty percent of the treatment group and 75% of the control group correctly recognized that ice melting is not a chemical reaction. Seventy-one percent of the treatment group and 65% of the control group correctly considered that evaporation of water was not a chemical change. The mean total score on this question was 4.18 / 5 for the treatment group and was 3.96 / 5 for the control group. The difference between these means was not significant ($t = 0.91$, $df = 111$, $p > 0.05$). Students in both groups were capable of identifying events that were chemical reactions.

The data in Table 67 summarizes the results of statistical comparisons of each question on the pre-lab quiz for the two groups.

Table 67. Chemical Reactions: Statistical Comparison of Lab Groups' Means on Each Pre-lab Question

	Treatment (N = 56)		Control (N = 57)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1A	0.96	0.19	0.88	0.33	1.73	89[a]	0.09
1B	0.80	0.40	0.79	0.41	0.18	111	0.85
1C	0.95	0.23	0.93	0.26	0.36	111	0.72
1D	0.86	0.35	0.81	0.40	0.71	111	0.48
Question 1 Total	3.54	0.99	3.33	1.23	0.96	111	0.34
2	1.78	0.90	1.53	1.10	1.33	111	0.19
3A	0.88	0.29	0.81	0.32	1.34	110	0.18
3B	0.78	0.33	0.70	0.33	1.37	111	0.18
3C	0.77	0.38	0.80	0.35	-0.44	111	0.66
Question 3 Total	2.44	0.73	2.31	0.78	0.92	111	0.36
4	0.72	0.42	0.56	0.42	2.03	111	0.05
5A	0.89	0.31	0.84	0.37	0.79	111	0.43
5B	0.80	0.40	0.74	0.44	0.84	111	0.40
5C	0.89	0.31	0.86	0.35	0.53	111	0.60
5D	0.71	0.46	0.61	0.49	1.13	111	0.26
5E	0.88	0.33	0.91	0.29	-0.64	111	0.52
Question 5 Total	4.18	1.21	3.96	1.28	0.91	111	0.36

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

The only question that had a statistical difference between the two groups was Question 4. This question asked students to define a chemical reaction. No effort was made to determine if students had been exposed to this material prior to performing the lab. Had one group been exposed to a study of chemical reactions in the lecture prior to performing the lab while the other had not, it is conceivable they would have outperformed the other group on all of the quiz questions. Only Question 4 had a significant difference in its mean score for the two groups ($p \leq 0.05$).

The Treatment Group's Chemical Reactions Lab

The elicitation activities were performed before any terminology or information was introduced to the student in the treatment lab. Students recorded comments such as "the temperature dropped," "the water changes from clear to cloudy," and "it bubbled and air filled the balloon."

Students then read about evidences of chemical reactions and how chemical reactions are represented. Students were introduced to terminology, and they were shown a particle diagram of a chemical reaction. After this introduction, one student described what was happening in chemical reactions by writing on his lab sheet, "particles decomposed but (there are) the same elements after (the reaction) in a balanced chemical reaction." Examples that were not chemical reactions but were only physical changes were described by statements such as, "no chemical reaction … separated into the same stuff … elements," "they separated but no difference," and "melting or evaporation."

In the development activities, students discussed how to draw on their lab sheets particle diagrams that accompanied reactions given in their instructions. Students also determined the types these reactions were. Students, working in groups of four, drew particle diagram equations on dry-erase marker boards and displayed them to the class at the end of this activity. Each group's drawing correctly represented the three chemical equations that were discussed on their lab sheet. When called upon, students correctly explained to the class what their particle diagram represented.

The development activities also gave students the opportunity to observe indicators of chemical reactions and to observe that chemical reactions do not always occur. Students were provided with chemicals and equipment, and students were guided with instructions to perform activities and decide if a chemical reaction occurred. Students correctly identified and labeled on their lab sheets the activities that were and those that were not chemical reactions. Then, students worked in their groups and discussed five additional reactions. The students were able to discuss and agree upon each type of reaction that occurred.

Chemical Reactions Lab: Rubric and Responses for Each Question on the Post-lab Quiz

After the Chemical Reactions labs, students answered questions on a post-lab quiz. The two groups' responses are discussed below.

Post-lab Question 1:

Student responses to the four parts of this question are summarized in Tables 68 – 71. Students in both lab groups were taught using generic alphabetic equations like those exhibited in the following four parts of this question.

Label these reactions with these possibilities:
Composition (C), Decomposition (D), Single Replacement (SR),
Double Replacement (DR), or Something Else (SE).

1A: _____ AB + C → A + CB

Upon comparing this question to pre-lab quiz question 1B, the percentage of students who correctly recognized that this reaction represented a single replacement reaction improved from 80% to 96% for the treatment group. The control group's percentage changed from 79% to 84%.

Table 68. Chemical Reactions: Rubric and Responses for Post-lab Question 1A

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (0)	1[a] (2)[b]	5 (9)
D (0)	1 (2)	3 (5)
SR (1)[c]	54 (96)	48 (84)
DR (0)	0 (0)	0 (0)
SE (0)	0 (0)	1 (2)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct answer

The difference between the two groups' mean scores for the single-replacement example on the pre-lab quiz, question 1B, was not significant (Table 68). On this post-lab quiz question, the mean score for the treatment group was 0.96 / 1 and 0.84 / 1 for the control group. The difference between these means was significant ($t = 2.23$, $df = 84$, $p \leq 0.05$). These results suggested that the guided learning pedagogy was more effective at helping students recognize generic types of chemical reactions than the traditional lab instructional style.

1B: _____ AB + CD → AD + CB

This question was analogous to pre-lab quiz question 1C. The percentage of students who correctly recognized that this reaction represented a double replacement reaction improved from 95% to 98% for the treatment group. The percentages for the control group who correctly recognized this reaction as a double replacement reaction declined from 93% to 89%.

Table 69. Chemical Reactions: Rubric and Responses for Post-lab Question 1B

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (0)	0[a] (0)[b]	1 (2)
D (0)	0 (0)	0 (0)
SR (0)	1 (2)	4 (7)
DR (1)[c]	55 (98)	51 (89)
SE (0)	0 (0)	1 (2)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct answer

The difference between the two groups' mean scores for the double-replacement example on the pre-lab quiz, Question 1C, was not significant (Table 67). The mean score for the treatment group on this post-lab question was 0.98 / 1 and the control group's mean score was 0.89 / 1. The difference between these means was significant

($t = 1.95$, df = 76, $p \leq 0.05$). These results suggested that the guided learning pedagogy was more effective at helping students recognize types of chemical reactions than the traditional laboratory instructional style.

1C: _____ PQ + RS → PQRS

There was not a similar type of problem like this question on the pre-lab quiz. The composition reaction on the pre-lab quiz was question 1A. There, two elements combined to form a compound. In this problem, two compounds react to form another compound. This difference in the two questions could explain why the percentage of students who correctly recognized that this as a composition reaction declined from 96% to 79% for the treatment group and from 88% to 58% for the control group. Neither lab group experienced an example exactly like the one presented in this question. Nevertheless, this problem helped students to apply their understanding of what it means for a reaction to be a composition reaction.

Table 70. Chemical Reactions: Rubric and Responses for Post-lab Question 1C

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (1)[a]	44[b] (79)[c]	33 (58)
D (0)	3 (5)	0 (0)
SR (0)	1 (2)	2 (4)
DR (0)	2 (4)	7 (12)
SE (0)	6 (11)	15 (26)

[a] Correct answer
[b] Number of times this item was chosen
[c] Percentage of students

The mean score on this question was 0.79 / 1 for the treatment and 0.58 / 1 for the control group. The difference between these means was significant ($t = 2.40$, $df = 108$, $p \leq 0.05$). Students who experienced the guided learning pedagogy in their lab were better able to recognize composition reactions than the control group students who engaged in the traditional lab methodology, although both groups performed more poorly on this post-lab quiz question than they did on a similar pre-lab quiz question.

1D: _____ D + E → DE

Table 71. Chemical Reactions: Rubric and Responses for Post-lab Question 1D

Response (Points)	Treatment (N = 56)	Control (N = 57)
C (1)[a]	44[b] (79)[c]	40 (70)
D (0)	11 (20)	11 (19)
SR (0)	1 (2)	3 (5)
DR (0)	0 (0)	0 (0)
SE (0)	0 (0)	3 (5)

[a] Correct answer
[b] Number of times this item was chosen
[c] Percentage of students

Upon comparing this question to pre-lab quiz question 1A, one can see that the percentage of students who correctly recognized that this reaction represented a composition reaction declined from 96% to 79% for the treatment group. The percentage of correct answers for the control group also declined from 88% to 70%. These results were anomalous because the two questions were extremely similar. The pre-lab question

(1A) was "A + B → AB" and this post-lab question (1D) was "D + E → DE." Since these questions were similar but students in both lab groups scored more poorly, their responses were examined to see if an explanation could be found.

Of the students who missed this post-lab quiz question, 11 of the 12 treatment group students and 16 of the 17 control group students had answered the analogous pre-lab quiz question 1A correctly. This indicated that these students were capable of identifying composition reactions using generic equations. There were 11 treatment group students and ten control group students who gave four different answers on post-lab quiz question one. The design of this post-lab quiz (Appendix I) was such that students had blanks in front of four generic equations (1A to 1D) in which to place their answer. The pattern of answers given by students who missed post-lab quiz question 1D was that students put unique answers in each of the four blanks. This pattern suggested that students were guessing that the last answer would be different from the answers they had placed in the blanks for 1A to 1C. This reasoning was not sound since students should have placed the answer C in the blanks for both post-lab quiz questions 1C and 1D. Ten of the 12 treatment group students and 11 of the 17 control group students gave the wrong answer, D. Of the students who got this question correct, 33 of the 44 treatment group students and 24 of the 40 control group students got all four post-lab quiz questions correct. Of the students who got post-lab quiz question 1D correct, the mean total score on all of the answers for question one was 3.68 for the treatment group and 3.55 for the control group. Of those who missed this question, the mean total score for the treatment group was 2.91 and 1.82 for the control group. These observations lead to the suggestion that students who do not understand identifying chemical equations using generic alphabetic symbols tend to guess at answers, offering the widest variety of answers possible.

The difference between the two groups' mean scores for this composition reaction example on pre-lab quiz question 1A, was not significant ($p > 0.05$, Table 67). The mean score on this post-lab quiz question was 0.79 / 1 for the treatment group students and 0.70 / 1 for the control group. These means were not significantly different ($t = 1.02$, $df = 110$, $p > 0.05$). This suggested that students in both lab groups were able to identify composition reactions using generic alphabetic equations.

The first question of the pre-lab and post-lab quiz had four generic equations for which students had to determine the type of chemical reaction represented. Taking the sum of all four parts of question one, the treatment group had a mean of 3.54 / 4 on the pre-lab quiz and a mean of 3.52 / 4 on the post-lab quiz. The control group had a mean of 3.33 / 4 on the pre-lab quiz and a mean of 3.04 / 4 on the post-lab quiz. There was a statistical difference ($t = 2.83$, $df = 92$, $p \leq 0.05$) between the two groups' means on the post-lab quiz total for question 1. The data show that this occurred because the control group performed worse on the post-lab quiz than they did on the pre-lab quiz.

Post-lab Question 2:

Name at least 3 things that indicate a chemical reaction has occurred.

On pre-lab question 2 (Table 61), 37 different items were included in the students' lists of indicators of a chemical reaction. After students in both groups performed the lab, students consolidated their answers to 16 items (Table 72). Eighty-four percent of the treatment group and 72% of the control group mentioned a color change as the most

Table 72. Chemical Reactions: Rubric and Responses for Post-lab Question 2

Response (points)	Treatment (N = 56)	Control (N = 57)
Change color (1)	47[a] (84)[b]	41 (72)
Odor change (1)	36 (64)	35 (61)
Temp / heat change (1)	21 (38)	7 (12)
Gas formed (1)	19 (34)	20 (35)
Precipitate (1)	11 (20)	15 (26)
Energy change (1)	9 (16)	21 (37)
New substances appear / old substances disappear (1)	6 (11)	8 (14)
Change Form / phase (0)	6 (11)	0 (0)
Sound given off / explosion (1)	1 (2)	0 (0)
Rust (1)	1 (2)	0 (0)
Light given off (1)	0 (0)	2 (4)
Bonds made / broken (0.5)	0 (0)	5 (9)
Chemical composition changes (0.5)	0 (0)	1 (2)
Chemical Change (0)	0 (0)	3 (5)
Physical Change (0)	0 (0)	2 (4)
Mixture (0)	0 (0)	2 (4)

[a] Number of times this item was mentioned
[b] Percentage of students

common indicator of a chemical change. Odor change was listed second most often as an obvious indicator of a chemical change by 64% of the treatment group and by 61% of the control group. The next most common response dealt with energy changes. Thirty-seven percent of the control group used the generalized term "energy change" and 12% used the terms temperature or heat change. The treatment group was more specific about the energy changes. Thirty-eight percent of this group referred specifically to temperature or heat changes. Sixteen percent of the treatment group referred to "energy changes." Thirty-four percent of the treatment group and 35% of the control group mentioned the formation of a gas as evidence of a chemical reaction. The formation of a precipitate was mentioned by 20% of the treatment group and by 26% of the control group.

These results indicated that students knew chemical reactions could be verified by the senses -- particularly by sight, smell and touch. Students knew that a chemical reaction had occurred if they saw a precipitate form or if they saw gas bubbles forming. They responded that they knew a chemical reaction had occurred if there was an odor change or if they could feel a temperature change. The data in Table 72 indicates that students also cited evidence that a chemical change occurred with the disappearance of old substances and the appearance of new substances.

Eleven percent of the students in the treatment group expressed the idea that a form change or a phase change was an indicator of a chemical reaction. These students continued to be confused about how particles behaved as they change among solids, liquids and gases. The treatment group's mean score was 2.58 / 3 while the control group had a mean score of 2.64 / 3. The difference between these means was not significant ($t = -0.47$, $df = 92$, $p > 0.05$) suggesting that the guided learning lab and the traditional lab were both capable of helping students recognize evidence of chemical reactions.

Post-lab Question 3:

Student responses to the three parts of Question 3 are summarized in Tables 73 – 75.

In each of these, indicate if this represents a chemical reaction and tell why you think so.

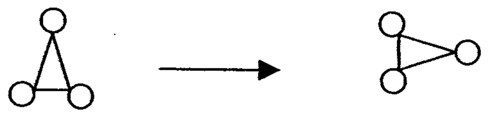
3A: 

Table 73. Chemical Reactions: Rubric and Responses for Post-lab Question 3A

Response (points)	Treatment (N = 56)	Control (N = 57)
No (1)[a]	53[b] (95)[c]	49 (86)
No (0.5)[d]	3 (5)	6 (11)
Yes (0)	0 (0)	2 (4)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, no reason

Ninety-five percent of the treatment group and 86% of the control group recognized that this particle diagram did not represent a chemical change and presented the logical explanation that the object reoriented itself but its composition did not change. Five percent of the treatment group and 11% of the control group correctly indicated this was not a chemical reaction, but they failed to give a reason. Four percent of the control group thought the diagram did represent a chemical change. The treatment group's mean score was 0.96 / 1 while the control lab group had a mean score of 0.91 /1. The difference between these means was not significant ($t = 1.47$, $df = 88$, $p > 0.05$), suggesting that both lab groups were capable of recognizing that the reorientation of a particle did not constitute a chemical change.

3B:

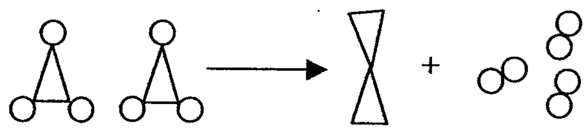


Table 74. Chemical Reactions: Rubric and Responses for Post-lab Question 3B

Response (points)	Treatment (N = 56)	Control (N = 57)
Yes (1)[a]	54[b] (96)[c]	38 (67)
Yes (0.5)[d]	2 (4)	19 (33)
No (0)	0 (0)	0 (0)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical or no reason

All students in both groups recognized that this particle diagram represented a decomposition reaction. The most common reason given was that the products were different from the reactants. The second most common response was that it simply represented a decomposition reaction. The third most common response was that bonds were broken and new bonds formed. Four percent of the treatment group and 33% of the control group said the diagram represented a chemical reaction but gave an illogical or no reason. Students offered reasons such as "loss of molecules and bonding of others," "two products form a reaction," "become different elements," and "two chemicals combine." The mean score for the treatment group was 0.98 / 1 while the mean score for the control group was 0.83 / 1. The difference between these means was significant (t = 4.39, df =

73, $p \leq 0.01$). Students instructed using the guided learning pedagogy were better able to recognize symbolic decomposition reactions as represented in this particle diagram.

3C:

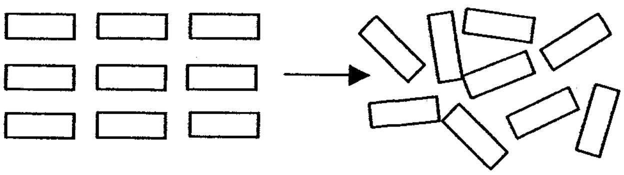


Table 75. Chemical Reactions: Rubric and Responses for Post-lab Question 3C

Response (points)	Treatment (N = 56)	Control (N = 57)
Yes (0.5)[a]	0[b] (0)[c]	2 (4)
Yes (0)	7 (13)	10 (18)
No (1)[d]	44 (79)	34 (60)
No (0.5)[e]	5 (9)	8 (14)
Unsure (0.5)[a]	0 (0)	1 (2)
No response (0)	0 (0)	2 (4)

[a] Incorrect answer, true statement for reason does not match response
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, logical reason
[e] Correct answer, illogical reason

The particle diagram in question 3C illustrated a physical change instead of a chemical change. Seventy-nine percent of the treatment group and 60% of the control group recognized that the particles became scattered without changing the basic composition of each particle. The most common incorrect answer given by both groups was that this represented a decomposition reaction because the bulk structure was broken down. The treatment group's mean score was 0.83 / 1 and the control group had a mean score of 0.69 / 1. The difference between these means was not significant ($t = 1.93$, $df = 109$, $p > 0.05$), suggesting that both groups were equally capable of recognizing that this generic alphabetic equation did not represent a chemical reaction.

Taking the sum of all three parts of question three, the treatment group had a mean of 2.44 / 3 on the pre-lab quiz (Table 68) and a mean of 2.78 / 3 on the post-lab quiz. The control group had a mean of 2.31 / 3 (Table 68) on the pre-lab quiz and a mean of 2.44 / 3 on the post-lab quiz. The difference between the groups' means on the post-lab quiz was significant ($t = 3.53$, $df = 101$, $p \leq 0.01$). This suggested that the guided learning lab style helped students achieve higher levels of mastery on problems like these that represent generic types of chemical reactions.

Post-lab Question 4:

How would you define a "chemical reaction"?

Student responses to this question are summarized in Table 76. The percentage of students who explained a chemical reaction in terms of a new composition of the products or the changed composition of the original material increased from 36% to 55% for the treatment group and from 35% to 54% for the control group. Four percent of the treatment group and seven percent of the control group continued to focus on the formation and breaking of bonds that occurs during a chemical reaction. Five percent of the treatment group and 5% of the control group mentioned that a chemical reaction was an event in which there were changes such as gas formation, color changing, or energy changing.

Table 76. Chemical Reactions: Rubric and Responses for Post-lab Question 4

Response (points)	Treatment (N = 56)	Control (N = 57)
New substance formed with new properties; change in composition (1)	31[a] (55)[b]	31 (54)
Evidence that change has occurred such as gas forms, color change, or energy change (1)	3 (5)	3 (5)
Result of change (bonds broken / formed) (1)	2 (4)	4 (7)
Takes on new characteristics (0.5)	2 (4)	2 (4)
Name for what happens when 2 materials interact (0.5)	2 (4)	4 (7)
Anything that causes a physical change (0)	4 (7)	4 (7)
Anything that has a reactant (0)	1 (2)	0 (0)
Element becomes a new element (0)	3 (5)	0 (0)
A chemical change (0)	6 (11)	6 (11)
No response (0)	2 (4)	3 (5)

[a] Number of times this answer was chosen
[b] Percentage of students

The percentage of students, who labeled a chemical reaction only as a process of two materials interacting, decreased from 21% on the pre-lab quiz to four percent on the post-lab quiz for the treatment group. For the control group, those who just labeled the process without giving any more detail declined from 16% on the pre-lab quiz to seven percent on the post-lab quiz. Vague or incorrect ideas were still being used after the lab. Students suggested that a chemical reaction is an event in which anything causes a physical change. They also suggested that a chemical change is anything that has a reactant or where elements become new elements. The mean score for the treatment group was 0.71 / 1 while a mean of 0.68 / 1 was for the control group. The difference between these means was not significant ($t = 0.38$, $df = 111$, $p > 0.05$) suggesting that both lab methodologies prepared students to recognize evidence of chemical reactions.

Students became more aware that chemical reactions involved atoms rearranging to give rise to new substances with new properties. Such a description was more revealing of understanding than a student who said that a chemical reaction occurred when two chemicals got together. Students who were instructed with either lab method were equally likely to be able to correctly describe a chemical reaction.

Post-lab Question 5:

Which of these are chemical reactions? Check all that are chemical reactions.

____ **Gasoline evaporating**
____ **Wax melting**
____ **Gasoline burning**
____ **Water freezing**
____ **Photosynthesis (Plants taking carbon dioxide and water, and making oxygen and glucose)**

Student answers to this question are summarized in Table 77. As in Chemical Reactions pre-lab question five, students in both lab groups were capable of recognizing events as chemical reactions. On pre-lab question five, three events were chemical reactions. On post-lab question five, two events were chemical reactions. The treatment group's percentage of those who correctly recognized chemical reaction events improved from an average of 89% on the pre-lab quiz to an average of 93% on the post-lab quiz. The control group remained at an average of 91% for both the pre-lab and post-lab question.

Students were less confident that the physical changes listed in the question were NOT chemical changes. Of those who correctly recognized the physical changes, the

Table 77. Chemical Reactions: Rubric and Responses for Post-lab Question 5

Response (points)	Treatment (N = 56)	Control (N = 57)
Gasoline evaporating (1)[a]	35[b] (63)[c]	27 (47)
Wax melting (1)[a]	43 (77)	44 (77)
Gasoline burning (1)[d]	51 (91)	52 (91)
Water freezing (1)[a]	48 (86)	44 (77)
Photosynthesis (1)[d]	53 (95)	52 (91)

[a] Correct if this item was unchecked
[b] Number of times this answer was identified correctly
[c] Percentage of students
[d] Correct if this item was checked.

treatment group percentage decreased from an average of 80% on the pre-lab quiz to an average of 75% on the post-lab quiz. The control group's average percentage decreased from 70% on the pre-lab to 67% on the post-lab. These results suggested that students in both lab groups were less clear of what constituted a chemical change when ordinary events of their world were considered. This is in contrast to the results in Chemical Reactions post-lab question two where students were able to satisfactorily identify evidence of chemical reactions. More investigation is needed to determine if students only considered chemical reactions as events which only occurred in a chemistry lab.

For this question, the treatment group had a mean total score of 4.11 / 5 and the control group had a mean score of 3.84 / 5. The difference between these means was not significant ($t = 1.37$, $df = 111$, $p > 0.05$). Students in either lab group were capable of deciding whether or not an event is a chemical reaction.

The data in Table 78 summarizes the statistical comparisons of the lab groups' means for each question on the Chemical Reactions post-lab quiz. The data show that there was a significant difference ($p \leq 0.05$) in the means of the two groups, in favor of the treatment group, in their ability to label generic equations as single or double

Table 78. Chemical Reactions: Statistical Comparison of Lab Groups' Means on Each Post-lab Question

	Treatment (N = 56)		Control (N = 57)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1A	0.96	0.19	0.84	0.37	2.23	84[a]	0.03
1B	0.98	0.13	0.89	0.31	1.95	76[a]	0.05
1C	0.79	0.41	0.58	0.50	2.40	108[a]	0.02
1D	0.79	0.41	0.70	0.46	1.02	110[a]	0.31
Question 1 Total	3.52	0.66	3.04	1.10	2.83	92[a]	0.01
2	2.58	0.78	2.64	0.57	-0.47	111	0.64
3A	0.96	0.13	0.91	0.23	1.47	88[a]	0.15
3B	0.98	0.09	0.83	0.24	4.39	73[a]	0.00
3C	0.83	0.34	0.69	0.41	1.93	109[a]	0.06
Question 3 Total	2.78	0.42	2.44	0.59	3.53	101[a]	0.00
4	0.71	0.43	0.68	0.41	0.38	111	0.71
5A	0.63	0.49	0.47	0.50	1.62	111	0.11
5B	0.77	0.43	0.77	0.42	-0.51	111	0.96
5C	0.91	0.29	0.91	0.29	-0.03	111	0.98
5D	0.86	0.35	0.77	0.42	1.16	108[a]	0.25
5E	0.95	0.23	0.91	0.29	0.70	111	0.48
Question 5 Total	4.11	1.00	3.84	1.05	1.37	111	0.17

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

replacement and composition reactions (question one). This was in spite of the fact that both groups received exposure to generic equations in their lab instructions. There was also a distinction in favor of the treatment group in identifying pictorial diagram chemical and physical changes, but this distinction may have been enhanced by the explicit use of pictorial diagrams with the treatment group. There was no distinction between the groups in their ability to list indicators of a chemical reaction, in their ability to define a chemical reaction, or in their ability to correctly identify and distinguish chemical and physical changes.

Chemical Reactions: Comparison of Pre- and Post-lab Quiz Means

The two groups' pre-lab and post-lab mean total scores were compared (Figure 5).

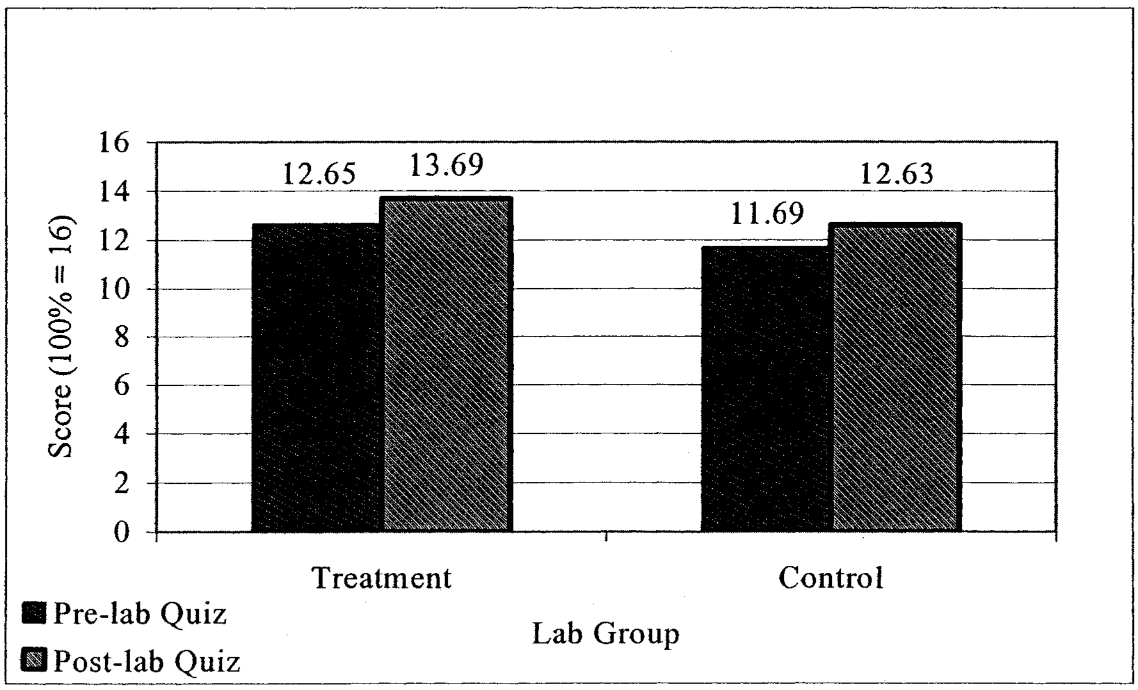


Figure 5. Comparison of Chemical Reactions pre-lab and post-lab quizzes by lab group

The lab groups' means continued not to be statistically different ($p > 0.05$) on question two on the post-lab quiz where students were asked to list evidence of a chemical reaction. The lab groups' means were not statistically different ($p > 0.05$) on post-lab quiz question four but they were significant ($p \leq 0.05$) on the pre-lab quiz. This question asked students to define a chemical reaction. On the post-lab, the treatment group essentially maintained its score on question four while the control group improved its score such that there was no longer a significant difference ($p > 0.05$) after the lab. Both groups remained capable of recognizing descriptions as chemical or physical changes (question five) without being significantly different ($p > 0.05$) on either the pre-lab or the post-lab quiz. The treatment group scored significantly higher ($p \leq 0.05$) on the post-lab quiz for questions one and three than did the control group. Analysis of the results for question one, where students recognized the type of reaction given a generic equation, indicated that the treatment group maintained its score, but the control group's mean decreased on the post-lab quiz, causing a significant difference in their scores. Both groups improved their mean score on question three in which students recognized whether or not a symbolic equation represented a physical change or chemical change, but the treatment group improved significantly ($p \leq 0.01$).

The data in Table 79 summarizes both lab groups' total scores on the Chemical Reactions pre-lab quiz and post-lab quiz. The treatment group improved its mean score by 1.04 points from the pre-lab to the post-lab quiz while the control group improved its mean score by 0.96 points. These results suggest that the guided learning method of presenting material on chemical reactions helped students produce significantly higher mean scores than the control group as measured by the responses to questions found on the Chemical Reactions post-lab quiz.

Table 79. Chemical Reactions: Statistical Comparison of Each Lab Groups' Mean Total Scores on the Pre-lab and Post-lab Quizzes

	Treatment (N = 56)		Control (N = 57)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
Pre-lab Total	12.65	2.49	11.69	3.24	1.76	111	0.08
Post-lab Total	13.69	1.90	12.63	2.42	2.58	111	0.01

An analysis of covariance, ANCOVA, was conducted to determine if the post-lab quiz score for the treatment group remained significant after the groups' pre-lab quiz scores were considered. The results of the ANCOVA indicated that these two scores remained significantly different, $p \leq 0.05$, after controlling for differences in the pre-lab quiz. The results of the ANCOVA added strength to the claim that students who used the guided learning lab pedagogy to study chemical reactions outperformed those who studied chemical reactions using traditional lab pedagogy.

Chemical Reactions: Rubric and Responses for Conceptual Questions

The following questions probed students' conceptual understanding of chemical reactions. Fifty-two treatment group students and 29 control group students responded to the questions.

Conceptual Question 1:

A friend claimed a chemical reaction had occurred when two solutions were poured together. What other information would you need in order to agree with your friend?

Students' responses, which fell into the two distinct categories of macroscopic changes and microscopic change, are summarized in Table 80. Students further responded to these categories in either general or specific ways. Thirty-seven percent of the treatment group and 69% of the control group said they would look for a specific macroscopic change. These changes included: a color change, the liberation of a gas, an energy change, an odor change, and evidence that a precipitate had formed. Two percent of the treatment group and seven percent of the control group identified the microscopic change of the formation of a new product or of a new substance.

Table 80. Chemical Reactions: Rubric and Responses for Conceptual Question 1

Response (points)	Treatment (N = 52)	Control (N = 29)
Logical macroscopic changes (1)[a]	19[b] (37)[c]	20 (69)
Logical microscopic changes (1)[a]	1 (2)	2 (7)
Logical macroscopic changes (0.5)[d]	9 (17)	5 (17)
Logical microscopic changes (0.5)[d]	1 (2)	0 (0)
Illogical macroscopic changes (0)	1 (2)	0 (0)
No response (0)	21 (40)	2 (7)

[a] Specific evidence cited
[b] Number of times this item was mentioned
[c] Percentage of students
[d] General evidence cited

Seventeen percent of the treatment group and 17% of the control group gave general macroscopic answers. They said that it would be important to know what happened after the solutions were poured together, and they wanted to know what the chemicals in the solutions were. These students did not describe what that information would tell them. Two percent of the treatment group gave a general microscopic response wanting to know if any chemical bonds had been broken or formed. Two percent of the treatment group responded by stating the need to know if a mass change had occurred. This qualified as a specific macroscopic response. Without more information, this question did not tell whether one would know if a chemical reaction had occurred.

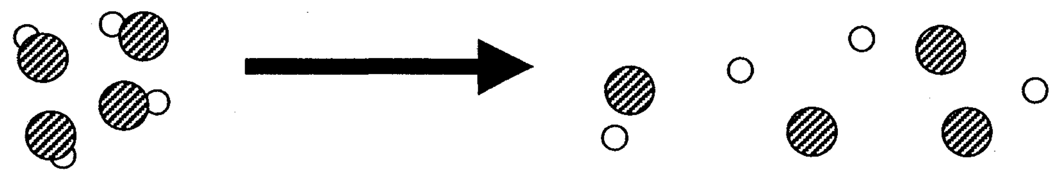
Forty percent of the treatment group and seven percent of the control group left this question blank. The reason for so many students in the treatment group leaving this question blank was inexplicable, given that there was the space of three blank lines between questions (Appendix L) and that the question was seen and answered correctly by other students. The resulting low score on this question for the treatment group reflected the fact that so many students did not answer the question.

The treatment group mean on this question was 0.57 / 1 and the control group had a mean of 0.88 /1. The difference between these means was significant ($t = -3.63$, $df = 79$, $p \leq 0.01$). An examination of student papers revealed that 21 of the 52 treatment group students and two of the 29 control group students did not answer this question. The question was clearly visible at the top of the page, but it appears that these students simply overlooked it. These students did not omit other questions, so it appears their omission of this question was an oversight. However, since it cannot be determined why these questions were not answered, their scores are taken to be valid for this question. These results suggest that the control lab better equipped students to discern what information is needed before deciding if a chemical reaction has occurred.

Conceptual Question 2:

For each of the following illustrations, indicate if a chemical reaction is represented AND explain your answer.

2A:



The responses by the students are summarized in Table 81. Ninety-four percent of the treatment group and 90% of the control group correctly thought the particle diagram represented a chemical reaction. Four percent of the treatment group failed to explain why they thought it was a chemical reaction. Sixty-three percent of the treatment group and 69% control group claimed that a chemical reaction had occurred because the units on the left had decomposed or separated. These students chose to base their answer on what had happened to the reactant. Twenty-five percent of the treatment group and 14% of the control group based their answer on the fact that new substances were formed.

Only three students spoke of bonds within units being broken or formed during the reaction. Four percent of the treatment group and seven percent of the control group thought this was not a chemical reaction. One control group student did recognize that units had broken apart.

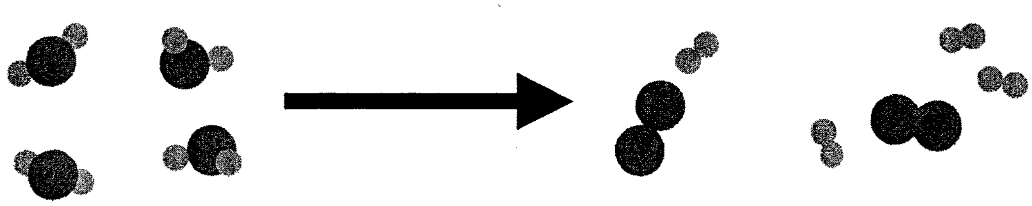
Table 81. Chemical Reactions: Rubric and Responses for Conceptual Question 2A

Response (points)	Treatment (N = 52)	Control (N = 29)
Yes (1)[a]	47[b] (90)[c]	26 (90)
Yes (0.5)[d]	2 (4)	0 (0)
No (0.5)[e]	0 (0)	1 (3)
No (0)[f]	2 (4)	1 (3)
No response (0)	1 (2)	1 (3)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, no reason
[e] Incorrect answer, logical reason
[f] Incorrect answer, illogical or no reason

The treatment group had a mean of 0.93 / 1 while the mean for the control group was 0.91 / 1. The difference between these means was not significant ($t = 0.32$, $df = 79$, $p > 0.05$) suggesting that students who participated in either the guided learning or the traditional lab were able to recognize that this particle diagram represented a chemical reaction.

2B:



Answers to this question are summarized in Table 82. This problem was another representation of a decomposition reaction. This example involved the atoms rejoining to form diatomic molecules whereas the particle diagram in conceptual question 2A showed the atoms remaining isolated. Every student in the treatment group and 97% of the control group thought this particle diagram represented a chemical reaction. Fifty-two percent of the treatment group offered a description of the reaction type. Forty percent of treatment group and 14% of the control group correctly stated that the particle diagram represented a decomposition reaction.

Table 82. Chemical Reactions: Rubric and Responses for Conceptual Question 2B

Response (points)	Treatment (N = 52)	Control (N = 29)
Yes (1)[a]	44[b] (85)[c]	17 (59)
Yes (0.5)[d]	8 (15)	11 (38)
No response (0)	0 (0)	1 (3)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical or no reason

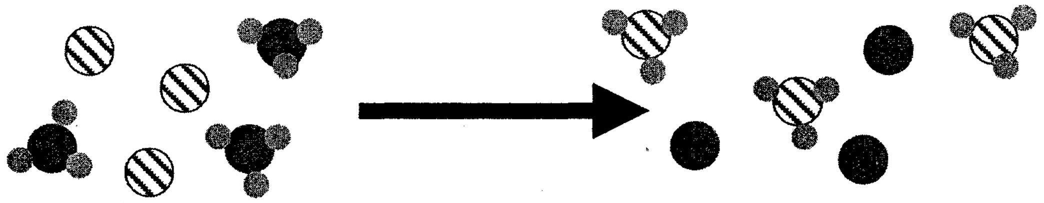
Forty-four percent of the treatment group and 34% of the control group who correctly recognized that new substances with different compositions were formed. They noted that this represented a chemical change, though they did not identify the reaction type. Ten percent of the control group noted that a chemical reaction had occurred because bonds between the big and little circles had been broken and new bonds between two big circles and between two little circles had formed.

Students also identified the particle diagram as a chemical reaction but gave illogical reasons. Twelve percent of the treatment group and 38% control group said it was a single or double replacement reaction. The control group responded similarly on Chemical Reactions post-lab quiz questions 1C and 3B. These results suggested that the traditional laboratory method did not help the students clearly distinguish decomposition from double replacement reactions.

Both groups identified this particle diagram as representing a chemical reaction. Students were not required to label the type of reaction, but for those who did, an interesting observation was noted. It was more difficult for students in both groups to identify the type of reaction on this question than on question 2A. The control group was more likely than the treatment group to call this decomposition reaction a double replacement reaction as shown by nine control group students compared to five treatment group students. Though question 2A and 2B represented decomposition reactions, the atoms in 2A remained separated. In 2B, the individual atoms of the product joined to make elemental molecules. This meant that not only were bonds broken when the reactant molecules decomposed, but bonds formed between atoms of the same element to make new molecules. Students in the control group who called this a double replacement reaction made statements such as, "the original molecule bonds separated and connected with those similar to themselves," and "elements exchanged." One control group student said, "The products broke from original elements to recombine with new elements. Possibly double replacement." That same student answered question 2A, "Apparently, decomposition occurred which means the product mixed with something to separate into two substances. Therefore it is different than before." These statements indicated that students considered a decomposition reaction to be one where the reactants separated into individual atoms and remained that way. These students suggested that if the separated atoms join with other atoms, then it is not a decomposition reaction. This explanation matched one control group student's statement, "double replacement, because 2 elements exchanged." One treatment group student repeated the misunderstanding when he/she said "Double replacement. On the left, there were 4 molecules, now 6 double molecules exist on the right. The smaller circles detached from the bigger circles and attached to each other." Not all students in the treatment group shared this concept. Another treatment group student made the remarks, "Decomposition. The two small balls moved from the dark balls. The big balls moved to the big ball. The small ball paired w/ small ball."

The treatment group had a mean of 0.93 / 1 and the mean for the control group was 0.88 / 1. The difference between these means was not significant ($t = 1.00$, $df = 43$, $p > 0.05$). Both the guided learning and the traditional style laboratory helped students to recognize a chemical reaction from a particle diagram.

2C:



The responses to this question are reported in Table 83. Ninety-six percent of the treatment group and 97% of the control group recognized this particle diagram as a chemical reaction. Though the students did not have to identify the type of chemical reaction, 44% of the treatment group and 59% of the control group correctly noted this particle diagram represented a single replacement reaction. Thirty-eight percent of the treatment group and 28% of the control group noted that the composition of the particles

Table 83. Chemical Reactions: Rubric and Responses for Conceptual Question 2C

Response (points)	Treatment (N = 52)	Control (N = 29)
Yes (1)[a]	44[b] (85)[c]	27 (93)
Yes (0.5)[d]	6 (12)	1 (3)
No (0)[e]	1 (2)	0 (0)
No response (0)	1 (2)	1 (3)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical reason
[e] Incorrect answer, no reason

changed. Only two percent of the treatment group and seven percent of the control group spoke of chemical bonds being broken and new bonds being formed. They cited bond breaking and bond formation as evidence that a chemical reaction had occurred. Only six percent of the treatment group and three percent of the control group incorrectly called this a double replacement reaction. The treatment group had a mean of 0.91 / 1 while the mean for the control group was 0.95 / 1. The difference between these means was not significant ($t = -0.67$, $df = 79$, $p > 0.05$). The high mean scores indicated that both groups recognized this as a chemical reaction.

2D:

A summary of the students' responses to this question are shown in Table 84. All of the treatment group and 90% of the control group stated that this particle diagram did not represent a chemical reaction. The remainder of the control group did not answer the question. Ninety-two percent of the treatment group and 72% of the control group justified their answer by saying that the particles moved around but the composition of the particles did not change. Four percent of the treatment group said this represented a physical change.

Table 84. Chemical Reactions: Rubric and Responses for Conceptual Question 2D

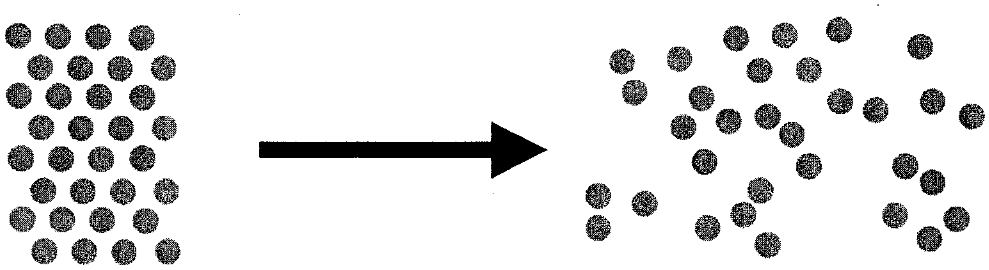
Response (points)	Treatment (N = 52)	Control (N = 29)
No (1)[a]	50[b] (96)[c]	22 (76)
No (0.5)[d]	2 (4)	4 (14)
No response (0)	0 (0)	3 (10)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, no reason

One treatment group student said, "Both sides of the equation have seven portions of the same substance. There is no significant change in the spacing that might indicate a change in physical state – the substances are the same." Another treatment group student said, "The composition is the same on both sides, allowing no reaction." A control group student said, "No reaction - The objects' positions were only rearranged." These remarks made it clear that students knew that if the make-up of connected atoms had changed, they would know a chemical reaction had occurred. If the products had the same composition as reactants, even though they were rearranged in space, students knew that this did not constitute a chemical reaction.

The treatment group had a mean of 0.98 / 1 while the mean for the control group was 0.83 / 1. The difference between these means was not significant ($t = 2.41$, $df = 31$, $p \leq 0.05$) suggesting that students in the guided learning labs produced higher scores on the conceptual questions than their control group counterparts. Both groups recognized this was only a physical change marked by the physical separation of particles but not by a change in the particles' composition. Students taught using either lab method were able to recognize that this particle diagram did not represent a chemical reaction.

2E:



Student responses to this question are summarized in Table 85. Eighty-five percent of the treatment group and 79% of the control group correctly recognized that this particle diagram did not represent a chemical reaction. Students offered these justifications: "Nothing new formed," "No bonds formed," "It was a physical change," and "It looked like evaporation." The control group student who gave an illogical reason said that this "particle diagram represented a changed composition but the particles still had not reacted." Four percent of the treatment group and three percent of the control group did not give a reason for stating that this diagram did not represent a chemical reaction.

Table 85. Chemical Reactions: Rubric and Responses for Conceptual Question 2E

Response (points)	Treatment (N = 52)	Control (N = 29)
No (1)[a]	42[b] (81)[c]	21 (72)
No (0.5)[d]	2 (4)	2 (7)
Yes (0)[e]	7 (13)	3 (10)
No response (0)	1 (2)	3 (10)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical or no reason
[e] Incorrect answer, illogical reason

Thirteen percent of the treatment group and ten percent of the control group said the particle diagram represented a chemical reaction. Four percent of the treatment group and three percent of the control group said this diagram represented a composition or decomposition reaction. Eight percent of the treatment group and seven percent of the control group said this represented a chemical reaction because the structure had changed. Two percent of the treatment group said "all of the molecules formed bonds."

The treatment group had a mean of 0.86 / 1 while the mean for the control group was 0.72 / 1. The difference between these means was not significant ($t = 1.42$, $df = 47$, $p > 0.05$). These data suggested that both the treatment group and the control group labs helped students recognize a physical change.

2F:

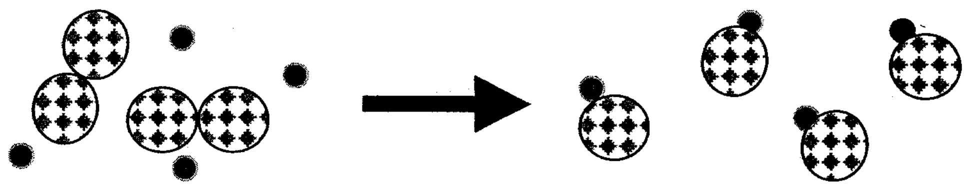


Table 86 details the summarized responses to this question by the students. Ninety-eight percent of the treatment group and 90% of the control group recognized this particle diagram as representing a chemical reaction. Forty-four percent of the treatment group and 41% control group described the diagram as a composition reaction. Forty-four percent of the treatment group and 21% of the control group used the formation of new substances as evidence of a chemical reaction. Two percent of the treatment group and seven percent of the control group remarked about the breaking and forming of chemical bonds in the diagram. Four percent of the treatment group and 14% of the control group continued to believe the diagram represented a single or double replacement type of reaction.

Table 86. Chemical Reactions: Rubric and Responses for Conceptual Question 2F

Response (points)	Treatment (N = 52)	Control (N = 29)
Yes (1)[a]	47[b] (90)[c]	20 (69)
Yes (0.5)[d]	4 (8)	6 (21)
No response (0)	1 (2)	3 (10)

[a] Correct answer, logical reason
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct answer, illogical or no reason

Six students in the control group said this particle diagram represented a chemical reaction, but their reason was faulty. Two said it represented a double replacement reaction while two said it represented a single replacement reaction. The other two said "changed shape" and "bonding." Four treatment group students said this represented a chemical reaction but missed the correct reason. They said it represented a single replacement reaction or a double replacement reaction. Two did not answer the question.

The treatment group had a mean of 0.95 / 1 while the mean for the control group was 0.79 / 1. The difference between these means was significant ($t = 2.34$, $df = 37$, $p \leq 0.05$). Students in the treatment group lab outperformed the control lab in being able to identify this as a composition reaction.

Conceptual Question 3:

Some unbalanced equations are given below. Your lab partner has already identified them as being possibly Composition (C), Decomposition (D), Single Replacement (SR) or Double Replacement (DR); you are not completely sure they are labeled correctly. You want these to be right, so you want to check them. In the blank, put a check mark if the identification by your lab partner is right. If it is wrong, in the blank put the correct letter to designate the type of reaction it really is.

3A: ____ **SR : $S + O_2 \rightarrow SO_2$**

Students' responses to this question are provided in Table 87. Ninety-six percent of the treatment group and 66% of the control group knew the equation represented a composition reaction. Four percent of the treatment group and 14% of the control group believed that the reaction was a single replacement reaction. This suggested that the control group students were uncertain of their ability to discern the reaction type. This suggestion was likewise supported by the fact that 21% of the control group did not answer the question.

Table 87. Chemical Reactions: Rubric and Responses for Conceptual Question 3A

Response (points)	Treatment (N = 52)	Control (N = 29)
Agree that it is SR (0)	2[a] (4)[b]	4 (14)
Should be C (1)[c]	50 (96)	19 (66)
No answer (0)	0 (0)	6 (21)

[a] Number of times this answer was chosen
[b] Percentage of students
[c] Correct

The treatment group had a mean of 0.96 / 1 while the mean for the control group was 0.66 / 1. The difference between these means was significant ($t = 3.27$, $df = 33$, $p \leq 0.01$) suggesting that students who studied chemical reactions using the guided learning lab method outperformed their fellow students who studied chemical reactions using the traditional lab format.

3B: ___ C : $MgO + H_2O \rightarrow Mg(OH)_2$

Answers to this question are summarized in Table 88. This chemical equation corresponded to the generic example in post-lab question 1C: PQ + RS → PQRS. Eighty-seven percent of the treatment group and 76% of the control group agreed that the equation represented a composition reaction. This improvement in scores from the post-lab quiz to this conceptual question suggested that students were able to apply their understanding when given actual chemical formulas. Fourteen percent of the treatment group and ten percent of the control group were confused over whether it should be a single or double replacement reaction or a decomposition reaction. These data supported the idea that a core of students in both the treatment group and in the control group did not completely understand symbolic representations of chemical reactions.

Table 88. Chemical Reactions: Rubric and Responses for Conceptual Question 3B

Response (points)	Treatment (N = 52)	Control (N = 29)
Agree that it is C (1)[a]	45[b] (87)[c]	22 (76)
Should be D (0)	1 (2)	0 (0)
Should be SR (0)	2 (4)	2 (7)
Should be DR (0)	4 (8)	1 (3)
No answer (0)	0 (0)	4 (14)

[a] Correct
[b] Number of times this answer was chosen
[c] Percentage of students

The treatment group had a mean of 0.87 / 1 and the mean for the control group was 0.76 / 1. The difference between these means was not significant ($t = 1.14$, $df = 48$, $p > 0.05$). Students in both lab groups performed without distinction on this question.

3C: ___ **D : HgO → Hg + O_2**

Answers to this question are summarized in Table 89. This decomposition reaction was recognized by 98% of the treatment group and by 69% of the control group. The treatment group had a mean score of 0.96 / 1 and the mean score for the control group was 0.69 / 1 ($t = 2.97$, $df = 33$, $p \leq 0.05$). These results suggest that the treatment group outperformed the control group in their ability to recognize this reaction as decomposition reaction. Upon analyzing the students' responses, it was noted that seven students in the control group omitted this question. Three of these seven students failed to answer any question on the back page where this question was located. Since it is not known why these questions were left unanswered, these students' scores are included in the statistical analysis.

Table 89. Chemical Reactions: Rubric and Responses for Conceptual Question 3C

Response (points)	Treatment (N = 52)	Control (N = 29)
Agree that it is D (1)[a]	51[b] (98)[c]	20 (69)
Should be SR (0)	0 (0)	2 (7)
Should be C (0)	1 (2)	0 (0)
No answer (0)	0 (0)	7 (24)

[a] Correct
[b] Number of times this answer was chosen
[c] Percentage of students

3D: ___ DR: Al + FeS → Al_2S_3 + Fe

Student responses to this question are summarized in Table 90. Eighty-five percent of the treatment group and 55% of the control group recognized this as a single replacement reaction. Fifteen percent of the treatment group and 31% of the control group agreed that this was a double replacement reaction. Treatment group students had a mean of 0.83 / 1 and the control group had a mean of 0.55 / 1. The difference between these means was significant ($t = 2.55$, $df = 46$, $p \leq 0.05$), suggesting that students in the treatment group lab were better able to recognize a single replacement reaction than the control lab group.

Table 90. Chemical Reactions: Rubric and Responses for Conceptual Question 3D

Response (points)	Treatment (N = 52)	Control (N = 29)
Agree that it is DR (0)	8[a] (15)[b]	9 (31)
Should be SR (1)[c]	44 (85)	16 (55)
No answer (0)	0 (0)	4 (14)

[a] Number of times this answer was chosen
[b] Percentage of students
[c] Correct

The results from an independent samples t-test for the Chemical Reactions conceptual questions are summarized in Table 91. As indicated by question one, there was a statistical difference favoring the treatment group ($p \leq 0.01$) in the ability to recognize evidence of chemical reactions. Students in both lab groups were statistically indistinguishable ($t = 1.84$, $df = 44$, $p > 0.05$) in their ability to recognize whether a particle diagram represented a chemical or physical change as seen by their total score on question two. On question three, the data in Table 91 reveal a mean total of 3.62 / 4 for the treatment group and 2.66 / 4 for the control group ($t = 3.30$, $df = 36$, $p \leq 0.01$). This suggests that the guided learning pedagogy was able to help students recognize the type of chemical reaction better than the traditional laboratory pedagogy.

Table 91. Chemical Reactions: Statistical Comparison of Each Lab Groups' Mean Score on the Conceptual Questions

	Treatment (N = 52)		Control (N = 29)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
1	0.57	0.49	0.88	0.29	-3.63	79	0.00
2A	0.93	0.24	0.91	0.27	0.32	79	0.75
2B	0.93	0.17	0.88	0.26	1.00	43[a]	0.32
2C	0.91	0.24	0.95	0.20	-0.67	79	0.51
2D	0.98	0.10	0.83	0.33	2.41	31[a]	0.02
2E	0.86	0.33	0.72	0.43	1.42	47[a]	0.16
2F	0.95	0.18	0.79	0.34	2.34	37[a]	0.03
Total of 2	5.57	0.89	5.09	1.25	1.84	44[a]	0.07
3A	0.96	0.19	0.66	0.48	3.27	33[a]	0.00
3B	0.87	0.34	0.76	0.44	1.14	48[a]	0.26
3C	0.96	0.19	0.69	0.47	2.97	33[a]	0.01
3D	0.83	0.38	0.55	0.51	2.55	46[a]	0.01
Total of 3	3.62	0.72	2.66	1.47	3.30	36[a]	0.00

[a] Computed due to low significance value ($p \leq 0.05$) for the Levene test. Equal variances for both groups is not assumed.

Chemical Reactions: Comparison of Conceptual Questions' Total Scores

The mean total score for the treatment group was compared to the mean total score for the control group on the Chemical Reactions conceptual questions (Figure 6).

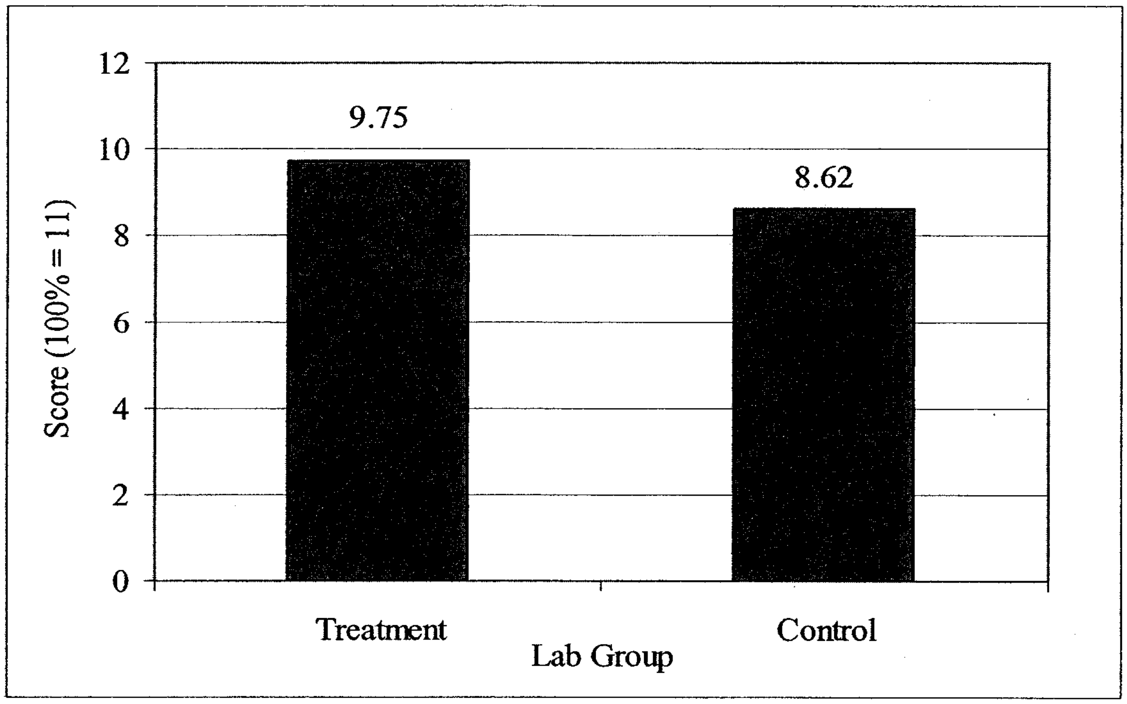


Figure 6. Group comparisons of Chemical Reactions lab conceptual questions

The treatment group had a total score mean of 9.75 / 11 while the control group had a total score mean of 8.62 / 11. The difference between these two mean scores was significant ($t = 2.28$, $df = 39$, $p \leq 0.05$), suggesting that students who study chemical reactions using the guided learning lab pedagogy score significantly higher on conceptual questions than those studying the same material using traditional lab methods.

Post-Course Quiz for all Labs

Scores received on a post-course quiz measured students' mastery of concepts. Sixty-six of the 87 students in the treatment group and 82 of the 116 control group students signed an agreement form on the first day of class to take a post-course quiz via email. Eighteen of the treatment group students and 14 of the control group students emailed their responses to the post-course quiz. The students who took part in the post-course quiz represented 16 % of the total participants.

A breakdown of the numbers of students in each group who took the post-course quiz is listed in Table 92. According to Witte and Witte (*106*), sample sizes of less than five are unduly small, producing hypotheses tests with large standard errors. Since the number of respondents for the treatment group was 18 and the number of respondents was 14 for the control group, the results of t-tests have been taken to be statistically sound. The values for the results of the t-tests are discussed below.

The post-course quiz (Appendix M) contained four questions from each of the three labs in this study. The quiz was designed to take ten minutes or less response time. Students' responses indicated that the second question on the Chemical Reactions section contained formatting that was lost as the quiz was sent to students' email address. This question was eliminated from the study.

Table 92. Post-Course Quiz: Number and Percentage of Participants by Lab Style Group

	Lab Group					
	Treatment		Control		Total	
	N	% of original total	N	% of original total	N	% of original total
Number in study	87	43	116	57	203	100
Number who agreed to take the post-course quiz	66	33	82	40	148	73
Number who actually took the post-course quiz	18	9	14	7	32	16

Density Question 1:·

Compare the density of water in a cup and in a bathtub. [Choose only ONE, and give your reason please.]
A. The water in the cup and the water in the bathtub have the same density because
B. The water in the cup has more density than the water in the bathtub because
C. The water in the bathtub has more density than the water in the cup because

Student answers are recorded and summarized in Table 93. Eighty-nine percent of the treatment group and 79% of the control group said that density of a material is independent of the amount of the material present. These students justified their response by saying that density is not determined alone by size, amount, mass, volume or container. One control group student said, "They have different volumes, but not different densities since they have the same mass per unit volume." Another control group student said, "Density is not affected by amount." A treatment group student said, "Water always has the same density regardless of what size container it is in." They also said that unless the substance actually changed composition, the density would not

Table 93. Post-course Quiz: Rubric and Responses for Density Question 1

Response (points)	Treatment (N = 18)	Control (N = 14)
A (1)[a]	16[b] (89)[c]	11 (79)
A (0.5)[d]	1 (6)	1 (7)
B (0)	0 (0)	0 (0)
C (0)	0 (0)	0 (0)
No response (0)	1 (6)	2 (14)

[a] Correct response, logical explanation
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct response, no explanation

change. Three students argued the densities would remain the same unless some factor such as heat or pressure changed them. Students who gave these responses did not elaborate on how they believed those factors would change the density. The mean score for the treatment group on this question was 0.92 / 1 while it was 0.82 / 1 for the control group. The difference between these means was not significant ($t = 0.86$, $df = 30$, $p > 0.05$). Both lab methodologies were successful in helping students recognize that density is a property that is independent of mass or volume alone.

Density Question 2:

Describe density (as studied in the lab).

Answers to this question are summarized in Table 94. Seventeen percent of the treatment group and 43% of the control group described density by using the formula D = m/v. Thirty-three percent of the treatment group and 21% of the control group said that density is the amount of matter in a given space. Seventeen percent of the treatment group exchanged the term "area" for "volume." Six percent of the treatment group and 21% of the control group considered particle compactness as density.

Students in the control lab were more likely to recall density to be the formula, D = m/v than the treatment lab. While that formula is used to determine the density of a material, the response given by more treatment group students displayed mastery of the concept of density by concluding that it is the amount of matter in a given space. Sixty-one percent of students in the control lab gave acceptable answers while only 50% of the students in the treatment group did. Seventeen percent of the students in the treatment group misused the term "area" for "volume." Students in the treatment group described density in terms of the weight or amount of matter in an object while students in the control group did not.

Table 94. Post-course Quiz: Rubric and Responses for Density Question 2

Response (points)	Treatment (N = 18)	Control (N = 14)
Formula: D = m/v (1)[a]	3[b] (17)[c]	6 (43)
Amount of matter in a given space (1)[a]	6 (33)	3 (21)
"Ratio of mass to volume." (1)[a]	0 (0)	1 (7)
Mass per area (0.75)[d]	3 (17)	0 (0)
Particle compactness (0.5)[e]	1 (6)	3 (21)
Weight and volume (0.5)[e]	1 (6)	0 (0)
Amount of matter in an object (0)	1 (6)	0 (0)
Weight of object (0)	3 (17)	0 (0)
Distance between particles (0)	0 (0)	1 (7)

[a] Correct response, logical explanation
[b] Number of times this answer was chosen
[c] Percentage of students
[d] Correct response, but said "area" instead of "volume"
[e] Addresses qualities that could help define density but more explanation needed

The mean score for the treatment group on this question was 0.79 / 1 and 0.86 / 1 for the control group. The difference between these means was not significant ($t = -0.62$, $df = 30$, $p > 0.05$). These results indicated that after the course was over, both the treatment and control students maintained an understanding of what the term density means.

Density Question 3:

Which has lesser density: 2.0 g mass occupying 5.0 cm^3 or a 12.0 g mass occupying 21.0 cm^3? Give your explanation in clear terms so I know how you determined your answer. Don't just guess.

Table 95 contains a summary of students' responses to this question. Thirty-nine percent of the treatment group and 50% of the control group recognized that the 8.0 g sample occupying 21 cm^3 had less density and justified their answer by stating that the mass-to-volume ratio was less. One control group student said, "The 8.0 g with the volume of 21.0 cubic centimeters has less density because there is less of something in the space comparatively speeking (sic)." Two equally correct responses from control group students were that the 8.0 g sample had less mass per unit of volume and that there

Table 95. Post-course Quiz: Rubric and Responses for Density Question 3

Response (points)	Treatment (N = 18)	Control (N = 14)
8 g / 21 cm^3 is less (1)[a]	7[b] (39)[c]	6 (43)
8 g / 21 cm^3 is less (0.5)[d]	0 (0)	1 (7)
Incomplete response (0.5)[e]	5 (28)	1 (7)
Incomplete response (0.25)[f]	0 (0)	1 (7)
Illogical response (0)	2 (11)	1 (7)
2 g / 5 cm^3 is less (0)	2 (11)	4 (29)
No Response	2 (11)	0 (0)

[a] Correct answer, logical explanation
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct answer, illogical explanation
[e] Student chose neither 8 g / 21 cm^3 nor 2 g / 5 cm^3 but gave a logical explanation, or student made mathematics error
[f] Response was a true statement but which did not answer the question

was more volume per unit of mass. One control group student said, "The 8 g object has less density because it is taking up more space per gram than the 2 g object, so molecules are more spread out." This indicated conceptual understanding. Another control group student reasoned, "2.0/5.0 = 0.40g/cm^3 is greater than 8.0/21.0 = 0.38g/cm^3 from the formula Density = Mass/Volume." Analysis of the students' answers revealed that three treatment group students and one control group student did reciprocal division. Students offered ideas that were incomplete and which needed further explanation to be acceptable. One student suggested making a mass-divided-by-volume calculation to see which answer was less. This student gave an acceptable algorithm but did not give an answer. Another student explained that the material with the least density will have the larger volume. This student made a conceptually correct response but did not answer the question. Other answers were incorrect, such as "find area/mass," or the least dense material would be the most compact, not necessarily largest.

Students who chose the 2 g / 5 cm^3 answer gave these reasons: "The 2.0 gram object has less density because it takes up less space," "2 g mass has lesser density. I used the equation D = m/V but I didn't convert the cm^3 to grams," "The first object has a smaller volume and weight," and "The two gram object has less because it has a smaller ratio (Mass/Volume)."

The mean score for the treatment group on this question was 0.53 / 1 while it was 0.52 / 1 for the control group. The difference between these means was not significant ($t = 0.06$, $df = 30$, $p > 0.05$). These results indicated that students were capable of doing the calculations to get the correct answer, but students also relied on faulty logic or poor math skills to get their answer. Student comments have shown that students considered a lesser density to accompany a smaller mass and/or volume. Other students provided noncommittal rationale. These students gave a correct algorithm to solve the problem but did not work the problem and get an answer.

Density Question 4:

A rectangular block of material has the dimensions of: 1 cm x 3 cm x 4 cm and it has a mass of 15.0 g. Would you say the material is Zool (D = 1.88 g/cubic cm), Pretic (D= 1.25 g/cubic cm), Salup (D = 0.80 g/cubic cm), or something else (give density).

Student responses to this question are cataloged in Table 96.

Table 96. Post-course Quiz: Rubric and Responses for Density Question 4

Response (Points)	Treatment (N = 18)	Control (N = 14)
Zool: 1.88 g/cm^3 (0)[a]	0[b] (0)[c]	2 (14)
Pretic 1.25 g/cm^3 (1)[d]	14 (78)	5 (36)
Salup: 0.80 g/cm^3 (0.25)[e]	1 (5)	3 (21)
Something else (0)[a]	0 (0)	2 (14)
No response (0)	3 (17)	2 (14)

[a] Incorrect answer
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct answer
[e] Incorrect answer due to inverted division

This question involved performing a simple calculation where the student had to find the volume of the material, divide it into the mass and then match the answer with a choice provided. Seventy-eight percent of the treatment group and 36% of the control group correctly answered the question. Five percent of the treatment group and 21% of the control group did reciprocal division. Seventeen percent of the treatment group and 14% of the control group did not answer the question.

The mean score for the treatment group on this question was 0.79 / 1 and 0.41 / 1 for the control group. The difference between these means was significant ($t = 2.47$, $df = 30$, $p \leq 0.05$. The control group had more practice working this type of problem, but the treatment group outperformed the control group on this question. This suggested that students who studied the topic of density using the guided learning conceptual pedagogy was better prepared than their traditional lab counterparts to solve calculation problems like the one in this question.

The four questions of this section on the Density lab were worth four points. The treatment group students had a mean total score of 3.03 for an average of 76% on each question. The control group had a mean total score of 2.61 for an average of 65% on each question. This suggested that students in both groups retained their density knowledge after finishing the course. The groups' means scores were not significantly different ($t = 1.12$, $df = 30$, $p > 0.05$).

Kinetic Theory Question 1:

Suppose you could obtain a very powerful set of eye glasses capable of seeing the particles of air. If you took a snapshot of what you saw, the scientific idea is that you would see tiny dots of particles inside a vessel (such as a balloon or flask). What do you think is between the particles? What leads you to that conclusion?

Student responses are recorded in Table 97. Sixty-seven percent of the treatment group and 50% of the control group answered that empty space exists between particles of air. One control group student expressed the conception by writing, "Between the particles you would see nothing......only empty space." One treatment group student said, "Empty space is between the particles."

Table 97. Post-course Quiz: Rubric and Responses for Kinetic Theory Question 1

Response (points)	Treatment (N = 18)	Control (N = 14)
Space (1)[a]	5[b] (28)[c]	2 (14)
Space (0.5)[d]	7 (39)	5 (36)
Other (0)	6 (33)	7 (50)

[a] Correct answer, complete explanation
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct answer, incomplete explanation

Students had the concept that there had to be something between the particles of air. There were two categories of responses: tangible and intangible items. Two treatment group students said that more air or dust was between the particles of air. Control group students said "air," "oxygen," or "gas." Intangible items between particles of air were "electrons" or "some sort of bond." A treatment group student said "energy" was between particles of air. The mean score for the treatment group on this question was 0.47 / 1 while it was 0.32 / 1 for the control group. There was no significant difference ($t = 1.09$, $df = 30$, $p > 0.05$), in the means of the two groups on this question. Students from the control lab did as well as students from the treatment lab.

Kinetic Theory Question 2: According to the kinetic theory, how are solids, liquids and gases different?

Students responded to this question (Table 98) by focusing on three things: the freedom of movement that particles have, the free space separating the particles, and the macroscopic properties of the phases of matter. Seventy-six percent of the treatment group and 70% of the control group related differences between solids, liquids and gases based on the movement of particles, particle spacing, phases and internal energy. Among the responses, students associated particle movement within an object to the object's temperature. Students further acknowledged that the strength of the bonds between the particles affected the ease of movement. Students noted that solids have less inter-particle space while gases have the most space between particles.

Table 98. Post-course Quiz: Rubric and Responses for Kinetic Theory Question 2

Response (points)	Treatment (N = 18)	Control (N = 14)
Particle Movement, Particle Spacing, and Phases (1)[a]	9[b] (49)[c]	7 (49)
Particle Movement, Particle Spacing, Internal Energy, and Phases (0.5)[d]	5 (27)	3 (21)
Other (0)	2 (11)	4 (29)
No Response (0)	2 (11)	0 (0)

[a] Correct response, complete explanation
[b] Number of times this item was mentioned
[c] Percentage of students
[d] Correct response, incomplete explanation

One treatment group student mentioned that solids, liquids and gases differed in whether they possessed a definite shape and volume or not. Two control group students mentioned that solids, liquids and gases were different phases of matter but they did not elaborate on what caused the distinction. Three treatment group students said that solids have less internal energy than gases. Other answers students gave were true but vague. These students did not explain what they meant when they said that solids, liquids and gases have different densities or that they "can be described differently." One treatment group student said that gases do not have any volume. Another treatment group student mentioned that solids, liquids and gases have mass and weight. Students considered particle spacing and relative particle movement as the two most defining characteristics of solids, liquids and gases. Students also related their kinetic energies to the particles' movement. One student added that phases changes occurred when the energy level of particles reached certain values. Two control group students generalized about the relative densities of solids, liquids and gases. One student characterized solids, liquids and gases based on whether it had a definite shape and volume.

The mean score for the treatment group was 0.68 / 1 and was 0.64 / 1 for the control group. The difference between these means was not significant ($t = 0.28$, $df = 30$, $p > 0.05$). Students who studied in both labs were capable of answering this question.

Kinetic Theory Question 3:

You may recall that we heated a flask with a balloon over its mouth. Explain why the balloon expanded. Be as specific as possible.

A summary of student answers are provided in Table 99. Seventy-two percent of the treatment group and 71% of the control group associated the addition of heat to particle movement. Students associated increased particle speed with increased pressure and with greater distance between particles. Two of these treatment group students and six of these control group students said that the heat made the air from the flask expand and it just rose into the balloon. This was a description of what happened, but the students did not explain why this occurred. They attributed the expansion of the air to the heat. Two treatment group students simply claimed that the heat made the particles expand, but they did not discuss the consequences of that phenomenon.

Table 99. Post-course Quiz: Rubric and Responses for Kinetic Theory Question 3

Response (points)	Treatment (N = 18)	Control (N = 14)
Particle Speed and/or Pressure (1)[a]	9[b] (50)[c]	3 (21)
Particle Speed and/or Expansion of air (0.5)[d]	4 (22)	7 (50)
Other (0)	5 (28)	4 (29)

[a] Correct response, complete explanation
[b] Number of times this item was mentioned
[c] Percentage of students
[d] Correct response, incomplete explanation

Three treatment group students and four control group students offered other ideas. One student in each group mentioned that air rose into the balloon. This was true, but there was no explanation of why that occurred. Two treatment group students said that CO_2 rose into the balloon. An examination of student answers on previous questions such as the fourth, seventh and ninth Kinetic Theory lab conceptual questions revealed that students did not make a chemical distinction between air, CO_2 and oxygen. These terms all were synonymous with "gas." The mean score for the treatment group on this question was 0.63 / 1 while it was 0.59 / 1 for the control group. The difference between these means was not significant ($t = 0.24$, $df = 30$, $p > 0.05$). Students who studied using either the treatment lab or the traditional lab performed equally well on answering this question.

Student answers revealed that they associated particle speed with temperature, but their explanations for an expanded balloon blended kinetic theory and descriptions of what they observed. One treatment group student said, "It expanded because of the particles going faster and faster the hotter they got and it made the balloon expand." One treatment group student gave the particles human-like qualities by saying "When the particles got hot they began moving very fast and this made the particles to want to expand and fill the balloon." One treatment group student made the statement "Particles expand and move faster when heated." This student did not clarify whether he/she thought the expansion resulted from individual particles getting larger, or particles remaining the same size but their increased motion caused them to sweep out a larger volume of space.

Kinetic Theory Question 4:

When water is boiling in a pan on the stove, what is the makeup of the bubbles in the boiling water?

Responses to this question are summarized in Table 100. Thirty-nine percent of the treatment group believed the bubbles in boiling water were water vapor. Fourteen percent of the control group answered this question correctly. Fifty percent of the treatment group and 43% of the control group believed that the heat liberated bubbles of air, oxygen or other gases that were trapped in the matrix of water. Two students of each lab group said the bubbles were hydrogen and oxygen. These responses pointed to the fact that not all students had a clear understanding of the phase change of a liquid to a gas, especially in the case of boiling water.

Table 100. Post-course Quiz: Rubric and Responses for Kinetic Theory Question 4

Response (points)	Treatment (N = 18)	Control (N = 14)
Water vapor (1)[a]	7[b] (39)[c]	2 (14)
Air (0)	4 (22)	3 (21)
Oxygen (0)	2 (11)	2 (14)
Hydrogen and Oxygen (0)	2 (11)	2 (14)
Carbon dioxide (0)	2 (11)	1 (7)
Gas (0)	1 (5)	0 (0)
I don't understand the question (0)	0 (0)	1 (7)
No response (0)	0 (0)	3 (21)

[a] Correct response
[b] Number of times this item was mentioned
[c] Percentage of students

The mean score for the treatment group on this question was 0.39 / 1 and 0.14 / 1 for the control group. There was no significant difference ($t = 1.61$, $df = 30$, $p > 0.05$) in the means of the two groups for this question. These results were similar to the results on Kinetic Theory conceptual question number nine where the treatment group had a mean score of 0.35 and the control group had a mean score of 0.34. Without regard to the type of lab methodology, students continued to maintain a misunderstanding of the nature of the bubbles in boiling water.

The questions of this section from the Kinetic Theory lab were worth four points. The treatment group students had a mean total score of 2.17 for an average of 54% on each question. The control group had a mean total score of 1.73 for an average of 43% on each question. This suggested that students in both groups retained some knowledge of the kinetic theory but less than density knowledge after finishing the course. The difference between the two groups' mean total scores was not significant ($t = 1.14$, $df = 30$, $p > 0.05$).

Chemical Reactions Question 1:
List as many things as you can that indicate the occurrence of a chemical reaction.

Both groups were able to list evidence of chemical reactions (Table 101). The responses students offered include such evidence as: temperature or energy changes, color changes, gas, smoke or precipitation formation, and odor changes. Students in the treatment group listed these items 71 times and the control group students listed these answers 54 times. The first three responses by students were recorded.

Unacceptable responses included: "change in consistency," change in phase," "crystallization," "de-crystallization," "nothing is added or taken," and "composition, decomposition, single replacement, and double replacement." Three treatment and ten control group students demonstrated a misconception by stating that a phase change represented a chemical change. The mean score for the treatment group on this question was 2.17 / 3 while the mean score was 2.39 / 3 for the control group. There was no significant difference in the means of the two groups ($t = -0.55$, $df = 30$, $p > 0.05$) for this question.

Table 101. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 1

Response (points)	Treatment (N = 18)	Control (N = 14)
Energy change (1)[a]	14[b] (78)[c]	14 (100)
Color change (1)[a]	14 (78)	12 (86)
Gas forms (1)[a]	9 (64)	10 (71)
Odor change (1)[a]	8 (44)	8 (57)
Precipitation (1)[a]	7 (39)	5 (36)
Smoke (1)[a]	19 (6)	5 (36)
Appearance change (0.5)[d]	4 (22)	3 (21)
Composition change (0.5)[d]	5 (28)	2 (14)
Phase change (0)	3 (17)	10 (71)
Other (0)	9 (50)	2 (14)

[a] Correct response, complete explanation
[b] Number of times this item was mentioned
[c] Percentage of students
[d] Correct response, incomplete explanation

Chemical Reactions Question 2:

Look at the following diagram. Does it represent a chemical reaction? Why or why not? (Be as specific as possible.)

ABA ABA AA BBBB

ABA → AA

ABA AA AA

Students were to decide if this represented a chemical reaction. When this question was sent to participants by email, the line spacing changed for six students. These students who replied either tried to answer the question based on bad formatting or they said that they could not understand the question. This question was omitted from scoring.

Chemical Reactions Question 3:

Three chemical equations are below. Indicate the type (C = Composition, D = Decomposition, SR = Single Replacement and DR = Double Replacement).

Tables 102 – 104 summarize the responses students gave for questions 3A – 3C.

3A: Mg + S → MgS

Table 102. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 3A

Response (Points)	Treatment (N = 18)	Control (N = 14)
C (1)[a]	16[b] (89)[c]	11 (79)
D (0)	0 (0)	0 (0)
SR (0)	0 (0)	1 (7)
DR (0)	1 (6)	0 (0)
No Response (0)	1 (6)	2 (14)

[a] Correct response
[b] Number of times this item was chosen
[c] Percentage of students

Students in both groups recognized this was a composition reaction. One student from each group mistakenly called the type of reaction a single-replacement or double replacement reaction. Students did not have to justify their choice of reaction type. The treatment group student who missed this question also missed the next two questions, post-course quiz, Chemical Reactions section 3B and 3C. This student did not understand how to recognize reaction types either. The students who did not answer this question did not answer any of the reaction type questions on the post-course quiz. This suggested that these students did not understand enough of how to recognize chemical reaction types to guess at an answer.

3B: $CaCO_3 \rightarrow CaO + CO_2$

The data in Table 103 show that 83% of the treatment group and 86% of the control group recognized this represented a decomposition reaction. These results support the idea that students in both groups were able to correctly recognize decomposition reactions from this given equation.

Table 103. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 3B

Response (Points)	Treatment (N = 18)	Control (N = 14)
C (0)	0[a] (0)[b]	0 (0)
D (1)[c]	15 (83)	12 (86)
SR (0)	1 (6)	0 (0)
DR (0)	1 (6)	0 (0)
No Response (0)	1 (6)	2 (14)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct response

3C: $Al + Zn(NO_3)_2 \rightarrow Al(NO_3)_3 + Zn$

Eighty-nine percent of the treatment group and 57% of the control group recognized this as a single replacement reaction. The one treatment group student who answered incorrectly also missed the other questions in this section. Two of the control group students who chose "DR" as the answer had correctly answered the previous two questions. One of the control group students who answered this question incorrectly also missed another question in this section. Another control group student who missed this question did not attempt the previous two question in this section.

Table 104. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 3C

Response (Points)	Treatment (N = 18)	Control (N = 14)
C (0)	0[a] (0)[b]	0 (0)
D (0)	1 (6)	0 (0)
SR (1)[c]	16 (89)	8 (57)
DR (0)	0 (0)	4 (29)
No Response (0)	1 (6)	2 (14)

[a] Number of times this item was chosen
[b] Percentage of students
[c] Correct response

Students in both lab groups were successful in recognizing composition (Table 102) and decomposition (Table 103) reactions. Eighty-nine percent of the treatment group and 57% of the control group recognized single replacement reactions (Table 104). Students who did not know how to determine the reaction type either left the questions blank or missed multiple questions in this section. Students had the most difficulty differentiating double replacement reactions from single replacement reaction and from decomposition reactions.

The total mean score for the treatment group on this question was 2.61 / 3 and the total mean score for the control group was 2.14 / 3. There was no significant difference in the means of the two groups ($t = 1.27$, $df = 30$, $p > 0.05$). This suggested that students in both lab groups were equally capable of identifying composition, decomposition, and single replacement reactions from given chemical equations.

Chemical Reactions Question 4:
Do these represent chemical reactions? (Yes or No) Then tell why you answered the way you did.

4A: Snapping a wooden Popsicle stick into two pieces

The data in Table 105 indicate that 89% of the treatment group and all of the control group students recognized that snapping a wooden Popsicle stick into two pieces was not a chemical reaction. Twelve treatment group students and five control group students reasoned that this was not a chemical reaction because the composition of the wood had not changed. Only two control group students justified their answer by stating that there was no evidence of a chemical reaction such as an energy change or color change.

Table 105. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 4A

Response (points)	Treatment (N = 18)	Control (N = 14)
No (1)[a]	14[b] (78)[c]	10 (71)
No (0.5)[d]	2 (11)	4 (29)
Yes (0)	2 (11)	0 (0)

[a] Correct response, logical reason
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct response, no reason

The two treatment group students who said this was a chemical reaction said, "Yes - the object did change in form" and "Yes because you got two different pieces after breaking the stick, making two new pieces." These comments suggested that they thought that a change of physical form or a change in the number of particles constituted a chemical reaction. These concepts were not widespread throughout the other assessments on the Chemical Reactions lab.

The mean score for the treatment group was 0.83 / 1 and was 0.86 / 1 for the control group. The two groups' mean scores were not significantly different ($t = -0.22$, $df = 30$, $p > 0.05$). This suggests that students who studied about chemical reactions from either the guided learning lab or the traditional lab were both successful at recognizing this scenario as not being a chemical change.

4B: Burning wood in a fireplace

Ninety-four percent of the treatment group and 85% of the control group said that burning wood in a fireplace was a chemical reaction (Table 106). Fifteen treatment

Table 106. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 4B

Response (points)	Treatment (N = 18)	Control (N = 14)
Yes (1)[a]	15[b] (83)[c]	9 (64)
Yes (0.5)[d]	2 (11)	3 (21)
No (0)	1 (6)	2 (14)

[a] Correct response, logical reason
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct response, no reason

group students and seven control group students relied on evidence of a chemical reaction to support their decision. Students made these sample comments, "Yes because the chemical form of the wood changed," '"Yes, the molecular structure of the molecules change and energy is released, "Yes, changes wood to ash," "Yes because it changes color and physical appearance and has an odor while burning," and "Yes, heat is given off and different materials exist at the end of the reaction." One person in each group said this represented a chemical change because there was a change in physical state. Another control group student thought burning a piece of wood was a physical change, citing that the wood changes states of matter from a solid to a gas.

These results indicated that students were capable of recognizing that a burning piece of wood was a chemical reaction. Another observation was that students who observed a change in the physical appearance of the wood during the chemical change of associated with burning only focused on the physical change. These students did not recognize the indicators of a chemical reaction, such as the release of energy or the formation of products that were different from the reactants as presented in either lab.

Thirty-nine percent of the treatment group believed the bubbles in boiling water were water vapor. Fourteen percent of the control group answered this question correctly. Fifty percent of the treatment group and 43% of the control group believed that the heat liberated bubbles of air, oxygen or other gases that were trapped in the matrix of water. Thirty-nine percent of the treatment group believed the bubbles in boiling water were water vapor. Fourteen percent of the control group answered this question correctly. Fifty percent of the treatment group and 43% of the control group believed that the heat liberated bubbles of air, oxygen or other gases that were trapped in the matrix of

water. The mean score for this question was 0.89 / 1 for the treatment group and 0.75 / 1 for the control group. The difference between these means was not significant ($t = 1.20$, $df = 30$, $p > 0.05$). Both lab methodologies were equally capable of helping the majority of students recognize that burning wood was a chemical reaction.

C: Baking soda and vinegar put together

Eighty-three percent of the treatment group and 64% of the control group correctly recognized that when baking soda and vinegar are mixed, a chemical reaction occurs because the composition changed or there was evidence of a reaction (Table 107). One control group student incorrectly thought this represented a physical change.

Table 107. Post-course Quiz: Rubric and Responses for Chemical Reactions Question 4C

Response (points)	Treatment (N = 18)	Control (N = 14)
Yes (1)[a]	15[b] (83)[c]	9 (64)
Yes (0.5)[d]	3 (17)	3 (21)
No (0)	0 (0)	1 (7)
No Response (0)	0 (0)	1 (7)

[a] Correct response, logical reason
[b] Number of times this item was chosen
[c] Percentage of students
[d] Correct response, illogical or no reason

The mean score for the treatment group on this question was 0.86 / 1 and the control group had a mean score of 0.75 / 1. There was no significant difference in the means of the two groups ($t = 0.88$, $df = 30$, $p > 0.05$). Both lab methodologies were equally capable of helping the majority of students to recognize that baking soda and vinegar involve a chemical reaction when they are place together.

Table 108. Post-course Quiz: Comparison of Each Lab Groups' Mean Scores on Each Post-course Quiz Question

	Treatment (N = 18)		Control (N = 14)				
Question Number	Mean score	SD	Mean score	SD	t	df	p
Density 1	0.92	0.26	0.82	0.37	0.86	30	0.40
Density 2	0.79	0.33	0.86	0.23	-0.62	30	0.54
Density 3	0.53	0.44	0.52	0.46	0.06	30	0.95
Density 4	0.79	0.40	0.41	0.47	2.47	30	0.02
Kinetic Theory 1	0.47	0.40	0.32	0.37	1.09	30	0.29
Kinetic Theory 2	0.68	0.41	0.64	0.34	0.28	30	0.78
Kinetic Theory 3	0.63	0.42	0.59	0.41	0.24	30	0.81
Kinetic Theory 4	0.39	0.50	0.14	0.36	1.61	30	0.12
Chemical Reactions 1	2.17	1.26	2.39	1.02	-0.55	30	0.59
Chemical Reactions 3	2.61	0.98	2.14	1.10	1.27	30	0.22
Chemical Reactions 4A	0.83	0.34	0.86	0.23	-0.22	30	0.83
Chemical Reactions 4B	0.89	0.27	0.75	0.38	1.20	30	0.24
Chemical Reactions 4C	0.86	0.33	0.75	0.38	0.88	30	0.39

The three questions of this section on Chemical Reactions were worth nine points. The treatment group students had a mean total score of 7.36 for an average of 82% on each question. The control group had a mean total score of 6.89 for an average of 77% on each question. This suggested that students in both groups retained knowledge of chemical reactions after finishing the course. The difference between the mean total scores (Table 109) was not significant ($t = 0.65$, $df = 30$, $p > 0.05$). Both lab methodologies were equally capable of helping the majority of students to recognize chemical reactions from descriptions of phenomena.

Table 109. Post-course Quiz: Statistical Comparison of Each Lab Groups' Individual Lab Section Mean Score and Total Score

	Treatment (N = 18)		Control (N = 14)				
Individual Lab Section	Mean score	SD	Mean score	SD	t	df	p
Density	3.03	1.01	2.61	1.10	1.12	30	0.27
Kinetic Theory	2.17	1.07	1.73	1.08	1.14	30	0.27
Chemical Reactions	7.36	1.96	6.89	2.11	0.65	30	0.52
Post-course Quiz Total	12.56	3.43	11.23	3.34	1.10	30	0.28

All lab section total scores and the post-course quiz total score were compared (Figure 7). A statistical comparison of the mean scores for each lab group's total on each lab's section of the post-course quiz and the overall mean score on the post-course quiz was conducted (Table 109). The treatment group had a mean total score of 12.56 and the control group had a mean total score of 11.23. The difference between the two groups' mean total scores on the post-course quiz was not significant ($t = 1.10$, $df = 30$, $p > 0.05$). This indicated that students who had completed the course PSCI 1030 with either lab methodology were equally capable of answering questions regarding the Density, Kinetic Theory, and Chemical Reactions labs.

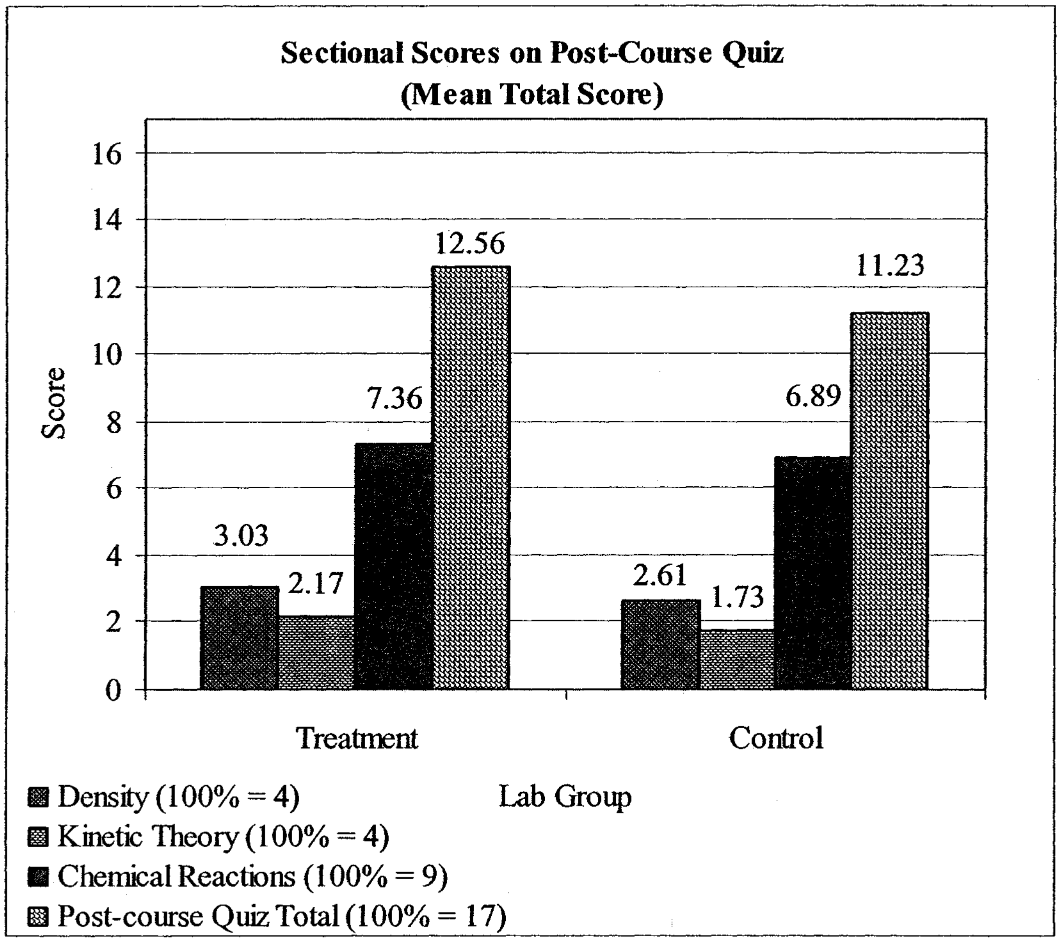


Figure 7. Sectional scores and mean total scores on post-course quiz by lab group

Correlation of Post-course Quiz Score and Days Since the Course Was Taken

A quiz was sent by email to each willing participant after the course was over. Seventeen students did not participate because their email addresses were incorrect. Two control group students who had indicated a willingness to participate in the post-course quiz did not respond within 152 days (five months) of being sent the email quiz. These students were sent the post-course quiz again. One of these students received the quiz after the second issuance 218 days after the course was over and responded within ten days. The other control group student received the quiz after the third issuance 516 days after the course was over and responded in two days. Their eventual reply made the return time for these students exceptionally long. The remaining 12 control group students received their email quiz within a range of 33 – 152 days and responded within 21 days giving a response to the post-course quiz an average of 82 days after having taken the course. All of the treatment group students replied after the first appeal, but due to an oversight, two of these students were not sent the post-lab quiz until 429 days (14 months) later. Of the remaining 16 students from the treatment group, these students received their post-course quiz from 31 – 183 days after the course was over and responded within 33 days for an average of 74 days after the course was over. The two students who received their quiz over a year later responded within four days for an average of 433 days after the course was over.

Given the range of days since the students had taken the course, 33 – 516 for the control group and 31 – 435 for the treatment group, (Table 110), an examination was conducted to determine if there was a pattern of knowledge retention as a function of time since the course had been taken. Using linear regression, student scores on the three labs and their total score on the post-lab quiz were examined as a function of the number of days that had passed since students took the course (Table 111). The linear equations generated from the regression analyses all had Pearson correlation (r) coefficients less than 0.5, which meant that their linear trends were not reliable. The conclusion was that there were no clear trends about knowledge retention as a function of time for either group based on the results from these students' responses.

Table 110. Data of Students Taking Post-Course Quiz

			Section of Post-Course Quiz			
Lab Group	Student Number	Days since end of course	Density (%)	Kinetic Theory (%)	Chemical Reactions (%)	Total (%)
Control (N = 18)	204	62	100	75	100	94
	1684	62	88	50	100	85
	2022	173	38	50	33	38
	2081	62	44	31	100	71
	3578	516	100	75	89	88
	5841	95	56	50	89	72
	6153	228	63	38	22	35
	6523	173	50	13	67	50
	7337	67	25	44	83	60
	7566	64	44	6	78	53
	8432	33	69	13	67	54
	9315	70	38	19	78	54
	9329	64	100	44	78	75
	9497	63	100	100	89	94
Treatment (N = 15)	1907	38	88	50	78	74
	3359	93	88	38	94	79
	3718	31	38	63	67	59
	3894	92	69	25	78	63
	3902	42	100	50	100	88
	3926	51	100	94	100	99
	4961	45	75	81	100	90
	4962	68	94	25	89	75
	6741	65	75	63	78	74
	7506	185	88	44	56	60
	7824	32	50	50	67	59
	7827	435	100	100	100	100
	7854	64	81	75	94	87
	9070	431	13	25	17	18
	9530	31	100	100	100	100

Table 111. Linear Regression Analysis of Post-Course Sectional Quiz Scores and Total Scores as a Function of Days Since Course Was Taken

Source for Score	Equation based on:	Treatment (N = 18) Equation	r	Control (N = 14) Equation	r
Density Section	Raw Score	Score = -0.002*Days + 3.253	0.24	Score = 0.0019*Days + 2.37	0.22
	Percentage	Percentage = -0.0493*Days + 81.313	0.24	Percentage = 0.0476*Days + 59.293	0.22
Kinetic Theory Section	Raw Score	Score = -0.0002*Days + 2.194	0.03	Score = 0.0023*Days + 1.4536	0.26
	Percentage	Percentage = -0.006*Days + 54.846	0.03	Percentage = 0.0563*Days + 36.339	0.26
Chemical Reaction Section	Raw Score	Score = -0.0066*Days + 8.112	0.42	Score = -0.0037*Days + 7.35.48	0.22
	Percentage	Percentage = -0.0733*Days + 90.138	0.42	Percentage = -0.0415*Days + 81.719	0.22
Total on Post-Course Quiz	Raw Score	Score = -0.0088*Days + 13.559	0.32	Score = 0.0004*Days + 11.18	0.02
	Percentage	Percentage = -0.0518*Days + 79.758	0.32	Percentage = 0.0025*Days + 65.765	0.02

Correlation of Post-course Quiz Sectional and Total Scores

All sectional scores and the total score on the post-course quiz were correlated to each other using a Pearson correlation analysis to identify pairs of assessment values that corresponded. The results are shown in Table 112. A strong correlation between pairs of data was defined as a value where $r \geq 0.80$. A moderate correlation was defined as $0.80 > r \geq 0.5$, and a weak correlation existed if $r < 0.50$. There was a strong to moderate relationship between the total score and each quiz sectional lab score at the $p \leq 0.01$ level. This was expected since the total score is comprised of the sum of the individual lab sectional scores. There was a moderate correlation at the $p \leq 0.01$ level between the treatment group's Density and Chemical Reactions sectional scores. This meant that there was a less-than-one percent chance these two sectional scores could have been similar by chance. There was also a moderate correlation at the $p \leq 0.05$ level between the Kinetic Theory and Chemical Reactions sectional scores for the treatment group. This suggested that students taught using the guided learning pedagogy for the Density lab performed similarly on the guided learning Chemical Reactions labs. Students taught using the guided learning pedagogy for the Kinetic Theory lab performed similarly on the guided learning Chemical Reactions labs. There was no significant correlation between the Density or Kinetic Theory lab and the Chemical Reactions lab for the control group.

For both the treatment and control labs, there was an emphasis on matter being composed of individual particles that have mass, which are in motion and which occupy space. The Density lab helped students recognize that matter has both mass and volume. The Kinetic Theory lab helped students in both lab groups focus on the fact that individual particles of a material have mass, particles' motions are proportional to their temperature, and that particles exert a force on objects with which they collide. Students observed in their work that the rates of chemical reactions can be explained by the kinetic theory. When students performed the chemical reactions lab, both sets of lab instructions emphasized that chemical reactions occur due to the interaction of particles.

The strong correlation for the treatment group between the Density lab or the Kinetic Theory and the Chemical Reactions lab suggested that the guided learning pedagogy helped students recognize the particle nature of matter.

Table 112. Pearson Correlations between Sections of Post-course Quiz and Total Score

Quiz Section		Kinetic Theory		Chemical Reactions		Post-Quiz Total	
		Treatment (N = 18)	Control (N = 14)	Treatment (N = 18)	Control (N = 14)	Treatment (N = 18)	Control (N = 14)
Density	r[a]	0.36	0.65	0.69	0.33	0.81	0.74
	p	0.14	0.01*	0.00**	0.25	0.00**	0.00**
Kinetic Theory	r[a]			0.52	0.29	0.72	0.72
	p			0.03*	0.32	0.00**	0.00**
Chemical Reactions	r[a]					0.94	0.83
	p					0.00**	0.00**

[a] Pearson's correlation coefficient
* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

Verification of the Scores on Pre- and Post-lab Quizzes and on the Conceptual Questions: Inter-rater Reliability

A Pearson correlation was performed on student scores that the external graders obtained when they graded the pre-lab and post-lab quizzes and the conceptual questions for all three labs. The results of the correlation are found in Table 113.

Table 113. Inter-rater Reliability

Lab	Assessment Instrument	Correlation to Grader One (r[a])	Correlation to Grader Two (r[a])
Density	Pre-lab quiz ($N = 168, p \leq 0.01$)	0.98	0.98
	Post-lab quiz ($N = 168, p \leq 0.01$)	0.98	0.98
	Conceptual Questions ($N = 21, p \leq 0.01$)	1.00	1.00
Kinetic Theory	Pre-lab quiz ($N = 17, p \leq 0.01$)	0.99	0.99
	Post-lab quiz ($N = 24, p \leq 0.01$)	0.99	0.99
	Conceptual Questions ($N = 15, p \leq 0.01$)	0.98	0.99
Chemical Reactions	Pre-lab quiz ($N = 32, p \leq 0.01$)	1.00	1.00
	Post-lab quiz ($N = 24, p \leq 0.01$)	0.99	0.99
	Conceptual Questions ($N = 20, p \leq 0.01$)	1.00	1.00

[a] Pearson's Correlation Coefficient

There was a 0.98 correlation coefficient, or reliability factor, on the Density pre-lab and post-lab quizzes and a correlation coefficient of 0.998 for Grader One and 0.999 for Grader Two, rounded to two decimal places in the table, for the conceptual questions. This indicated that the scores we assigned to students in this research were consistent with scores assigned by external graders.

For the Kinetic Theory lab, the correlation coefficients were 0.99 for the external graders for the pre-lab quiz and the post-lab quiz. For the Kinetic Theory conceptual questions, Grader One had a 0.98 inter-rater factor and Grader Two had a 0.99 factor of agreement. On the Chemical Reactions lab, the external graders had identical ratings with 1.00 on the pre-lab quiz, 0.99 on the post-lab quiz and 1.00 on the conceptual questions. In all cases, the two external graders' values agreed very strongly ($r > 0.98$,

$p \leq 0.01$) with the values already assigned. The results of this inter-rater reliability gave credibility and reliability to the scores used in this research.

Correlation of Potential Predicting Factors to Lab Quizzes and Questions

The data were analyzed to determine if there were any pre-existing factors that could predict the outcome on assessments. A Pearson correlation test was conducted on each lab group to compare student scores on assessments to potential predicting factors. The student assessments were the labs' post-lab quizzes, conceptual questions and the post-course quizzes. Potential predicting factors for student successes were students' ACT Mathematics, Reading Comprehension and Science Reasoning scores. A comparison was also made between the number of mathematics and science courses that students had taken prior to taking PSCI 1030 and the assessment scores used in this research. The rationale for this latter comparison was that students who had taken more mathematics or science courses might score higher on these assessments than students who had taken fewer math or science courses due to greater exposure to subject content and associated skills in those courses to those encountered in PSCI 1030. Other demographic data also investigated were students' age categories and the students' gender. The treatment group's correlation results are recorded in Tables 114 and 115. The control group's correlation results are recorded in Tables 116 and 117.

A strong correlation between potential predicting factors of success and the assessment scores was defined as a value where $r \geq 0.80$. A moderate correlation was

Table 114. Correlation of ACT Scores and Number of Courses Taken in High School to Lab Assessments for the Treatment Group

		ACT			Number of Courses Taken in High School	
Lab	Assessment Instrument	Mathematics (r^a)	Reading (r)	Science (r)	Mathematics (r)	Science (r)
Density	Post-lab quiz	0.60**	0.48**	0.67**	0.33*	0.13
	Conceptual Question	0.58**	0.48**	0.67**	0.34*	0.11
	Post-Course	0.44	0.38	0.47	0.45	0.31
Kinetic Theory	Post-lab quiz	0.18	0.26	0.01	0.41**	0.27*
	Conceptual Question	0.33	0.31	0.56	0.14	0.11
	Post-Course	0.29	0.42	0.31	0.20	-0.21
Chemical Reactions	Post-lab quiz	0.52**	0.64**	0.66**	0.29*	-0.06
	Conceptual Question	0.23	0.26	0.33	0.12	-0.01
	Post-Course	0.62	0.49	0.63*	0.54*	0.19
	Post-Course Quiz Total	0.56	0.49	0.62	0.48	0.12

[a] Pearson's Correlation Coefficient
* Correlation significant at the 0.05 level
** Correlation significant at the 0.01 level

Table 115. Correlation of Age Category and Gender to Lab Assessments for the Treatment Group

Lab	Assessment Instrument	Age Category[a] (r^b)	Gender[c] (r)
Density	Post-lab quiz	-0.05	-0.20
	Conceptual Question	-0.20	-0.19
	Post-Course	0.16	-0.36
Kinetic Theory	Post-lab quiz	-0.10	-0.14
	Conceptual Question	0.12	-0.27
	Post-Course	0.56	-0.72*
Chemical Reactions	Post-lab quiz	0.08	-0.42**
	Conceptual Question	-0.01	0.05
	Post-Course	0.22	-0.36
	Post-Course Quiz Total	0.35	-0.52*

a 1 = under 18 years old, 2 = 18 – 20, 3 = 21 – 23, 4 = 24 – 27, 5 = over 27 years old
b Pearson's Correlation Coefficient
c Male = 1, Female = 2
* Correlation significant at the 0.05 level
** Correlation significant at the 0.01 level

Table 116. Correlation of ACT Scores and Number of Courses Taken in High School to Lab Assessments for the Control Group

		ACT			Number of Courses Taken in High School	
Lab	Assessment Instrument	Mathematics (r^a)	Reading (r)	Science (r)	Mathematics (r)	Science (r)
Density	Post-lab quiz	0.31*	0.02	0.25	0.23	-0.14
	Conceptual Question	0.20	-0.02	0.09	0.16	-0.14
	Post-Course	0.56	0.33	0.76**	0.32	-0.39
Kinetic Theory	Post-lab quiz	0.43**	0.06	0.22	-0.01	-0.09
	Conceptual Question	0.33	0.15	-0.02	-0.10	0.06
	Post-Course	0.58	-0.27	0.37	0.47	-0.00
Chemical Reactions	Post-lab quiz	0.23	0.16	0.29	0.07	0.00
	Conceptual Question	0.13	-0.20	0.12	0.11	0.33
	Post-Course	0.47	-0.05	0.44	0.15	-0.44
	Post-Course Quiz Total	0.68*	-0.00	0.66*	0.35	-0.41

[a] Pearson's Correlation Coefficient
* Correlation significant at the 0.05 level
** Correlation significant at the 0.01 level

Table 117. Correlation of Age Category and Gender to Lab Assessments for the Control Group

Lab	Assessment Instrument	Age Category (r^a)	Gender[b] (r)
Density	Post-lab quiz	-0.01	-0.06
	Conceptual Question	0.06	-0.12
	Post-Course	0.09	-0.36
Kinetic Theory	Post-lab quiz	0.02	-0.33*
	Conceptual Question	0.07	0.03
	Post-Course	0.07	-0.22
Chemical Reactions	Post-lab quiz	-0.17	-0.07
	Conceptual Question	-0.28	-0.08
	Post-Course	0.11	-0.40
	Post –Course Quiz Total	0.12	-0.44

[a] 1 = under 18 years old, 2 = 18 – 20, 3 = 21 – 23, 4 = 24 – 27, 5 = over 27 years old
[b] Pearson's Correlation Coefficient
[c] Male = 1, Female = 2
* Correlation significant at the 0.05 level
** Correlation significant at the 0.01 level

defined as $0.80 > r \geq 0.5$, and a weak correlation existed if $r < 0.50$. For the treatment group, there were moderate correlations (Table 114) between the ACT Mathematics, Reading Comprehension and Science Reasoning scores and student performances on the Density and Chemical Reactions post-lab quizzes. There were also moderate correlations between the ACT Mathematics and Science Reasoning scores and the Density lab's conceptual questions, the Chemical Reactions lab's post-course sectional quiz and the total score on the post-course quiz. There was also a moderate correlation between the treatment groups' ACT Science Reasoning score and the Kinetic Theory conceptual questions.

For the control group, there was only a moderate correlation (Table 116) between the ACT Mathematics and Science Reasoning scores and the Density lab's section of the post-course quiz and the total score on the post-course quiz. There was also a moderate correlation between the ACT Mathematics score and the Kinetic Theory lab's section of the post-course quiz.

These results suggested that those in the treatment group who have higher ACT Mathematics scores were more likely to score higher on five of the 10 assessments used in this research, of which the Density post-lab quiz and conceptual question, the Chemical Reactions post-lab quiz and post-course section, and the post-course quiz assessment scores were significant. Those in the treatment group who have higher ACT Science Reasoning scores were also more likely to score higher on six of the 10 assessments used in this research, four scores of which were significant. These assessments were: Density post-lab and conceptual questions and Chemical Reactions post-lab and post-course quizzes. Students in the treatment group also had a moderate correlation of their ACT Reading score and their Chemical Reactions post-lab quiz.

Those in the control group who had higher ACT Mathematics scores were more likely to score higher on three of the 10 assessments used in this research, of which the post-course quiz total score was significant. Those in the control group who had higher ACT Science Reasoning scores were more likely to score higher on two of the 10 assessments used in this research, of which both Density post-course and Post-course quiz total scores were significant.

No strong correlations, $r \geq 0.80$, existed between the students' ages, gender, number of mathematics courses or number of science courses taken in high school and their performances on the assessments for either group (Table 115 and Table 117). There was, however, a moderate negative correlation between students' gender (males were assigned a value of one and females were assigned a value of two) in the treatment group and two assessments in this research. These assessments were the Kinetic Theory section of the post-course quiz and the total score on the post-course quiz. There were eight females and six males in the control group who responded to the post-course quiz. There were 11 females and four males among the treatment group students who responded to the post-course quiz. In the control group, the males had a mean total score on the post-course quiz of 12.88 while the females had a mean total score of 10.00 (Table 118). For the treatment group, the males had a mean total score of 15.81 and the females had a mean total score of 11.61 (Table 118). The difference in scores on the post-course quiz along gender lines was reason to explore how students scored on the other assessments when organized by gender. Student mean scores on the pre-lab and post-lab quizzes, the conceptual questions and the post-course quiz were analyzed based on gender and on the lab group. These results are reported in Table 118.

Males' mean scores were higher than females' mean scores on six of the assessments. For the treatment group, three of the assessments were significant at the $p \leq 0.01$ level. These included the Kinetic Theory pre-lab quiz, the Kinetic Theory post-course sectional quiz and the Chemical Reactions post-lab quiz. There were two control group comparisons showing a significant difference between the males' and females' mean scores. The Kinetic Theory pre-lab quiz was significantly different at the $p \leq 0.05$

level and the Kinetic Theory post-lab quiz, significant at the $p \leq 0.01$ level. These results suggested that males outscored the females on these assessments of lab pedagogy in this research. The post-course quiz total score for the treatment group was significantly higher for the male student ($p \leq 0.05$).

On the basis of gender, an analysis was conducted which correlated ACT sectional scores to the number of mathematics and science courses. The purpose of this analysis was to investigate the possibility of an underlying gender difference in preparation of students in this research. The results are reported in Table 119. For the treatment group males, the number of mathematics courses they took correlated significantly to the number of science courses they had taken as well as all of the ACT subsection scores. This implied that males in the treatment group who took more mathematics courses also took more science courses and scored higher on the ACT Mathematics, Reading, and Science Reasoning subsections. This implication was not true for females in the treatment group. The data also implies that there is no significant relationship between the number of science courses and how well treatment group females or males performed on the ACT sectional scores. For the control group, there was a significant correlation between the number of mathematics courses both females and males had previously taken and the number of science courses both had taken and how well both genders performed on the ACT Mathematics sectional score.

The data in Table 120, broken down by gender, shows the mean number of science and mathematics courses students took in high school. It also shows their ACT sectional scores in Mathematics, Reading, and Science Reasoning. For both the treatment and control groups, females had taken more mathematics courses than males

Table 118. Score Comparisons on All Research Assessments by Group and Gender

			Treatment		Control	
Assessment		Gender	N	Mean	N	Mean
Density	Pre-lab quiz	F	39	10.13	56	9.16
		M	17	10.35	35	9.91
	Post-lab quiz	F	39	12.44	56	11.14
		M	17	13.35	35	11.49
	Conceptual Questions	F	42	4.56	29	4.07
		M	16	5.09	16	4.16
	Post-course quiz	F	11	2.84	8	2.28
		M	4	3.75	6	3.04
Kinetic Theory	Pre-lab quiz	F	37	1.77	41	3.05
		M	16	2.91**	22	3.96*
	Post-lab quiz	F	37	3.91	41	2.65
		M	16	4.47	22	3.80**
	Conceptual Questions	F	37	14.23	19	12.47
		M	15	16.33	10	11.60
	Post-course quiz	F	11	1.91	8	1.53
		M	4	3.56**	6	2.00
Chemical Reactions	Pre-lab quiz	F	39	12.39	39	11.55
		M	17	13.27	18	12.00
	Post-lab quiz	F	39	13.17	39	12.51
		M	17	14.88**	18	12.89
	Conceptual Questions	F	38	9.80	19	8.47
		M	14	9.64	10	8.95
	Post-course quiz	F	11	6.86	8	6.19
		M	4	8.50	6	7.83
Post-course quiz: Total Score		F	11	11.61	8	10.00
		M	4	15.81*	6	12.88

* Significant at the 0.05 level
** Significant at the 0.01 level

Table 119. Correlation of Number of Courses Taken in Mathematics and Science and ACT Sectional Scores by Gender

			Number of Science Courses	ACT Mathematics	ACT Reading	ACT Science Reasoning
Treatment						
	Number of Mathematics Courses	F	0.407[a]	0.009	0.059	-0.065
		M	0.497**	.691**	0.727**	0.583**
	Number of Science Courses	F		0.490	-0.185	0.027
		M		0.160	0.325	0.234
	ACT Mathematics	F			0.646*	0.845**
		M			0.753**	0.790**
	ACT Reading	F				0.894**
		M				0.595**
Control						
	Number of Mathematics Courses	F	0.459**	0.592**	0.112	0.247
		M	0.337**	0.447**	0.121	0.269
	Number of Science Courses	F		0.037	0.012	-0.114
		M		0.110	0.123	0.159
	ACT Mathematics	F			0.462*	0.772**
		M			0.579**	0.747**
	ACT Reading	F				0.609**
		M				0.800**

[a] Pearson correlation coefficient
* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

while males had taken more science courses than females. With the exception of the control group's ACT Reading scores, females in both the treatment group and the control group this project outscored their male counterparts on all of the ACT sectional scores.

These analyses showed that females in both lab groups had taken more math classes prior to taking PSCI 1030. Taking students' ACT scores as a reliable measure of academic preparedness, females were more academically prepared since their ACT scores were higher than their male counterparts were. The difference between male and female performance was not due to differences in academic preparation.

Since males in both groups had taken more science courses, the data in Tables 114 and 116 were further analyzed by gender to see if there was a correlation between the number of science courses taken in high school and success on the assessments used in this research. There was one moderate correlation ($r = 0.512$, $p \leq 0.05$) for the females in the control group between the number of high school science classes taken and the conceptual questions over the Chemical Reactions lab. There was also one moderate negative correlation ($r = -0.565$, $p > 0.05$) for the males in the control group between the number of high school science classes taken and the conceptual questions over the Chemical Reactions lab. These results suggest that success on assessments used in this research by either group was not correlated to the number of science courses students had taken. Therefore, the number of science courses taken by males did not cause them to have higher scores on the assessments used in this research.

No known gender bias was introduced into the development of the treatment labs or into the assessments used in this research. Had there been gender bias in the treatment labs, males should not have consistently outscored their female counterparts in the

Table 120. Comparison of Number of Courses Taken in Mathematics and Science and ACT Sectional Scores by Gender

	Treatment		Control	
	Female	Male	Female	Male
Number of Mathematics Courses	4.88	4.26	4.40	4.18
Number of Science Courses	3.35	3.67	3.45	3.51
ACT Mathematics	22.30	20.12	21.14	19.85
ACT Reading	26.30	21.92	21.45	21.77
ACT Science Reasoning	25.00	20.44	22.41	20.67

control lab group. These results indicated the existence of unanticipated and unidentified variables at work in this research. No data was collected on other variables such as size of course load being taken, number of hours the student works at a job, hours of sleep students get per night, and responsibilities outside of class that could prevent spending enough time preparing for the lab in PSCI 1030. No survey was given to students to assess their interest in the subject matter or their motivation to perform well. More research needs to be conducted to determine contributing factors of success in PSCI 1030 lab.

Comparison of Fall and Summer Students

An examination was made to determine if students' demographics and performances on assessments were significantly different based on when they took the course. The two categories of course lengths were the fall semester and the summer sessions of May, June or July. The treatment group took PSCI 1030 only during summer months, so a comparison between fall and summer students was not made for the treatment group. Fifty-five control group students took PSCI 1030 during the fall while 61 control group students took the course during May, June or July (Table 1).

The data contrasting the control groups' demographics and academic performance are found in Table 121. There was no significant difference, $p > 0.05$, in any of the ACT sectional scores for the control group students who took PSCI 1030 during the fall semester or those who took the course during the summer. The students who took the course during the summer were significantly older, $p \leq 0.01$, than those who took the course during the fall.

There was no significant difference ($p > 0.05$) in the number of mathematics and science courses the groups had taken. The summer group significantly outperformed the fall group, $p \leq 0.05$, on both the Density and the Kinetic Theory post-lab quizzes, but the summer group performed more poorly than the fall group on the Chemical Reactions post-lab quiz. The summer control group students answered the conceptual questions relating to the Density lab but not the other two labs. The fall control-group students answered the conceptual questions on all three labs. There was no significant difference, $p > 0.05$, between the mean scores of the fall and summer groups for the Density conceptual questions.

Of the ten categories in Table 121, two (Density post-lab quiz and Kinetic Theory post-lab quiz) of the means for the categories were higher for the fall control group and one (Age category) was higher for the Summer control group. These results suggest that

Table 121. Comparison of Control Groups' Demographic Data and Assessment Scores: Fall Semester versus Summer Sessions

Criterion for Comparison	Fall Semester Mean score	Fall Semester SD	Summer Mean score	Summer SD	t	df	p
ACT Mathematics	20.42	4.08	20.24	4.35	0.19	75	0.85
ACT Reading	20.84	4.81	22.68	4.64	-1.69	75	0.10
ACT Science	21.14	3.79	21.56	3.96	-0.47	75	0.64
Age Category	2.55	0.94	3.18	1.00	-3.52	113	0.00
Number of Mathematics Courses	4.02	1.21	4.48	1.58	-1.78	110	0.08
Number of Science Courses	3.29	1.24	3.67	1.57	-1.42	113	0.16
Density: Post-lab Quiz	12.05	2.46	10.55	3.11	2.53	89	0.01
Density: Conceptual Questions	6.35	2.02	6.29	2.00	0.08	43	0.93
Kinetic Theory: Post-lab Quiz	3.63	1.60	2.59	1.45	2.71	61	0.01
Kinetic Theory: Conceptual Questions	12.17	4.09	-[a]	-	-	-	-
Chemical Reactions: Post-lab Quiz	12.42	2.43	12.80	2.43	-0.59	55	0.56
Chemical Reactions: Conceptual Questions	8.62	2.44	-[a]	-	-	-	-

[a] The summer control group did not answer these questions; therefore, no t-test could be performed.

older students took the Summer course and the two Fall assessments were higher than those for their Summer counterparts. Inasmuch as the ACT scores and the other assessments in Table 121 were not significantly different, it is reasonable to combine the two groups and use their results as data for the control group. Another comparison that might have been made would be to compare the percentage of students earning an A, B, or C in the Fall versus those in the summer classes. This information was not obtained to make such a comparison.

Student Comments

The following unedited comments were received by email. They serve as data on the use of guided learning lab pedagogy in PSCI 1030 labs. Treatment group students said:

> "Your labs were more interesting than the ones I the book. They explained things in a more down-to-earth way and related them to everyday things. There were also more fun. When you have compiled your research, I want a copy to see how it turned out."

> "Just to let you know, I did fully enjoy your labs. They were very interesting to me and many people I spoke with. I wish you the best of luck with your research and let me know if I can be of any more assistance. Good luck."

> "I THOUGHT YOUR EXPIRIMENTS (sic) WERE CHILDISH. THEY WOULD BETTER SUIT A HIGH SCHOOL ENVIRONMENT. I THINK IT LEFT LITTLE ACUTAL LEARNING TO BE DONE BY THE STUDENT BECAUSE YOU ALWAY JUST EXPLAINED EVERYTHING TO US BY THE END ANYWAY. HOWEVER I DONT THINK THAT THE QUESTIONS YOU ASKED WERE VERY RELAVANT TO THE TYPE OF INFORMATION ONE SHOULD DERIVE FROM A SCIENCE CLASS. SKILLS LIKE DEDUCTIVE REASONING AND EXPIRMENTATION (sic). I APOLOGIZE FOR THE AWFUL SPELLING"

“I really enjoyed the layout of your labs. They were entertaining as well as educational. Too many of today's labs simply want numbers and final answers. Your labs focused on understanding the concepts. I wish more labs were set-up like yours. Thank you, I hope this isn't too late for your research.”

“I think it is a good idea to do follow ups on what students are learning.”

“I GUESS I DIDNT REMEMBER AS MUCH AS I THOUGHT I WOULD. SORRY. I HOPE YOUR RESEARCH GOES WELL THOUGH. GOOD LUCK.”

"I feel that the labs took up to (sic) much time due to the timeframe we were given! I felt as if we rushed through the material. If more time was granted I would have liked for some of the things to be split up b/c it was a lot of information to take in and process."

“GOOD LUCK. THIS HAS BEEN VERY INTERESTING. ... As a future teacher I was extremely impressed with your dedication and need to understand our minds. Have a wonderful day.”

"I stunk at this class. Way over my head ... It does not seem like an introduction to anything, more like a class for those already in the scientific community. I wanted to understand more as I am studying to become a teacher, but I finally gave up understanding and focused on just making it through. I'd like to see a class for those of us who have been out of school (over 20 yrs for me) for awhile where we are really introduced to the topics on a level we can understand and enjoy. I think I would probably have enjoyed the class more and learned more if I didn't spend so much time frustrated and feeling stupid."

Control group students said:

“I really appreciate the fact that you are actively trying to help students learn by research the way in which one learns. Thank you for all of your help.”

“I am guessing at this. Haven't even thought about it since class.”

"Good luck"

> "I HOPE MY ANSWERS HAVE BEEN HELPFUL IN YOUR RESEARCH, AND I WOULD BE INTERESTED TO KNOW HOW IT TURNS OUT. GOOD LUCK!"

These comments indicated that students were interested in being part of research that has the potential to improve learning. These comments also indicated that not all students cared for the guided learning style of the treatment labs. Some of the comments revealed the student was overwhelmed with the magnitude of the course work, not necessarily the material to be learned in the lab. These responses were reported just as the student wrote them. Comments indicated that students desired for their lab experiences to be based on research and for labs to be experiences where student understanding as well as content introduction were objectives.

CHAPTER 5

CONCLUSIONS

Summary

This research compared the guided learning lab style to the traditional lab style in PSCI 1030. The effectiveness in helping students master concepts associated with three chemistry-related labs was studied. The three labs were Density, Kinetic Theory and Chemical Reactions. A total of 176 students participated in this project, 60 of which comprised the guided learning or treatment group while 116 comprised the traditional lab or control group.

Permission from MTSU's Institution Review Board to conduct research using human subjects was received. The lecture instructors were approached for permission to involve the PSCI 1030 lab class that they were teaching. Every instructor who was asked participated willingly in this project.

Students had signed up for PSCI 1030 without any knowledge they would be eligible to participate in this research. No student participant knew this researcher or was knowledgeable of the guided learning pedagogy that would be used. Participating classes were selected on the basis of convenience to the timing of this research. Instructors were asked to allow their class to participate in the three chemistry-related labs being studied.

Students in the treatment group and in the control group were asked to provide non-identifying data which revealed that student participants had similar demographics (Table 2). The treatment group was, on the average, older than the control group and more had attended private high schools than had control group students. These differences may have created bias in favor of the treatment group in this research, though no effort was made to measure their potential impact. The two groups' gender ratios were comparable. Other than the treatment group having a significantly higher ($p \leq 0.01$) exposure to trigonometry, both groups had similar exposure to previous mathematics and science courses (Tables 3 and 4). The ACT math, reading comprehension and science reasoning scores were similar (Table 5). Students in both lab groups were asked to take a pre-lab quiz and take a post-lab quiz when the three labs were scheduled to be performed. Students were also asked to answer questions of a conceptual nature that related to the material in the lab. Students were also asked to take a post-course quiz via email after the course was concluded. Assessments were the same for both groups.

Traditional labs were events where students engaged in hands-on activities to familiarize themselves with procedures and techniques used by scientists. The traditional labs were taught by either the lecture professor or by graduate teaching assistants. Students received initial instructions about any special precautions they needed to take during the lab and then followed the written procedures in their lab manual to complete the lab assignment. In addition to the familiarity students gained with the equipment, the labs allowed the students to verify content to which they had been introduced in the lecture. The lab instructor's role was mainly to be a supervisor, to be available to answer questions of students, and to monitor for safety.

This researcher taught the guided learning labs rather than training another individual to use the pedagogical style referred to as guided learning. While efforts were made to remain unbiased as the instructor in order to avoid skewing the results, it is recognized that being completely unbiased is not possible. The results of this research should be interpreted in light of who the treatment group instructor was. In the guided learning labs, the instructor actively directed students' attention or pro-actively discussing, questioning and making suggestions with individual lab groups. Guided learning labs were more teacher-involved than traditional labs. Guided learning labs began with an elicitation activity and progressed through a series of development activities. During the elicitation segment, students made predictions about an activity yet to be conducted, and the class discussed their reasons for their predictions. Students observed or conducted the activity and then shared their conclusions with the class about why they believed the phenomenon occurred as it did. By having students openly explain their ideas before beginning the lab, scientific misconceptions were exposed and helped students realize that their initial ideas about a science topic were not always correct.

In the developmental activities, students interacted with others in a group of four or five to make sense of the issue being studied. The instructor was actively involved in the progression of the development activities. Sometimes the instructor probed individual groups asking students to defend their ideas based on evidence from their experiment. At other times, the instructor stopped all of the students to focus their attention toward the concepts intended to be learned. Rather than telling the students what they were supposed to have observed, the lab instructor polled the class for observations and explanations, looking for ideas that were scientifically correct. The instructor asked the students to support their claims with evidence. On other occasions, the lab instructor played the role of an antagonist pretending to argue for scientific misconceptions to see if students would disagree and prove the lab instructor wrong.

After the lab concluded, students were asked to complete conceptual questions for homework which involved applying concepts from the labs to new situations.

The guided learning labs were designed to address scientific concepts students often did not understand. The development activities helped students recognize the principles of the topic without being told by the instructor or from a lab manual. The teacher guided the student to change his or her conceptions about a scientific concept. After the course was completed, students completed a post-course quiz using email. Although 148 (73%) originally agreed to participate, only 32 (16%) students actually took the post-course quiz.

Comparisons of treatment groups' and control groups' scores on all assessments were made using independent samples t-tests. These tests compared the two groups' mean scores on the questions or on the totals of to see if their differences were statistically different. The standard significance level of 0.05 or smaller was used to identify differences as being significant.

Conclusions

The results of all of the tests performed in the comparison of the guided learning lab style to the traditional lab style are shown in Table 122. After instruction, the treatment group produced higher scores on the section totals and overall total on the post-course quiz, and they produced significantly higher scores on all post-lab quizzes and conceptual questions. These results suggest that students using guided learning Density, Kinetic Theory and Chemical Reactions labs were better able to apply the concepts than those who studied the same material using a traditional lab methodology.

The Density treatment lab statistically improved students' awareness that different sizes of the same material have the same density. Even though the control group worked more density calculation problems, the treatment group statistically outperformed the control group on this task. The treatment group outperformed the control group in relating the phenomenon of floating to density. This result may be due in part to the fact that the treatment group performed a lab activity involving the creation and discussion of a density tower while the control group did not.

Table 122. Summary of Mean Total Scores by Lab Groups for All Assessments

Type of Assessment		Treatment Mean score	Control Mean score
Density	Post-lab	12.71[a]	11.27
	Conceptual Questions	7.85[a]	6.34
	Post-Course Quiz, Section Total	3.03	2.61
Kinetic Theory	Post-lab	5.69[a]	3.05
	Conceptual Questions	14.84[a]	12.17
	Post-Course Quiz, Section Total	2.17	1.73
Chemical Reactions	Post-lab	13.69[a]	12.63
	Conceptual Questions	10.14[a]	8.90
	Post-Course Quiz, Section Total	7.36	6.89
Post-Course Quiz Total		12.56	11.23

[a] Significant at the 0.05 level

Students in the Kinetic Theory treatment lab demonstrated a better understanding than their control group counterparts that gases or independent particles have mass. The treatment group also had a clearer understanding of what pressure is and how it relates to movement of matter. Treatment students were also convinced that empty space exists between particles of a liquid. Students in the treatment group displayed a greater level of mastery of the concepts of particles having mass, particles being in motion and the presence of empty space between the particles.

The treatment group outperformed the control group in being able to identify evidence of a chemical reaction during the Chemical Reactions lab. The treatment group also outperformed the control group when using particle diagrams to recognize physical changes and types of chemical reactions. This result may have been related to the extensive use of particle diagrams in the treatment labs and not in the control labs. The data suggests that neither group had difficulty understanding particle diagrams.

Overall, the data suggests that the guided learning lab style helped students develop greater mastery of concepts for the three labs, Density, Kinetic Theory, and Chemical Reactions than did the traditional lab style. One might dismiss the superior performance by the students in the treatment labs on the basis that activities were performed in the treatment labs that were not performed by the control lab group. One might also dismiss the superior scores of the treatment group because of the inherent bias by the treatment group instructor. However, it should be noted that the students in the treatment groups were not detrimentally affected by studying density, the kinetic theory of matter and chemical reactions using the guided learning pedagogy.

Further Research

Novel approaches to classroom and lab instruction are capable of improving student understanding. The guided learning approach of lab instruction used in this project has demonstrated a method for helping students gain mastery of fundamental concepts.

There are issues that should be considered if this research is to be repeated in order to avoid compromises to internal validity. Data collected for a larger pool of subjects might verify the findings and statistical results of this research. Attention should be given to making the questions clearer and the drawings unambiguous. A specific deadline should be established for post-course quiz responses. An attitudinal survey should be incorporated to determine if students' attitudes about science and interest in science played a role in the differences observed.

Other improvements to this research could include only using students who completed every assessment and then monitoring that student's progress. Students could be randomly assigned to the treatment and control groups taking care to make the ratio of females to males the same. To neutralize any inherent bias from differences in the two groups, the groups could be swapped for the second lab so both groups of students could be part of the treatment and control categories, and students could be randomly separated into treatment and control groups for the third experiment. Another method that could be used is to let both groups conduct the same activities, but let the control group use "fill in the blank" traditional reports instead of the format used by the treatment group in this research. To avoid unintended instructor bias, a lab instructor who does not have a personal interest in the outcome of the labs should be used to teach the treatment labs. To avoid unintended effects, lab instructors' expertise should be controlled so that all instructors have the same academic credentials. The sequence in which topics are covered in the lecture should be monitored to note whether the labs precede or succeed those topics. The lack of control for the preceding issues may have had an unintended bearing on the data.

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APPENDIXES

APPENDIX A

Enrollment Data for PSCI 1030 from Fall 2001 – Spring 2005

Barry Farris

From: "Teresa Thomas" <tthomas@mtsu.edu>
To: <farrisb@k12tn.net>
Sent: Monday, March 14, 2005 9:03 AM
Subject: Enrollment for PSCI 1030

As you requested, the following are the official enrollment numbers for PSCI 1030 (Topics in Physical Science) at Middle Tennessee State University from Fall 2001 until Spring 2005:

506	Spring 2005
871	Fall 2004
94	Summer 2004
582	Spring 2004
780	Fall 2003
108	Summer 2003
599	Spring 2003
739	Fall 2002
112	Summer 2002
690	Spring 2002
744	Fall 2001

This type of detailed data is not available on our web site. The Office of Institutional Research has many documents available on the web; however, it covers more demographics and major data and not specific enrollment in specific courses. Please let me know if you need any additional data.

Thanks,
Teresa

Teresa Thomas, Director of Records
Middle Tennessee State University
Records Office
Cope Administration Building 102
Murfreesboro, TN 37132
Email: tthomas@mtsu.edu Phone: (615) 898-2600 Fax: (615) 898-5538

APPENDIX B

IRB Proposal

PLEASE PRINT OR TYPE	PROTOCOL NUMBER: SUBMISSION DATE:

MIDDLE TENNESSEE STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS RESEARCH REVIEW FORM

X Expedited Review ☐ Full Review

Investigator(s)
Name(s) **Barry Farris** SS# xxx-xx-xxxx ***(deleted for privacy)***

Project Title: **The Effectiveness of Guided-Inquiry Chemistry Activities in the PSCI 1030 Labs at Middle Tennessee State University**

Campus telephone: **(NONE); B.F.'s home: (xxx) xxx-xxxx (xxx, TN)**

Campus address: **(NONE); B.F.'s home: xxxxx, xxx, TN xxxxx**

Department or University Unit: **Chemistry**

Investigator Status (For each investigator)

☐ Faculty/Staff
X Graduate Student - DA
☐ Undergraduate Student
☐ Other

If the principal investigator is a student, list name department and local telephone of faculty supervisor, Please note that THE FACULTY SUPERVISOR MUST INDICATE KNOWLEDGE AND APPROVAL OF THIS PROPOSAL BY SIGNING THIS FORM.

Faculty Supervisor Name: **Dr. Judith Iriarte-Gross**

Address & Telephone: **WPS xxx, P.0. Box xxx; (xxx) xxx-xxxx**

Social Security #: **xxx-xx-xxxx**

Source of funding for project: **NONE needed**

Expected starting date for project: **June 1, 2001**

Is this project expected to continue for more than one year?

X Yes ☐ **No** Anticipated Completion Date: **May 31, 2002**

Approval for projects is valid for one year only. Investigators must request a continuation of the approval yearly if the activity lasts more than one year. Only two continuations will be granted for a given project. After three years, the project must be resubmitted.

PROJECT DESCRIPTION
The following information is required for all projects.

- Limit your answers to the space provided. (Further information may be attached to supplement this description, but not to replace it)
- Attach copies of all questionnaires, testing instruments or interview protocols; include any cover letters or instructions to subject ***(Note: The IRB committee received Appendixes D, E and F)***

DESCRIPTION
Provide a **BRIEF** description, in **LAYMAN'S TERMS,** of the proposed research:

This project will substitute 3 commonly-performed labs in Physical Science 1030 with ones designed using constructivist pedagogy and compare the outcome of student learning to those who take the current style labs of the same course. The intent is to test this instructional method in these chemistry labs to see if students develop longer-term retention and deeper understanding of the intended concepts as opposed to instruction using the current verification style. A fundamental premise of these labs is that students explain their ideas while they work through the activities rather than simply following steps of a procedure without being forced to justify their responses. In the scheme of these labs, the process of arriving at an answer is as important as obtaining an answer.

The 3 labs to be tested are:

- **Density**
- **Kinetic Theory**
- **Chemical Reactions**

This project will compare the current and experimental labs' methodologies by having students answer the same set of questions after each lab (questions for the density lab are submitted with this form). The number of correct responses to these questions will be used to gauge the effectiveness of each type of lab in helping students learn the concept taught. Further, a pre-lab and post-lab quiz (submitted with this form), and

post-l course lab quiz (given approximately 6 months after the course is over) will be given to participating students to track understanding levels.

Using a questionnaire (submitted with this form), this researcher will develop a background profile of the students participating in this study including: their major, previous math and science courses taken, information about the high school they attended (rural or urban, public or private, approximate size), their gender and general age, and their general attitudes about science. Students will be asked to give this researcher permission to obtain their ACT scores in reading comprehension, math and science reasoning; this data will be used to establish students' cognitive aptitude in areas essential to success in a science course.
Student information will be gathered during the course's lab period. Once collected, this researcher will assign each student a code number and will keep all codes and Social Security Numbers separate from the ACT scores. After the coding and project is complete, all identifying data will be destroyed, thus preventing any correlation of the students' data for this research and their personal identification. The ACT scores will be obtained from the Student Information System by this researcher's advisor, Dr. Judith Gross. All sensitive data will be kept under lock and key and will be maintained in a database on the personal computer of the researcher in his home in xxx, TN for analysis.

METHOD (check all that apply)

X QUESTIONNAIRE	☐ OBSERVATION	**X TEST**
☐ INTERVIEW	**X FILES**	☐ TASK
☐ TREATMENT		
☐ OTHER		

NUMBER OF SUBJECTS: 116 **SUBJECT POPULATION** (check all that apply)

X ADULT	☐ MINOR
☐ PRISONER	☐ MENTALLY RETARDED
☐ MENTALLY ILL	☐ PHYSICALLY ILL
☐ DISABLED	☐ OTHER Specify

SUBJECT SELECTION

Are subjects to be drawn from the Psychology subject pool? (Y/N)

- If yes, a completed sample sign-up sheet must be submitted.

• If no, describe how subjects will be selected for participation in this project and any payment to be received by the subject:

Participants will be students who are taking MTSU Physical Science 1030 labs during the school year of June 1, 2001 - May 30, 2002 and who allow their data to be used for this study.

NOTE: If the subjects are to be drawn from an institution or organization (e.g., hospital, social service agency, prison, school, etc.) which has the responsibility for the subjects, then documentation of permission from that institution must be submitted to the Board before final approval can be given.

CONFIDENTIALITY

Specify steps to be taken to guard the anonymity of subjects and/or the confidentiality of their responses. Indicate what personal identifying indicators will be kept on subjects. Specify procedures for storage and ultimate disposal of personal information,

The lab instructor will pass out and later collect the student questionnaires. This researcher will then assign a code to each participant so the data can be examined while providing the students total anonymity.

Student questionnaires will provide this researcher with participants' backgrounds regarding the previous math and science courses they have taken, the type of high school they attended (rural or urban, public or private), their gender, their major course of study, and their general attitude about science. Participants will also grant this researcher permission to obtain their ACT scores in reading comprehension, math and science reasoning.

The data will be analyzed for relationships between students' backgrounds and their success in the chemistry section of the course, as determined by pre- and post-lab tests. Further, the effectiveness of these experimental labs on concept retention will be analyzed by examining post-course quiz grades taken by participating students six months later.

CONSENT

Specify how subjects will be informed of the following: a) the nature of their participation in the project, b) that their participation is voluntary and that they may withdraw at any time without repercussions, and c) that their responses are confidential. (If a consent form is being used, attach a copy. If presented orally, a copy of presentation must be submitted.)

See Consent Sheet

ADDITIONAL PROCEDURAL INFORMATION

INDICATE BELOW WHETHER YOUR PROJECT INVOLVES ANY OF THE FOLLOWING. FOR EACH ITEM CHECKED, PROVIDE THE REQUESTED INFORMATION IN THE ADDITIONAL PROCEDURAL INFORMATION SECTION BEGINNING ON PAGE 5

- ☐ A) Risk (p. 5)
- ☐ B) Minors as subjects (p. 5)
- ☐ C) Psychological intervention (p. 6)
- ☐ D) Deception (p. 6)
- ☐ E) Physiological intervention (p. 7)
- ☐ F) Biomedical procedures (p. 7)

SEE THE PAGE INDICATED FOR A MORE DETAILED DESCRIPTION OF THESE CATEGORIES

SIGNATURES

The **Principal Investigator** must sign this form.

I certify that 1) the information provided for this project is accurate, b) no other procedures will be used in this project, and c) any modifications in this project will be submitted for approval prior to use.

Barry S. Farris — June 4, 2001

Signature of Investigator **Date**

If the P. I. is a student, his/her **Faculty Supervisor** must also sign this form.

I certify that this project is under my direct supervision and that I am responsible for insuring that all provisions of approval are complied with by the investigator.

Judith Duarte-Gross — June 4, 2001

Signature of Faculty Supervisor **Date**

Committee Use Only

NOTE: APPROVAL OF THIS PROJECT BY THE IRB ONLY SIGNIFIES THAT THE PROCEDURES ADEQUATELY PROTECT THE RIGHTS AND WELFARE OF THE SUBJECTS AND SHOULD NOT BE TAKEN TO INDICATE UNIVERSITY APPROVAL TO CONDUCT THE RESEARCH.

Expedited Review

Approved: [signature] 5/4/2001

College Representative Date

Committee Review

Approved: ______________________ ________

Committee Chair Date

Elementary and Special Education Department
P.O. Box 69
Middle Tennessee State University
Murfreesboro, Tennessee 37132
(615) 898-2680

Mr. Barry Farris
C/o Dr. Judith Iriarte-Gross
Box X161 MTSU
Murfreesboro, TN 37132

March 7, 2002

"The Effectiveness of Constructivist-based Chemistry Activities in the Science 100 Labs at Middle Tennessee State University"
#01-050

Dear Mr. Farris:

A representative of the MTSU Institutional Review Board has reviewed your request to extend your study through May 31, 2003. However, I am unable to grant the request for more than one calendar year. This simply means that your data must be gathered prior to March 7, 2003. Analysis of the data and preparation of the dissertation may occur after this date without further extension.

Approval is granted for up to 100 subjects based on the number submitted in the protocol.

Final approval is for one (1) year from the date of this letter.

Please note that any further change to the protocol must be submitted to the IRB before implementing the change.

Please call if you have questions. I may be reached at 615 898-2146.

Final Approval: March 7, 2002

Sincerely,

Nancy Bertrand

Nancy Bertrand
Chair, MTSU Institutional Review Board

C: Dr. Judith Iriarte-Gross

APPENDIX C

Consent Form to Use Student Data

CONSENT FORM TO USE STUDENT DATA

Dear Physical Science 1030 Student,

This semester or session, you will be involved in some chemistry labs as part of this Physical Science 1030 course. It is of interest to know how students generally perform in this section of the course. I am a doctoral student, and for my dissertation research in the department of Chemistry, I have written some chemistry labs to test their effectiveness in helping you learn the material. Some of you will be taking my new labs in the place of the current labs of the same name.

I am asking all of you to participate in this study (regardless of which lab you take) in 3 ways:
(1) Respond to pre- and post-lab questions for each of 5 labs that are part of this study. YOU ARE NOT OBLIGATED TO DO THIS, and YOUR RESPONSES ON THESE QUESTIONS WILL HAVE NO EFFECT ON YOUR COURSE GRADE AT ALL.
(2) Grant me access to your ACT scores in the areas of Reading Comprehension, Math and Science Reasoning. To do this, I will need your Social Security Number. (I will ONLY use it to get the ACT scores; I will NEVER record your name or other identifying information such as phone number or address. Further, after getting the ACT data, I will code your particular information using only the last 4 digits of your Social Security Number to make your records anonymous to me. I will keep all identifying data in a separate file from the data for my research ERASING your Social Security Number from my records once the coding and project is completed.)
(3) Participate in a post-course quiz. To accomplish this, please supply your email on the questionnaire at the bottom, and I will send you the quiz about 6 months later. The purpose of this is to see how much you retain of the material after several months have gone by.

Your privacy is VERY important to me. To protect it, you will code your questionnaire with the last 4 digits of your Social Security Number. I will enter your data into a general database but keep all coding and Social Security Number information in a separate file under lock and key. After coding is complete and data is entered into my computer, I will DESTROY your questionnaire that will contain your Social Security Number. This will assure your privacy and keep anyone, including me, from associating your pre- and post-lab responses with you personally. My only interest is to relate student backgrounds with the effectiveness of the 5 labs in this study.

If at any time you wish to withdraw your data from this project, let your instructor know so I can remove your data. However, I want to assure you that the information you supply will not be personally identifiable to you (especially after your Social Security Number has been erased). I want you to realize it is important to get a good cross-section of students' responses to determine the effectiveness of these labs. If you are willing to participate in this important study, affirm by signing below. Thank you,

Barry Farris, DA student, Chemistry

I am willing to answer pre- and post-lab questionnaires after performing selected chemistry labs in Science 100. I give my permission for Mr. Barry Farris to analyze the data for inclusion in his dissertation research; such data will be used to assess the effectiveness of some revised chemistry activities conducted in this course relative to existing labs. I realize that my responses on this questionnaire will have no effect on my grade in the course. I am also willing to participate in a general (not personal) survey that gives Mr. Farris an idea of my academic high school background, and I give him permission to obtain pertinent ACT data. I have been assured that my data will be coded in such a way as to provide total anonymity to avoid any association of my data with me. I know I have the right to withdraw my data (responses to questions about material covered in chemistry labs I have completed and about my academic background) at any time up to the time I finish the final exam in Physical Science 1030.

(Your Name) ____________________ **(Date)**__________________

Survey of the General and Academic Background for Students Participating in Experimental Chemistry Labs in Physical Science 1030 Labs

Code: (Last 4 digits of your SSN: __________) Major: (e.g., business, education, etc.) ____________

Gender: (circle) Female Male

Age Category: (circle) under 18, 18-20 21-23 24-27 over 27

ACT Scores
I give my permission for my scores to be obtained from the Student Information System in the following categories: Reading Comprehension, Math, and Science Reasoning
[Soc. Sec #: ____ - ___ - ______]

High School Information (grades 9-12): (circle)

Category:	Public	Private	
Size:	Small (up to 500)	Medium (501 - 1000)	Large (1001 or more)
Description:	Rural	Urban	

Math courses taken (circle all that apply):

General math Business math Algebra I AlgebraII
Geometry Pre-Calculus Advanced math Trigonometry
Calculus Other: ____________________

Science courses taken (circle all that apply):

Earth science Physical science Biology I Biology II
Chemistry I Chemistry II Physics I Physics II
Astronomy Geology Environmental science/Ecology
Anatomy/Physiology Other: ____________________

Attitude about my science experience in high school (Circle one number):
(SD = strongly disagree, MD = mildly disagree, N = neutral, MA = mildly agree, SA = strongly agree)

1. I considered myself to be a good science student.	SD	MD	N	MA	SA
2. I found science courses interesting.	SD	MD	N	MA	SA
3. I was well prepared in high school for science in college.	SD	MD	N	MA	SA
4. I was encouraged to take all the science and math courses I could.	SD	MD	N	MA	SA
5. Grades were important to me.	SD	MD	N	MA	SA

Name one thing (or science topic) you enjoyed about high school science: ____________________
____

____ Check here if you are willing to participate in a follow-up questionnaire about 6 months after the course is over. If so, please supply your email address: ______________________________

APPENDIX D

Density Lab Pre-lab Quiz and Scoring Rubric

Density
Pre-Lab Quiz

Student ID ______________ Date ___________ Lab Instructor ____________

1. Density (to you) is BEST described as:

A. Heaviness or Weight   B. Thickness/ Compactness   C. Hardness   D. ______________ (other)

2. [CHOOSE only ONE] Compare the density of an iron horseshoe and an iron nail.

A. The horseshoe and the nail have the same density because ____________
____

B. The horseshoe has more density than the nail because ________________
____

C. The horseshoe has less density than the nail because ________________
____

D. It depends. It could be ____
____

3. Which has the <u>LESSER</u> density - a 2 gram mass which takes up 0.50 mL or a 3 gram mass which takes up 3.00 mL? SHOW YOUR WORK.

4. A ball has a density of 1.86 g / mL and it is dropped into a liquid that has a density of 2.54 g / mL. Will it float or sink, or do you have to know more information before you can decide? (IF so, what other information do you need?) EXPLAIN HOW YOU DECIDED.

5. You have a rectangular wooden block with a mass of 300 grams. It is 2.0 cm wide, 1.5 cm high and 11.5 cm long. What is its density? (The formula for volume of this object is: V=L x W x H.)

Density Pre-lab Quiz Scoring Rubric

Question 1		Question 2		Question 3		Question 4		Question 5	
Response	Points	Response	Points	Response	Points	Response	Points	Response	Points
No work	0	No work	0	No work	0	No work	0	No work	0
Incomplete attempt (1)	1	Incomplete attempt (1)	1	Incomplete attempt (1)	1	Incomplete attempt (1)	1	Incomplete attempt (1)	1
"Heaviness" or "Weight"	1	"A" - Same density **RIGHT**	3	"3 g / 3 mL" but no reason or incomplete reason given, or just guessed	2	"Float," no reason given or wrong reason	2	Only Volume (34.5 cm^3) calculated	1
"Thickness"	1	"B" - Horseshoe more dense	1	"3 g / 3 mL" with correct work shown, or chose 2g/0.5 mL because it was LARGER (same result) **RIGHT**	3	Float, right reason given **RIGHT**	3	8.7 g/cm^3, or set up correctly to get proper answer **RIGHT**	3
"Hardness"	1	"C" - Horseshoe less dense	1	"2 g / 0.5 mL" but no /poor work, or due to obvious math error that leads to wrong answer	1	Sink, no reason given, or faulty reason	1	0.115 cm^3 / g (reciprocal answer), or product 10350	1
Other / wrong	1	"D" - It depends	1	"2 g / 0.5 mL with work, but reciprocal answer, or product instead of quotient	1	Sink, partially logical reason given	1	Set up correctly but wrong math	2
Other / **RIGHT**	3	"A," wrong reason	2	"2 g / 0.5 mL" as LARGER = OK	2	Need more informa-tion	1	8.7 but wrong / no units	2

APPENDIX E

Kinetic Theory Lab Pre-lab Quiz and Scoring Rubric

Kinetic Theory
Pre-Lab Quiz

Student ID ______________________

In all these, try to respond by thinking about what is happening at the particle level.

1. If you put air into car tires, the pressure goes up, but which of these would you say also happens? The tire actually

A. Gets heavier B. Stays the same C. Gets lighter

Why?

2. Suppose you have a straw in a soft drink cup. Explain as best you can how the soft drink gets into your mouth.

3. What is it about air that makes the leaves move when the wind blows?

4. Suppose you had 2 cups - one with marbles and the other one had the same level of sand. Describe what would happen if you pour the sand in on top of the marbles and why?

5. Explain what is happening when ice melts.

Kinetic Theory Pre-lab Quiz Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1	Gets Heavier - Right Stays Same Gets Lighter	1 0 0	Logical reason True but irrelevant reason Illogical or no reason	1 0.5 0
2	Pressure difference Suction / Other	0.5 0	Logical reason Illogical or no reason	0.5 0
3	Force or Pressure Mass or Impact Other or no answer	0.5 0.5 0	Logical reason Illogical or no reason	0.5 0
4	Total is less than two volume's sum Total is equal to two volume's sum Total is more than two volume's sum Other or no answer	1 0 0 0	Logical reason Illogical or no reason	1 0
5	What particles are doing Addresses structure Phase change Heat or temperature Other or no answer	0.5 0.5 0.5 0 0	Logical reason True but irrelevant reason Illogical or no reason	0.5 0 0

APPENDIX F

Chemical Reactions Lab Pre-lab Quiz and Scoring Rubric

Chemical Reactions

Pre-Lab Quiz

Name: ______________ Do the best you can in answering these. Try not to leave any blank.

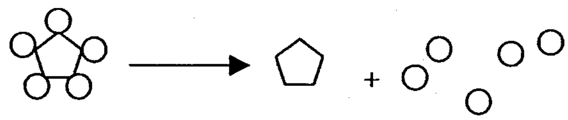
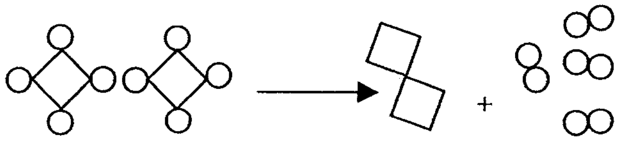
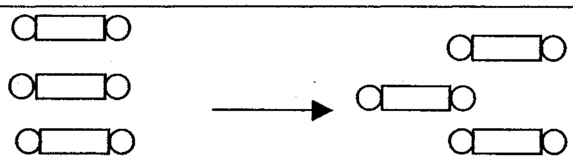
1. Label these reactions with these possibilities: Composition (C), Decomposition (D), Single Replacement (SR), Double Replacement (DR), or Something Else (SE).

____ A + B ⟶ AB
____ AB + C ⟶ AC + B
____ PQ + RS ⟶ PS + RQ
____ DE ⟶ D + E

2. Name at least 3 things that can happen which will indicate a chemical reaction has occurred.

a) ______________________________
b) ______________________________
c) ______________________________

3. In each of these, indicate if this represents a chemical reaction and tell why you think so.

	**Chemical reaction? ____** **Why?**
	**Chemical reaction? __ Why?**
	**Chemical reaction? ____** **Why?**

4. How would you define a "chemical reaction"?

5. Which of these are chemical reactions? Check all that are chemical reactions.

_____ Firecracker exploding
_____ Ice melting
_____ Nail rusting
_____ Water evaporating
_____ Paper burning

Chemical Reactions Pre-lab Quiz Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1A	C D, SR, DR or SE	1 0		
1B	SR C, D, DR or SE	1 0		
1C	DR C, D, SR or SE	1 0		
1D	D C, SR, DR or SE	1 0		
2	Color, Odor, Sound / light or Temperature change	1		
	Precipitate or Gas formed	1		
	Old disappear/new appear	1		
	Rearrangement or change in substance	0.5		
	Phase change	0		
	Type of reaction named Other or no answer	0 0		
3A, 3B	Yes No No answer	0.5 0 0	Logical reason Illogical or no reason	0.5 0
3C	No Yes No answer	0.5 0 0	Logical reason Illogical or no reason	0.5 0
4	New / changed composition, new properties Result of bonds broken and new bonds formed Cited evidence of a chemical reaction Unspecified change or other incomplete answer Unclear, incorrect or no answer	1 1 1 0.5 0		
5	Selected: firecracker exploding, nail rusting, paper burning Left unselected: ice melting and water evaporating	1, otherwise 0 1, otherwise, 0		

APPENDIX G

Density Lab Post-lab Quiz and Scoring Rubric

Density
Post-Lab Quiz

Student ID ______________ Date ____________ Lab Instructor _____________

1. Density (to you) is BEST described as: ___________________________________
____

2. [CHOOSE only ONE] Compare the density of a big brick and a broken piece of the brick.

A. The whole brick and the piece of brick have the same density because ____
____

B. The whole brick has more density than piece of the brick because ________
____

C. The whole brick has less density than the piece of brick because ________
____

D. It depends. It could be ____
____

3. Which has the <u>LESSER</u> density - a 1 gram mass which takes up 0.50 mL or a 5 gram mass which takes up 3.00 mL? SHOW YOUR WORK.

4. A ball has a density of 3.86 g / mL and it is dropped into a liquid that has a density of 1.54 g / mL. Will it float or sink, or do you have to know more information before you can decide? (IF so, what other information do you need?) EXPLAIN HOW YOU DECIDED.

5. You have a rectangular wooden block with a mass of 250 grams. It is 2.5 cm wide, 1.5 cm high and 10.5 cm long. What is its density? (The formula for volume of this object is: V=L x W x H.)

Density Post-lab Quiz Scoring Rubric

Question 1		Question 2		Question 3		Question 4		Question 5	
Response	Points	Response	Points	Response	Points	Response	Points	Response	Points
No work	0	No work	0	No work	0	No work	0	No work	0
Incomplete attempt (1)	1	Incomplete attempt (1)	1	Incomplete attempt (1)	1	Incomplete attempt (1)	1	Incomplete attempt (1)	1
"Heaviness" or "Weight"	1	"A" - Same density **RIGHT**	3	"3 g / 3 mL" but no or incom-plete reason or just guessed	2	Sink, no reason given	2	Only Volume (39.375 cm^3) calculated	1
"Thickness" or "Compact-ness"	2	"B" - Whole brick is more dense	1	"3 g / 3 mL" with correct work shown **RIGHT**	3	Sink, right reason given **RIGHT**	3	6.35 g/cm^3 **RIGHT**	3
"Hardness"	1	"C" – Whole brick less dense	1	"2 g / 0.5 mL" but no work or incomplete work, or due to math error	1	Float, no (or faulty) reason given	1	0.15759 (reciprocal answer) or product 9843	1
Other / wrong such as "Volume"	1	"D" - It depends	1	"2 g / 0.5 mL with work, but reciprocal answer, or product instead of quotient	1	float, partially logical reason given	1	Set up correctly but wrong math	2
Other / right (m/v) **RIGHT**	3			"2 g / 0.5 mL" as LARGER	2	Need more information	1	6.35 but wrong / no units	2

APPENDIX H

Kinetic Theory Lab Post-lab Quiz and Scoring Rubric

Kinetic Theory
Post-Lab Quiz

Student ID: __________

In all these, try to respond by thinking about what is happening at the particle level.

1. If you pump air into bicycle tire until it is firm, which of these would you say happens? The tire actually

a. A. Gets lighter. B. Stays the same weight. C. Gets heavier.

b. Why?

2. Suppose you have a soda straw down in a cup of your favorite cola. Explain as best you can (based on the kinetic theory) how the cola gets into your mouth.

3. On the basis of the kinetic theory, why do clothes hanging on the clothesline wave about when the wind blows?

4. Suppose you had a cylinder with BBs up to the 50 mL mark, and you had another one up to the 50 mL mark with marbles. If you pour the BBs in on top of the marbles, how will the final volume compare to the sum of the two materials' volumes (more than 100 mL, equal to 100 mL, or less than 100 mL)? Why did you say that?

5. How can you explain what is happening when water freezes?

Kinetic Theory Post-lab Quiz Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1	Gets Heavier - Right	1	Logical reason	1
	Stays Same	0	True but irrelevant reason	0.5
	Gets Lighter	0	Illogical or no reason	0
2	Pressure difference or force	0.5	Logical reason	0.5
	Suction / Other	0	Illogical or no reason	0
3	Force or Pressure	0.5	Logical reason	0.5
	Mass or Impact	0.5	Illogical or no reason	0
	Other or no answer	0		
4	Total is less than two volume's sum	1	Logical reason	1
	Total is equal to two volume's sum	0	Illogical or no reason	0
	Total is more than two volume's sum	0		
	Other or no answer	0		
5	What particles are doing	0.5	Logical reason	0.5
	Addresses structure	0.5	True but irrelevant reason	0
	Phase change	0.5	Illogical or no reason	0
	Heat or temperature	0		
	Other or no answer	0		

APPENDIX I

Chemical Reactions Lab Post-lab Quiz and Scoring Rubric

Chemical Reactions
Post-Lab Quiz

Name: _______________ Do the best you can in answering these. Try not to leave any blank.

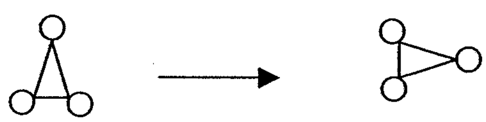
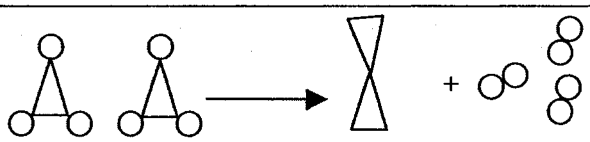
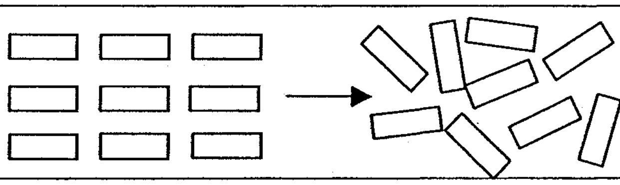
1. Label these reactions with these possibilities: Composition (C), Decomposition (D), Single Replacement (SR), Double Replacement (DR), or Something Else (SE).

_____ AB + C ⟶ A + CB
_____ AB + CD ⟶ AD + CB
_____ PQ + RS ⟶ PQRS
_____ D + E ⟶ DE

2. Name at least 3 things that can happen which will indicate a chemical reaction has occurred.

a) ____
b) ____
c) ____

3. In each of these, indicate if this represents a chemical reaction and tell why you think so.

	**Chemical reaction? ______** **Why?**
	**Chemical reaction? ______** **Why?**
	**Chemical reaction? ______** **Why?**

4. How would you define a "chemical reaction"?

5. Which of these are chemical reactions? Check all that are chemical reactions.

_____ Gasoline evaporating
_____ Wax melting
_____ Gasoline burning
_____ Water freezing
_____ Photosynthesis (Plants taking carbon dioxide & water and making oxygen & glucose)

Chemical Reactions Post-lab Quiz Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1A	SR C, D, DR or SE	1 0		
1B	DR C, D, SR or SE	1 0		
1C	C D, SR, DR or SE	1 0		
1D	C D, SR, DR or SE	1 0		
2	Color, Odor, Sound / light or Temperature change	1		
	Precipitate or Gas formed	1		
	Old disappear/new appear	1		
	Rearrangement or change in substance	0.5		
	Phase change	0		
	Type of reaction named Other or no answer	0 0		
3A, 3C	No Yes No answer	0.5 0 0	Logical reason Illogical or no reason	0.5 0
3B	Yes No No answer	0.5 0 0	Logical reason Illogical or no reason	0.5 0
4	New / changed composition, new properties Result of bonds broken and new bonds formed Cited evidence of a chemical reaction Unspecified change or other incomplete answer Unclear, incorrect or no answer	1 1 1 0.5 0		
5	Selected: gasoline burning and photosynthesis Left unselected: gasoline evaporating, wax melting and water freezing	1, otherwise 0 1, otherwise, 0		

APPENDIX J

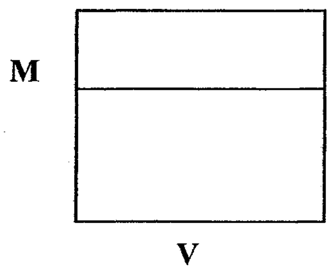
Density Lab Conceptual Questions and Scoring Rubric

Questions about Density
(Write on back if necessary)

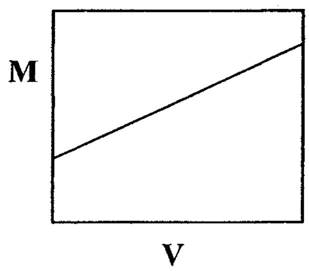
Student ID_______________ **Date** _______________

1. A table of densities (all in g/cm^3) of some metals gives the following data: Magnesium (1.74), Aluminum (2.70), Osmium (22.48), and Iron (7.86). If you have 1.00 gram of each of these metals in the shape of a cylinder, all with the same diameter, which would be the tallest cylinder? How did you arrive at your answer?

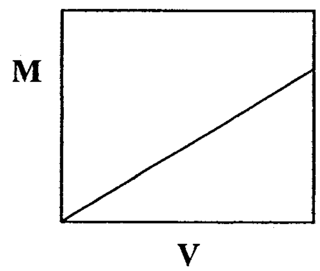
2. Suppose you have a supply of little aluminum cubes, all being about the size of dice. You have a 1000 mL graduated cylinder on a balance with 200 mL of water in it. You record the mass of the cylinder with just water but no aluminum cubes in the water. Then you add one cube at a time to the cylinder of water and record both the volume and the mass on the scale. Which, if any, of graphs A - F (M = mass, V = volume) do you think would represent this situation? If you do not believe any of them represent this situation, create your own that depicts how the graph would look. EXPLAIN your answer.



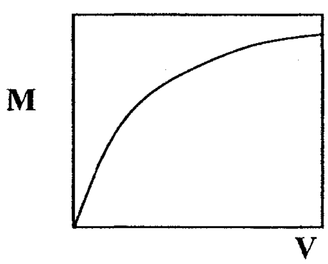
Graph A



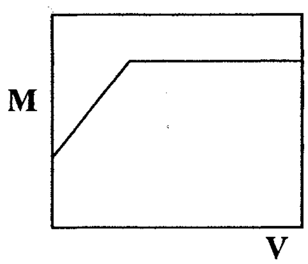
Graph B



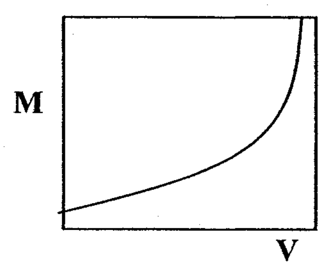
Graph C



Graph D



Graph E



Graph F

3. Suppose you have a piece of metal in a rectangular solid shape with dimensions 3.40 cm x 2.56 cm x 1.78 cm having a mass of 61.97 grams. Which one of the metals in question 1 is it most likely to be, if any? Justify your answer.

4. Calculate the density of a 17.52 gram block of wood that has the dimensions 3.59 cm x 1.94 cm x 2.65 cm. Recall that V = L x W x H. Show your work, and express your answer with 3 digits.

5. Calculate the density of a 25.71 gram cylinder of wood that has a length of 9.33 cm and a diameter of 1.92 cm. Recall that $V = 3.14 \times R^2 \times L$. Show your work, and express your answer with 3 digits.

6. Which has the greater density, 6.89 grams of cream which fills 8.11 cm^3 or 5.92 grams of milk with a volume of 6.23 mL? (Recall that 1 mL takes up the same amount of space as 1 cm^3.) Justify your answer.

7. A barge is fully loaded with corn and is moving down the Mississippi River from Iowa to be off-loaded at a port on the Gulf of Mexico. How will the barge's depth in the water change (if at all) as it moves from the fresh water of the Mississippi to the salt water of the Gulf? Note that the Gulf of Mexico water has a density of 1.05 g/cm^3 and the Mississippi River's water has a density of 1.01 g/cm^3. Explain your reasoning to the best of your ability.

8. Suppose you do not have a reference book, ruler or laboratory balance available, but you wish to decide which of 2 objects has the greater density. Describe an experiment you could perform to find out. Give as much detail as possible.

9. Without having any numerical data available, tell all you can about why a steel ship floats.

10. We all know that ice floats. Soft crunchy ice is white and has air trapped in it. Clear ice does not have much air in it, yet it also floats in water. What can you say about why ice floats in water?

Density Conceptual Questions Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1	No answer Wrong Right	0 0.2 0.5	No answer Guess, Feeble, poor Right	0 0.2 0.5
2	No answer Graph A, D, E, F Graph C Graph B	0 0.2 0.3 0.5	No answer Guess, Feeble, poor Right	0 0.2 0.5
3	No answer Mg, Os, Fe Al None of them	0 0.2 0.3 0.5	No answer Al is closer No match	0 0.2 0.5
4 - 5	No answer Tried, but calc. Vol wrong Correct Vol (#4) 18.5 Correct Vol.(#5) 27.0	0 0.2 0.4 0.4	Set up right Right answer (#4 = .949) Right answer (#5 = .952) Decimal error	0.3 0.2 0.2 0.1
6	No answer "Cream" no reciprocal "Cream" but reciprocal	0 0.2 0.2	No answer Guess, Feeble, Poor work Reciprocal	0 0.2 0.3
	"Milk" or obvious from work	0.5	Correct work Correct work but said "cream"	0.5 0.4
7	No answer "Lower in water" "Higher in water"	0 0.2 0.5	No answer Feeble, illogical reason Good reason	0 0.2 0.5
8 - 10	No answer Feeble Partial "Both in water" or mostly logical Fully logical	0 0.2 0.5 0.8 1		

APPENDIX K

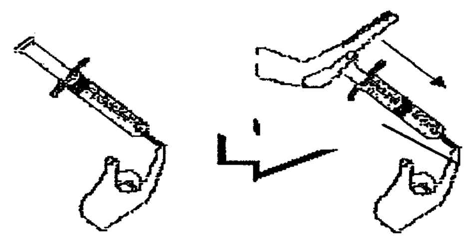
Kinetic Theory Lab Conceptual Questions and Scoring Rubric

Questions over the Kinetic Theory of Matter

Student ID ______________________

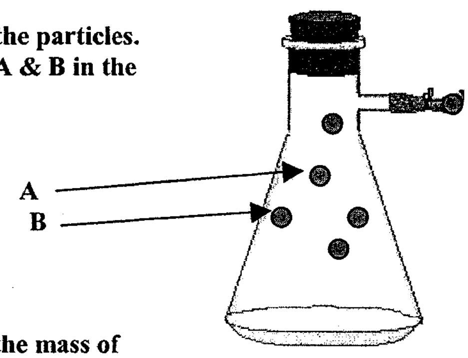
1. An aluminum rod was found in a chemical stockroom. It measured 1.0 cm in diameter and 50.0 cm long. Some students decided to take it and heat it with a laboratory burner to see what would happen. One thing they did was to check its length while hot. Do you think it was longer, the same length, or shorter? Based on your studies, tell why you chose that answer.

2. Based on the Kinetic Theory, explain what happens to the pressure as you push in the plunger of a syringe while the small end is stopped up as in the picture here. (Figure, courtesy of the CPU Project)

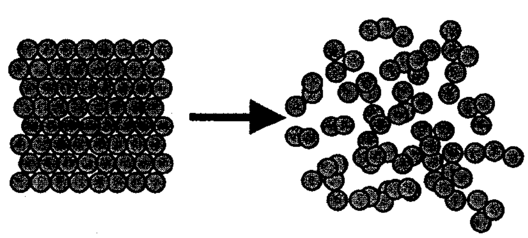


3. Suppose you were able to isolate one molecule of water at room temperature. How would you classify it? Is it a solid, a liquid, a gas, or would it be something else? Explain your answer.

4. Suppose you had a sample of air magnified so you see the particles. What would you say is between any two particles (such as A & B in the figure to the right)? (Figure, courtesy of the CPU Project)



5. If you spill a bucket of marbles, would you categorize the mass of marbles as a solid, a liquid or a gas? Why?

6. What is shown in the picture at the right? **A. Melting** **B. Dissolving** **C. Decomposing** **D. Evaporating** **E. Other: ____________________**	

7. Suppose you find the mass of a 2-L bottle of cola then loosen the cap for 4 hours so much of the gas comes out. Would the mass of the cola (including the cap as before) be more, less or the same? Why?

8. You have 2 cups of 100 mL of water; one is cold and the other is warm. You put 1 drop of red food coloring into the middle of each cup. Will the food coloring mix with the water at the same rate, and why? If not, which would mix faster, and why?

9. A pan of water is allowed to boil on a camp stove for 5 minutes. What is the makeup of the bubbles that rise from the bottom to the top? Explain (use drawings as needed). Note: hydrogen is a gas that can explode if ignited in the presence of oxygen.

10. Does air weigh anything? Explain your thinking.

11. Place a check mark in the blank preceding all the statement(s) with which you agree.

A _____ Molecules get larger or smaller when they are heated or cooled.

B _____ Particles of solids, liquids or gases are in constant motion, even when nothing is pushing them.

C _____ If a liquid's temperature increases, the particles move faster.

D _____ Solid aluminum has air in between its atoms so it is less dense than iron.

Kinetic Theory Conceptual Questions Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1	Longer Same length Shorter No answer	1 0 0 0	Logical reason True but irrelevant reason Illogical or no reason	1 0.5 0
2	Pressure increases Pressure decreases Pressure does not change Other or no answer	0.5 0 0 0	Logical reason Illogical or no reason	0.5 0
3	Something else Solid, Liquid or Gas No answer	1 0 0	Logical reason Illogical or no reason	1 0
4	Space or nothing Air, particles, pressure, etc. No answer	1 0 0		
5	Solid, Liquid or Gas No answer	1 0	Logical reason Illogical or no reason	1 0
6	Melting or evaporating Dissolving / decomposing Other or no answer	1 0 0		
7	Less mass Same or more mass No answer	1 0 0	Logical reason Incomplete reason Illogical or no reason	1 0.5 0
8	Hot faster Cold faster No answer	1 0 0	Logical reason Incomplete reason Illogical or no reason	1 0.5 0
9	Water vapor Air or other gases No answer	1 0 0	Logical reason Illogical or no reason	1 0
10	Yes No No answer	1 0 0	Logical reason Incomplete reason Illogical or no reason	1 0.5 0
11	Molecules change size Particles constantly move Higher temperature means faster particles Air in aluminum	0 1 1 0		

APPENDIX L

Chemical Reactions Lab Conceptual Questions and Scoring Rubric

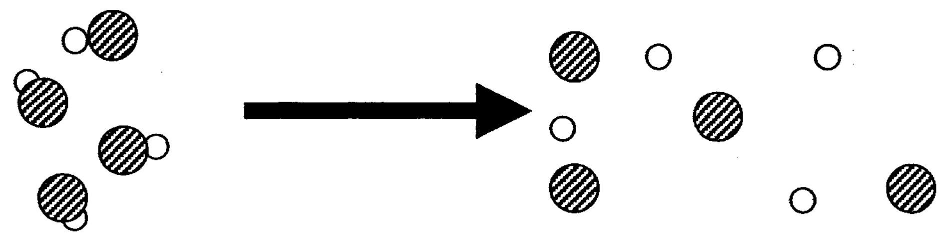
Questions about Chemical Reactions

Name ______________________

1. A friend claimed a chemical reaction had occurred when two solutions were poured together. What other information would you need in order to agree with your friend?

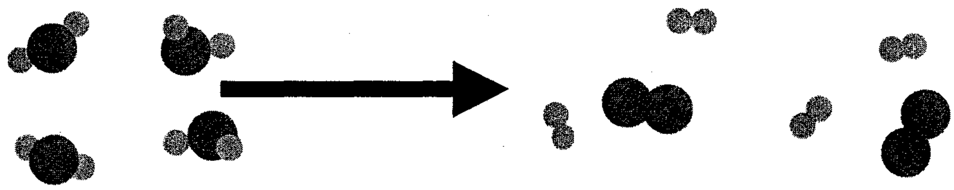
2. For each of the following illustrations, indicate if a chemical reaction is represented AND explain your answer.

A



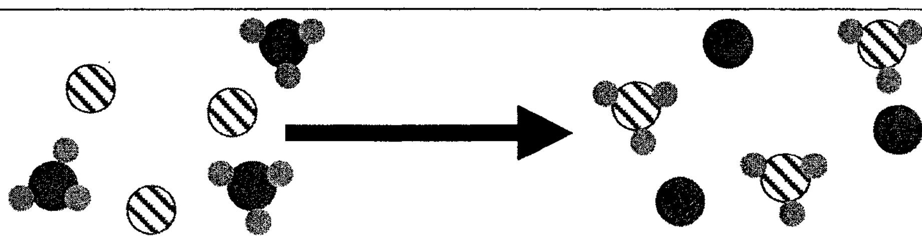
Did a chemical reaction occur?	Explain your answer.

B



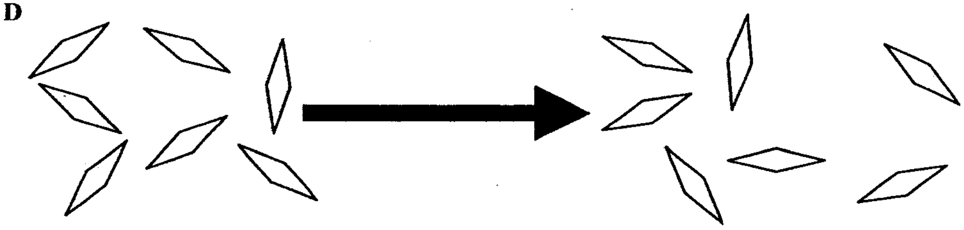
Did a chemical reaction occur?	Explain your answer.

C



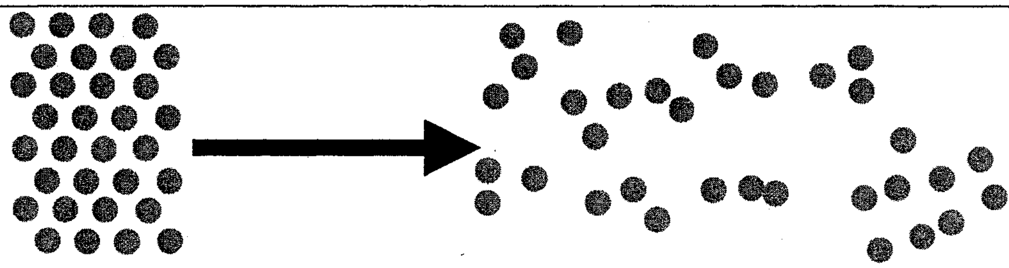
Did a chemical reaction occur?	Explain your answer.

D



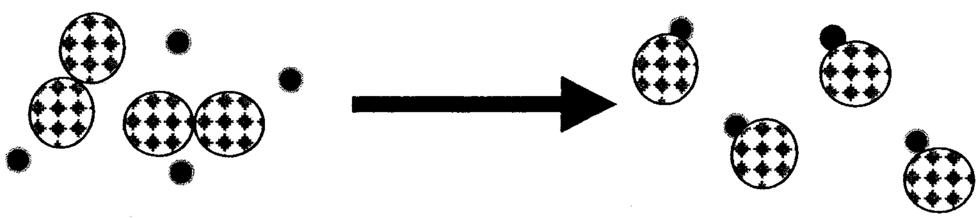
Did a chemical reaction occur?	**Explain your answer.**

E



Did a chemical reaction occur?	**Explain your answer.**

F



Did a chemical reaction occur?	**Explain your answer.**

3. Some unbalanced equations are given below. Your lab partner has already identified them as being possibly Composition (C), Decomposition (D), Single Replacement (SR) or Double Replacement (DR); you are not completely sure they are labeled correctly. You want these to be right, so you want to check them. In the blank, put a check mark if the identification by your lab partner is right. If it is wrong, in the blank put the correct letter to designate the type of reaction it really is.

a._____ SR : $S + O_2 \longrightarrow SO_2$
b._____ C : $MgO + H_2O \longrightarrow Mg(OH)_2$
c._____ D : $HgO \longrightarrow Hg + O_2$
d._____ DR: $Al + FeS \longrightarrow Al_2S_3 + Fe$

Chemical Reactions Conceptual Questions Scoring Rubric

Question Number	Answer		Reason	
	Response	Points	Response	Points
1	Logical macroscopic or microscopic changes identified noting **specific** evidence	1		
	Logical macroscopic or microscopic changes identified noting only **general** evidence	0.5		
	Illogical macroscopic changes identified	0		
	No answer	0		
2A, 2B, 2C, 2F	Yes	0.5	Logical reason	0.5
	No	0	Illogical or no reason	0
	No answer	0		
2D, 2F	No	0.5	Logical reason	0.5
	Yes	0	Illogical or no reason	0
	No answer	0		
3A	Should be C	1		
	Agree that it is SR	0		
	Should be D, DR	0		
	No answer	0		
3B	Agree that it is C	1		
	Should be D, SR or DR	0		
	No answer	0		
3C	Agree that it is D	1		
	Should be C, SR or DR	0		
	No answer	0		
3D	Should be SR	1		
	Should be C or DR	0		
	Agree that it is DR	0		
	No answer	0		

APPENDIX M

Density Lab – Student Copy

Density

Student ID ________________ (work in groups of 4-5) Date ________________

Objectives: This lab is designed to help the student:

- **Better understand what density means;**
- **Determine the density of an object; and**
- **Use knowledge of density to solve problems and resolve situations.**

Elicitation (write your individual responses in the space provided)

An aquarium is filled with water at the front of the room. Your instructor has 2 cans of colas to put in the water - one is a regular cola and the other is the diet version of the same drink. Both cans have the value "355 mL" written on the label and seem to weigh the same, though we can certainly put them on a scale after the demonstration. The water is straight from the tap so it is about room temperature.

1) Without discussing this with anybody, predict how the colas will behave in the water. Will both float, both sink, or will one float and the other sink (if so, which will float)? Why?

2) Discuss this with others in your group to get ideas (and reasons) different from your own. Write down all the different ideas in your group.

3) When called upon, let someone from your group be the spokesperson to deliver the consensus of the group (or explain the varying ideas - including the reasons).

4) The instructor will now perform the activity. What happens? Is this what you predicted?

5) After the cola cans are dried, have someone place them on a laboratory balance to get their masses (not weight! -a gram is a unit of mass; however, the more mass something has, the more it will weigh). Record the masses of both. Regular cola: ________ g Diet cola: __________ g

6) Do you think the mass has anything to do with whether something floats or sinks? Explain here what impact it has on sinking or floating.

7) Suppose we put a 2-L bottle of diet cola in the aquarium along side the can of regular cola. Predict on your own first: How do you think the 2-L will behave? It clearly has more mass than the regular cola. Will it float or sink?

8) What do others in your group think? Write down the ideas different from yours (if any).

9) The experiment will be performed. What happened? Is this what you predicted?

10) As a group, draw on a sheet of paper the initial ideas you have about floating and sinking.

Development Activity 1

1. Using disposable bathroom cups, put 5.00 g of aluminum powder into the 1st, 5.00 g of iron powder into the 2nd, 5.00 g of lead shot into the 3rd, and 5.00 g of flour into the 4th.

2. Compare the amount of space (volume) they each take up. Which takes up the most? Which takes up the least?

3. Why do you think that even though they all have 5.00 g of material in the cups, that they all don't take up the same amount of space?

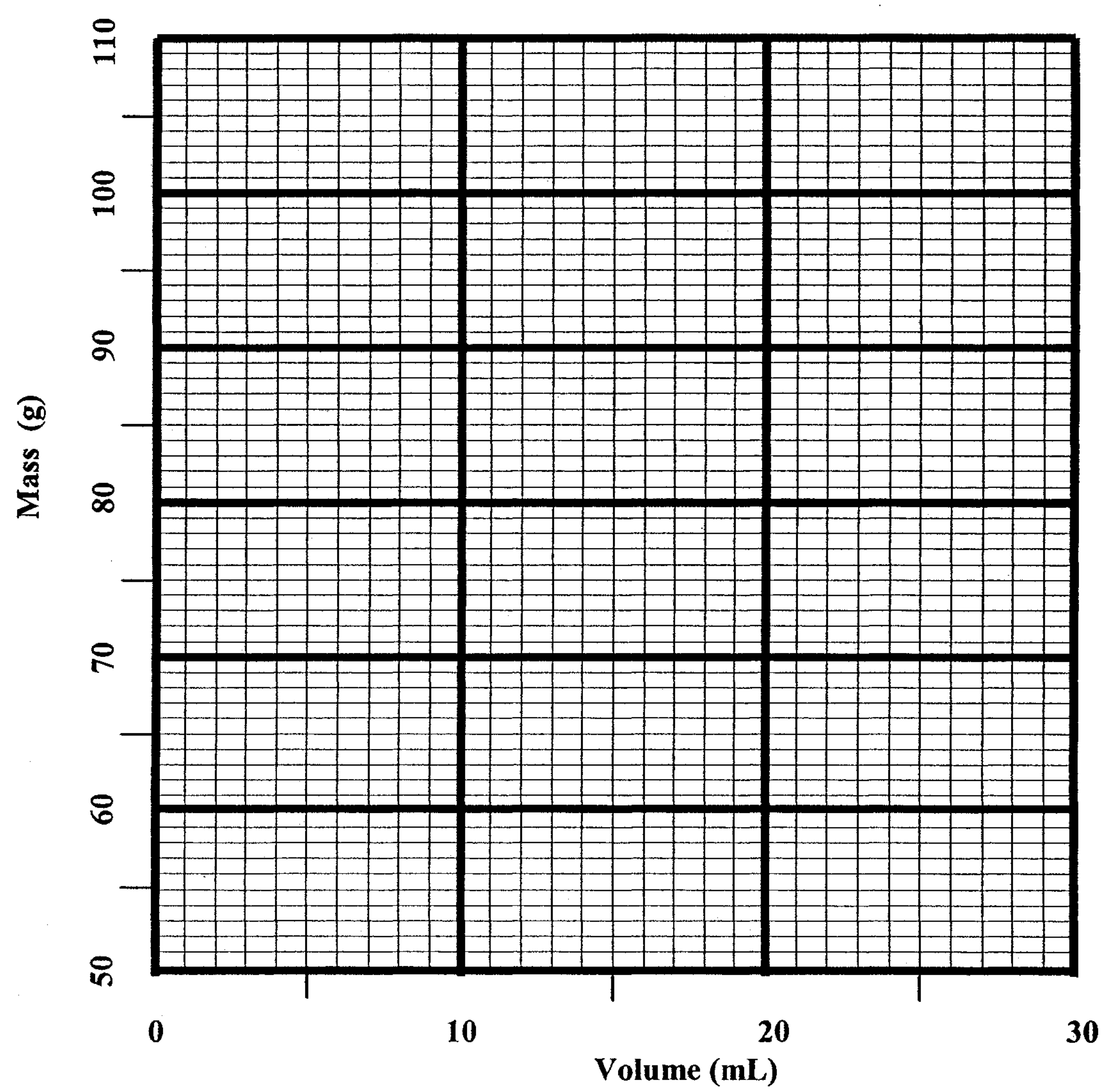
Development Activity 2 TALK TO EACH OTHER IN YOUR GROUP AS YOU DO THE FOLLOWING ACTIVITY TO HELP EACH OTHER UNDERSTAND. CALL OVER THE LAB INSTRUCTOR IF YOU GET CONFUSED!

1. Use the SAME 25-mL graduated cylinder as you work your way through this part. Just be sure to clean and dry it before moving on to the next liquid.
2. Place the empty graduated cylinder on the balance and find its mass. Record your answers in the table below.
3. Fill the graduated cylinder with WATER up to the 10.0 mL mark (the bottom of the curve is on the 10.0 mark). If any liquid gets on the outside of the cylinder, wipe it off. Record the mass of the cylinder with the water in it. Add more water and get the mass at 25.0 mL.
4. Next, repeat step 3 with alcohol, then corn syrup, and finally corn oil.

	Mass of liquid & graduated cylinder	Mass of liquid & graduated cylinder	Mass of liquid & graduated cylinder	Mass of liquid & graduated cylinder
Volume	Water	Alcohol	Corn Syrup	Corn Oil
Empty (0.0 mL)				
10.0 mL				
25.0 mL				

5. Plot the data on the graph on the next page. Using a ruler and a blue pencil/marker, draw a straight line through the water's data points; use green for alcohol, use red for corn syrup, and use yellow for corn oil.

Mass versus Volume for 4 Different Liquids



6. You should notice that the slopes (slantedness) of the lines are different; it is important to find their values so we can see what they mean. For the first amount of liquid, you put 10.0 mL of each liquid into the graduated cylinder. Even though they had the SAME volume of liquid, they had DIFFERENT masses for that 10.0 mL amount of volume. <u>We say they have different DENSITIES because they have different amounts of masses in the same amount of volume.</u> The one with the steepest line has the most mass at the 10.0 mL mark. Likewise, if you look at the 25.0 mL mark, even though they all have 25.0 mL at that point, they don't have the same amount of mass. DOES THAT MAKE SENSE? If not, call over the instructor. To find the slope of a line, do the following:

a. Notice that all of the slanted lines begin with the empty graduated cylinder. For this illustration, suppose the empty graduated cylinder had a mass of 60.0 grams. This will be your starting point for all 4 slopes.

b. Next, suppose the mass for 25 mL of water is 85 grams.

c. This means that, for this example, as you changed the volume of water from 0 mL to 25 mL, the mass changed from 60 g to 85 g. If that does not make sense, call over the lab instructor.

d. <u>Density can be thought of as the change in mass - symbolized by "Δ Mass" - relative to a change in volume - symbolized by "Δ Volume".</u> Using your data for water, subtract the mass amounts to see how much the mass changed from the empty graduated cylinder amount to the 25 mL amount. Δ Mass = _____________ (g). Now subtract the volume amounts to see how much the volumes changed from the empty graduated cylinder to the 25 mL volume. Δ Volume = ____________ (mL).

e. You probably remember from a math class that "slope equals rise over run." Since mass is plotted on the vertical axis, then the "rise" is the same as the change in mass (Δ Mass). Since the volume is plotted on the horizontal axis, then the "run" is the same as the change in volume (Δ Volume).

f. The density of water (this line) is calculated by dividing the change in mass by the change in volume; that is: Δ Mass / Δ Volume. When you divide, write your answers to the nearest tenth place. You should have obtained a value for water's density to be very near 1.0 g/mL. If not, recheck your math and/or call over the instructor to get some help.

g. Place your work in the table below for all 4 liquids.

Liquid	Empty graduated cylinder		Full graduated cylinder		Change in Mass (Δ Mass)	Change in Volume (Δ Volume)	Density or Slope (Δ Mass / Δ Volume)
	Mass	Volume	Mass	Volume			
Water		0 mL		25 mL			
Alcohol		0 mL		25 mL			
C. Syrup		0 mL		25 mL			
Corn Oil		0 mL		25 mL			

h. You should notice that the density for corn syrup is the largest value with the steepest line on your graph while the alcohol is the least steep. That means that there is more mass in each mL of corn syrup than in each mL of alcohol. Why that is the case is not the subject of this lab; it is, however, the purpose of this lab to realize that density is a specific property of substances.

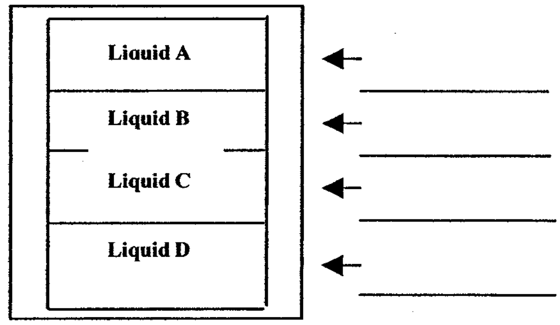
7. Notice that you have gathered data for 0, 10 and 25 mL of different liquids, yet the points seem to lie in a line with a constant slope. Suppose you had measured a larger volume of water. Does it seem reasonable that this new point would also lie on the line you created? Would it have the same density as the other water already in the cylinder?

Development Activity 3

1. Pour approximately 20 mL (doesn't have to be exact) of each of the liquids into a 100 mL graduated cylinder *in the following order*: corn oil, corn syrup, water, alcohol. Compare the order of stacking with the slopes.

2. Put the names of the liquids in the proper order beside each liquid in the drawing to the right.

3. How does the "stacking order" here compare to the slopes of the lines in the graph?



4. What general rule can be derived from the order of how things float?

Development Activity 4

We have seen that the mass of the material alone doesn't determine if something will float or sink, but it is the ratio of mass in a unit of volume that matters.

1. Take a small block of paraffin and measure its mass and volume (multiply length x width x height - all in centimeters); we will find the density of the paraffin by dividing its mass by its volume. Put your data in the table below.

Paraffin Mass	Paraffin Volume	Paraffin Density

2. Using what you know about the densities of your liquids and how they stack in a column, predict to what level a small block of the paraffin will sink in the tower you have made. Prediction:

3. Lower it into the tower and observe where it goes. Were you right?

4. If you took a smaller piece (maybe a shaving) of paraffin and put it into the tower, would it sink to the same place as the small block or to a different place (above or below)? How did you decide?

5. Perform the activity. Were you right?

6. Explain why the paraffin pieces behaved the way they did.

Problems

Examples to follow for practice problems:

1. A rectangular solid of cork has a mass of 3.42 g and measures 3.40 cm long, 2.88 cm wide and 0.47 cm high. Find the density of the metal. [Solution: Since the block is a rectangular solid, the volume can be found by the formula: V = l x w x h. Thus the volume is (3.40 cm x 2.88 cm x 0.47 cm) 4.6 cm^3. Density is found by mass / volume, so 3.42 g / 4.6 cm^3 is 0.74 g/cm^3. Since this value is less than water's density, 1.00 g/cm^3, it will float in water. Actually, it can be said that water exerts a buoyant force on the cork that is equal to its weight, so it floats. However, buoyant forces are proportional to objects' relative densities.]

2. An odd-shaped rock has a mass of 156.7 g. A graduated cylinder is filled to the 50.0-mL mark with water. The rock is lowered carefully into the graduated cylinder making the final water level to be 93.8 mL. Determine the density of the rock. [Solution: The volume of the rock is equal to the amount of water which is displaced by the rock, so 93.8 mL - 50.0 mL = 43.8 mL (or 43.8 cm^3). The density is determined to be (156.7 g / 43.8 cm^3) 3.58 g / cm^3. It sinks because it's density is greater than water's density. Likewise, it can be said that the water is not able to exert as much buoyant force on the rock as the rock weighs, so it sinks! Once again, buoyant forces are proportional to objects' relative densities.]

Practice problems (answers below):

1. What is the density of an irregularly-shaped solid which is 68.45 g and makes water level rise from 45.0 mL to 73.4 mL in a graduated cylinder?

2. The formula for the volume of a cylinder is $V = \pi R^2 L$ (where π is close to 3.14, R = the radius of a circle or half the diameter, and L = length of the cylinder). Find the density of a cylinder if its mass is 95.7 g, the diameter is 2.54 cm and the height is 7.00 cm.

Answers to practice problems:
1. 2.41 g/cm^3
2. 2.70 g/cm^3

APPENDIX N

Kinetic Theory Lab – Student Copy

Kinetic Theory

Objectives: **This lab is designed to help the student:**

- **Identify the main ideas of the kinetic theory;**
- **Describe solids, liquids & gases in terms of the motion of their particles;**
- **Explain the role pressure plays in the behavior of gases; and**
- **Establish a connection between the kinetic theory and rates of chemical reactions.**

Elicitation Activity (Courtesy in part of the CPU Project, San Diego State University)

Part I - Pumping air into a ball

1. Record in the blank the mass of a deflated, but still round, soccer-type ball. __________ g

2. INDIVIDUALLY: After your instructor pumps air into the ball, PREDICT how the mass will be affected (if at all). Will it be less, the same or more than when deflated?_______________
EXPLAIN your prediction here.

3. DISCUSS this situation with others in your group and be ready to explain to the class your prediction(s) and reason(s).

4. Your instructor will now put a few pumps of air in the ball. Record the value here: ______ g.

5. What conclusion do you draw from this activity?

Part II - Compressing 3 syringes

1. Take 3 syringes: 1 filled with sand, 1 filled with water, and 1 filled with air.

2. <u>Keep your finger over the end of the syringe you are testing</u>. Squeeze the plunger in on each syringe if you can. Record the results below.

3. The sand ______________ (could, could NOT) be compressed.
The water ______________ (could, could NOT) be compressed.
The air ______________ (could, could NOT) be compressed.

4. INDIVIDUALLY explain why the sand, water and air behaved as they did.

5. DISCUSS this situation with others in your group and be ready to explain to the class your prediction(s) and reason(s).

Part III - Mixing 2 liquids

1. Obtain two 100-mL graduated cylinders and place exactly 50.0 mL of water in one and 50.0 mL of denatured alcohol in the other. Caution: Poisonous if swallowed! Wear goggles!

2. INDIVIDUALLY, predict what the resulting volume would be if you were to pour these 2 liquids together. Would it be LESS than 100.0 mL, STILL BE 100.0 mL, or MORE than 100.0 mL? Explain your reason for your choice.

3. DISCUSS this situation with others in your group be ready to explain to the class your prediction(s) and reason(s).

4. After the instructor says so, pour them together. What happens? Were you right? Write down any observations you can that occurs in this activity.

5. How can you account for what happened?

Development Activity I - Analogies (No activity. Just READ in your group.)

Scientists describe solids, liquids and gases using the Kinetic Molecular Theory, or better known as simply the Kinetic Theory. This theory states that particles of matter are constantly moving. Thus they have kinetic energy. Since the particles of matter are too small to be viewed with even the most powerful light microscopes, most of the explanations for the way matter behaves come from experiments and human reasoning rather than from direct visual observations.

To understand the main ideas of the Kinetic Theory, analogies will be used.

1) The first idea is that matter is made of tiny particles in constant motion. Imagine children are the particles (molecules or atoms) of a school, and someone in an airplane is flying overhead looking down on the playground. If the children are having free play, the observer may not notice them since they are likely scattered around on the playground. However, if they are playing a game of soccer, sometimes they would be close enough together (around the ball) that a group of them with their colored uniforms could be seen, even if the whole group is moving around a bit. At an intermission, the players may be seen more easily as they are huddled together getting instructions from the coach. Anyone who has watched children realizes they can't be still, even if they are not running or walking around. Some may be rocking back and forth or wiggling in place while some may be spinning around not paying attention. Others may be slowly moving around; at the same time, others may even be running around. In a similar way, molecules have 3 types of movement: vibration, rotation, and translation which is actual movement from one place to another.

2) The temperature of an object (ice, water, or steam for example) is a measure of the average kinetic energy the particles in the object. It is related to how fast, on the average, the particles are moving around. The Kelvin temperature scale has no negative values. A zero value on the Kelvin scale (called "absolute zero" - an unreachable value experimentally) means that at that temperature matter has no disorder. {On the Celsius scale, there are negative numbers; it would make no sense to say something had "negative" movement or "negative" kinetic energy.}

As an analogy, suppose the children were sitting as still as they can. We would call that "zero" on our imaginary temperature scale. Next, the teacher has them stand in an orderly fashion and hold hands with the persons next to them while they play a musical game. As the music plays, the children hold on to each other, but move in time with the music. First the music is slow and the children move slowly, holding on to each other and staying together; this arrangement represents a solid. Gradually, the music gets faster, so the children do too. Eventually the children are moving fast enough that some can't hold on to both partners at the same time; the network of children break in places with groups of them moving independent of other groups. This represents the liquid state where groups of molecules move together past other groups of molecules and collectively spread out a tiny bit. Occasionally, as groups interact, some children leave one group to join another group. As the music gets even faster, the children let go of their individual neighbors and move freely of one another, spreading farther and farther apart. This represents the gaseous state.

The degree of children's movement represents temperature - some are moving more rapidly than others. Their interactions with other children represents the states of matter we call "solids," "liquids" and "gases". It would not make any sense to say that 1 child represented a solid, a liquid, or a gas. Such terms are used to explain the arrangement of MANY particles in space relative to each other, and it also has direct ties to both how close the particles are to each other and also to how much attraction particles have for one another.

3) The idea of melting point and boiling point can also be explained using the analogy of children moving around. While they are holding onto each other and dancing about with greater and greater movement, there comes a definite amount of movement when the network can't stay together; the whole single group divides into smaller energetic groups. We can associate melting with the process

of the collapse of a single network into smaller individual groups. Rather than thinking that the groups are moving faster, the added energy of movement just made the groups separate from one another. Similarly, if the music's pace increases and the group's movement gets so energetic that the students separate totally from each other, this can be thought of as boiling (a liquid changing into a gas).

Development Activity II - A model of Pressure ("Golf balls Galore")

1) In the Elicitation Activity, we noticed that the inflatable ball's mass increased when we added air to it. From this, we understand that air has mass. Scientists think of air (a gas) as made up of many tiny particles called molecules. In air, about 4 out of every 5 particles are nitrogen molecules. The remaining particle is usually just an oxygen molecule, (though there are traces of other gases in air too, such as carbon dioxide, water vapor, and argon). Since "air" has mass, then it follows that its molecules possess mass. Scientists think of these little particles as 1) moving wildly about inside a container with 2) mostly empty space between them, and 3) as they move, they occasional bump into each other and into the inside walls of the container pushing outward. Of course, air on the outside also is bumping into the walls of the container, pushing inward.

2) Each group member (at least 4 to a group) needs to get 5 g

3) Two boxes with one side and top cut off are glued together on the ends for this activity (see Figure 1). Take this box setup, and place it on the floor, using meter sticks on either side as guides. From about a meter away, roll 1 golf ball (representing a molecule of air that has mass) across the floor into the box so that the box moves about 10 cm. Now have 2 people each roll a ball into the same end of the box at the same time with the same speed. Measure how far they push the box. ______ cm Has the area of the end of the box changed (where the balls strike)? (yes, no)

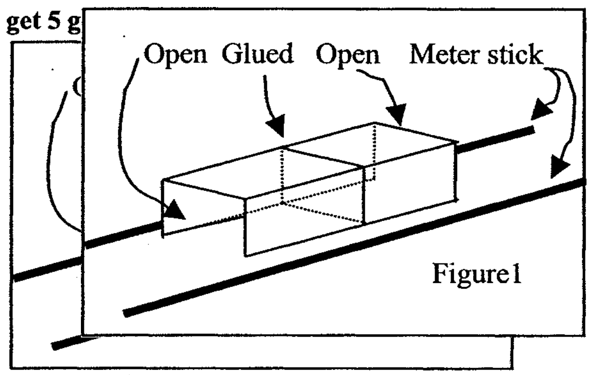


Figure1

How far do you think 3 balls would push the box if 3 people were to roll them at the same time and at the same speed? (CHOOSE: more, less, same distance) Go ahead and do it, then record the distance the box moves ________ cm. Now roll 1 ball into the box with more speed. How far did it push the box? ________ cm How does that result compare to the distance a slow golf ball pushed the box? (CHOOSE: more, less, same) From this you can see that both the <u>number of balls and their speeds</u> affect how much push is on each box end.

4) Scientists refer to the force something applies to a particular unit of area as PRESSURE. In formula form, it is $P = {}^{F}/_{A}$ and is often measured in units such as "pounds / in^2" or in the metric system, it would be "Newtons / meter^2". In chemistry, air pressure is measured in "atmospheres" (atm) because it simply represents the pressure that the air of the atmosphere applies to objects at sea level (though there is a more exact way to define an atmosphere, this will suffice for this discussion).

5) What effect do you think there would be on the box if 1 golf ball were to come into it from BOTH sides <u>at the same time</u>? (CHOOSE: still move one way, stay pretty much the same). Go ahead and try it several times. Were you generally right? (Yes, No). If 2 balls came in from each side at the same time and speed, would it still have the same effect? (Yes, No) Try it. Were you generally right? (Yes, No)

6) Even though air is pushing in on us, we are not crushed because we are pushing back on air. Our lungs have air in them pushing out and our heart pumps blood so that our skin is somewhat inflated with blood, thus pushing out on the air.

7) Remember that air has pressure (a force on each unit of area) because its molecules bump into the surfaces. Gases cannot pull or suck in because the particles are not attached to each other; they can only push. Also remember that their motion is random and is characterized by a wide range of

speeds, giving each particle various kinetic energies. Once again, the average kinetic energy of all the particles in an object is referred to as its TEMPERATURE.

8) There is a major difference between the golf balls in the previous activity and real air molecules. The golf balls moved because YOU made them move; they couldn't have moved on their own. Molecules, on the other hand, move simply because they have kinetic energy, not because something has moved them. This energy is reflected in the temperature of the substance.

Development Activity III - Balloon on a flask

1) Set up a ring stand with a 125-mL suction flask secured by a clamp onto a wire screen. The side arm should have a piece of tubing with a clamp closed on it. Stretch a balloon over the mouth of the flask and heat strongly for 2 minutes. What happens to the balloon? __________ Based on the fact that there is hot air (high energy molecules) inside the flask and balloon but cooler air (lower energy molecules) outside the balloon, explain why this occurred in terms of how the molecules were behaving and especially their pressures.

2) Remove the flame, then open the clamp to let higher-pressure air out and then clamp the hose again. As it cools, record your observations and why you think it behaved the way it did. (Keep in mind your explanations should be based on how the molecules are behaving.)

Development Activity IV - Melting Point: Identify an Unknown Substance

1) You saw earlier in the analogy section that as the children in the network danced around with more and more vigor, there eventually came a point that they couldn't keep holding onto each other any more. The single group gave way to making many smaller groups. The level of energy with which the jumping kids broke from a large group to more mobile smaller groups depended on how strongly the kids held on to each other. If they were holding on tightly, it would have taken more energy to make them break loose. If they held less tightly to one another, they would have to let go sooner with less jumping around.

2) Several samples of various compounds are available in capillary tubes in the lab. Attach a capillary tube to a thermometer using a piece of cut-off rubber tubing. Set up the heated-water apparatus like Figure 5.7 on page 44 of the lab manual. Using the 2nd paragraph of step 6 on page 44, decide which material you had. ____________________

Development Activity V - Kinetic Theory and Chemical Reactions

Introduction

Chemical reactions involve the changing of one substance into another. Sometimes two or more substances join to make one new material; at other times, a more-complex material breaks up into simpler substances. There are other types of chemical reactions that can occur as well. However, just because they can occur doesn't mean they will occur; conditions must be right for reactions to occur.

The following statements illustrate conditions which favor chemical reactions. Particle speed is important; for example, two substances might bump into each other too slowly or too quickly for a chemical reaction to occur. It also might be that the particles are moving the right speed as they collide but have the wrong collision orientation (see Figure 5.6, page 42 of lab text). Two other factors that can influence how well a chemical reaction occurs is the concentration of each of the reactants and if they have a 3rd party, called a catalyst, to get them in contact with each other.

An analogy may help clarify the previous statements. Suppose John and Mary would make a fine married couple if they just knew about each other. Suppose they are both at the same business meeting, or suppose they both move busily along a sidewalk but do not take the occasion to speak; they won't get together. Maybe they are moving down the hall in opposite directions and they bump

arms, excuse themselves, and keep on going. This will not be conducive to their getting to know each other. However, if they are the only ones on the elevator, or if she drops some papers and he picks them up to hand them back to her, then there is a chance they will find out about each other. If they both have a friend who introduces them to each other, then the chances of them becoming a couple improves significantly.

Activity

1) Measure 5 mL of warmed (~40°C) hydrogen peroxide into a test tube, 5 mL of room temperature hydrogen peroxide into a second test tube, and 5 mL of cold hydrogen peroxide into a third test tube.

2) Place the same small amount of manganese dioxide into each test tube. They all decompose to give water and oxygen gas. However, which one is the most vigorous? ______ Which reaction is slowest? ____________

3) To decompose readily, the hydrogen peroxide molecule comes into contact with the surface of the manganese dioxide. The manganese dioxide is called a catalyst here because it does not decompose or change itself, but it helps something else undergo a chemical reaction more rapidly. In order for the reaction to occur, the hydrogen peroxide molecules must contact the surface of the catalyst. The faster-moving molecules are the ones that get to the surface quickest, and are the ones that decompose most rapidly.

APPENDIX O

Chemical Reactions Lab – Student Copy

Chemical Reactions

Objectives: This lab is designed to help you:

- Identify the nature of chemical reactions,
- Recognize evidence of chemical reactions, and
- Categorize chemical reactions into broad types.

Elicitation Activity: Vinegar and Baking Soda

1. Take a 125-mL flask and place about 50 mL of vinegar in it. Put a thermometer in the liquid and measure its temperature, then remove the thermometer. Take a balloon and put 2 full scoops of baking soda in the balloon. Now, carefully stretch the balloon's opening over the flask, keeping the balloon from spilling its contents into the flask. After attaching the balloon on the flask, lift the balloon so the baking soda falls into the flask. Note what happens: ____________ ____. After the reaction is complete, carefully twist the balloon to capture the gas and keep it pinched closed. Now, carefully measure the temperature of the liquid again. How, if any, did the temperature change? _________________
2. WITHOUT LETTING ANY GAS ESCAPE YET, take a straw and insert it into the mouth of the pinched/twisted balloon neck. Using tape, attach it to the balloon so there will not be a leak. Take a 100-mL beaker and add about 50 mL of limewater to it. Now insert the end of the straw into the limewater and gently allow the gas to escape from the balloon. Watch the limewater for any changes and note them here: ____.
3. Now take a new straw and let 1 person blow breath into a separate beaker of about 50 mL of limewater. You should notice a similar change as happened in # 2 above.

Introductory Information Read in your group with a discussion to follow.

These and many other situations like them are called chemical reactions. Chemistry knowledge helps people manipulate materials to make new substances that didn't exist before. Chemists have learned that when a chemical reaction occurs, atoms rearrange to form new substances that have new properties. It is important to make careful observations to identify characteristics that indicate a chemical reaction has occurred. Evidence of chemical reactions include:

- Formation of a precipitate - solids that form during reactions, often settling to the bottom of the vessel over time,
- Production of a gas - one will observe bubbles present that were not in the original materials,
- A color change - an example is the silvery-gray color of iron changing to a reddish-brown color of rust when it combines with oxygen; color changes are permanent,
- A change in odor - the smell of something burning, for example, and
- A change in energy. If it absorbs heat from the environment, it may feel cooler after the reaction has occurred. If it releases heat to the environment, it may feel warmer after the reaction, or it may give off light or sound also.

It is important to realize that when we write symbols for chemical reactions, we are really representing particles that are combining, rearranging, or separating from one another. Those particles may be atoms, ions, or molecules. A generic equation is listed here:

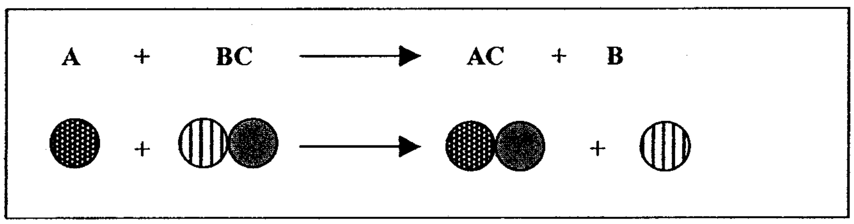
$$\underset{\text{(reactants)}}{A + BC} \longrightarrow \underset{\text{(products)}}{AC + B}$$

The items written in the equations **before** the arrow are the **reactants**, and the items written **after** the arrow are the **products**. The arrow itself is read "yields" and means "turns into" or "becomes." An equation then is a "before" and "after" summary of how matter interacts. When only one kind of symbol is given (such as A or B above), it represents just one element; when 2 or more different kinds of symbols are written (AB in this case), it represents a compound.

When a chemical reaction occurs, old things change into new things. New substances with new properties form out of old substances with their old properties. Another important feature to remember is that matter is never created or destroyed - the particles simply rearrange to make different substances. This means that if reactants were to be put in an enclosed vessel and placed on a balance and allowed to react, everything inside the vessel BEFORE the reaction is still there AFTER the reaction. The particles simply have rearranged themselves.

If no new materials are formed or old materials disappear, there has been no chemical reaction. This is simply a physical change. Often it is difficult to tell simply by observing if the material has the same or new properties. Thus, if there is just a change in state (solid to liquid, for example) or if there is a change in shape (crystal pounded into a powder, for example), only physical changes have occurred.

Graphically, the equation A + BC ⟶ AC + B can be represented using unique shapes or symbols. For example, an atom of the element A can be represented by  . Atoms of the elements B and C can be shown by  and  respectively. When two different symbols are joined, as in the case of  , this can represent a unit of a compound. So, A + BC ⟶ AC + B can be represented by:



Development Activity I: Types of reactions (Analogies) Read in your group.

Even though there are an enormous number of reactions that can occur, many of them can be identified by their type. There are four types of reactions we will study. Analogies for them are given here.

#1: Composition (also known as Combination or Synthesis)

Suppose Allen and Betty go individually to a party, but meet each other there and leave as a couple. We could represent this situation by the symbolic equation:

$$A + B \longrightarrow AB$$

Allen + Betty form the couple Allen-Betty

Here, Allen and Betty are alone (single elements) BEFORE the party and combine to be a couple (compound) Allen-Betty AFTER the party. We see that the number of people have not changed; they have simply rearranged from being individuals to being a couple. Furthermore, their mass did not change; the sum of their individual masses equals their mass as a couple. In chemistry, we say that these two principles represent the laws of conservation of atoms and conservation of mass.

The same is true of reacting chemicals. Suppose an atom of magnesium (an element) and an atom of sulfur (another element) "meet" each other and form magnesium sulfide (a compound). We can represent it as:

$$Mg + S \longrightarrow MgS$$

Note: there is more than one item (2 separate elements) on the left side of the arrow and only 1 item (a compound) on the right. This is typical of composition reactions. Note: while this shows 2 atoms combining, it is also possible for an atom to combine with a compound, or 2 compounds can join to form another compound. As long as they can join together to make a single compound, it is known as a composition or combination reaction.

#2: Decomposition
Now, suppose this new couple, Allen-Betty, have a disagreement and they decide to break off their relationship. They will not be a couple any longer. We can represent this by the equation:

$$AB \longrightarrow A + B$$

Once again, both the number of people and the total amount of mass has not changed. The people simply have rearranged themselves; in this case, they have parted company! A chemical example of this could be the decomposition of the compound calcium selenide into the elements calcium and selenium. This is written:

$$CaSe \longrightarrow Ca + Se$$

Note: there is just one item on the left of the yields sign (arrow) and two or more items on the right. This is typical of decomposition reactions. It may also occur when a substance breaks down into an element and a compound or into two compounds.

#3: Single Replacement
Suppose Allen-Betty go to a party and Carl is there by himself. During the course of the party, somehow Carl and Betty decide to become a couple and Allen leaves alone. This is represented by:

$$AB + C \longrightarrow CB + A$$

Of course it is also possible that Allen-Betty go to the party together, and Debby is there by herself. Somehow, Allen and Debby get together and Betty leaves alone. This can be shown by:

$$AB + D \longrightarrow AD + B$$

In either case, just 1 person was replaced in the couple. Thus it is called a "single-replacement" reaction.

An example of this could be:

$$CuCl_2 + Fe \longrightarrow FeCl_2 + Cu$$

In this case, Fe (iron) replaces Cu (copper). The Cl_2 means that before the reaction, there are two chlorine atoms joined to the Cu, then later they join to the Fe.

While there are many factors involved in deciding whether a chemical reaction will occur, it is important to realize that chemical reactions proceed on their own only if favorable conditions exist for them to happen. In the previous case, iron was more reactive to chlorine than the copper.

#4: Double Replacement
Suppose Allen-Betty go to a party and Carl-Debby are also there. During the party, somehow Carl and Betty decide they like each other more than their date, so they become a couple; this leaves Allen and Debby each alone, so they decide to leave the party as friends. We represent this by:

$$AB + CD \longrightarrow CB + AD$$

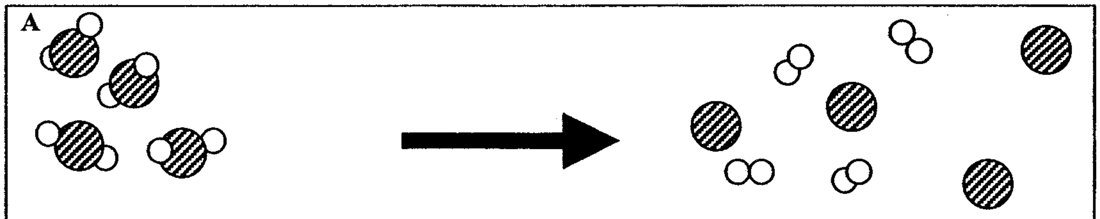
In this case, 2 couples swap partners. That is why this type of reaction is called a "double-replacement" reaction. An example of this is:

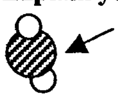
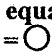
$$AgF + NaCl \longrightarrow AgCl + NaF$$

Development Activity II: Graphical representations of a chemical reaction

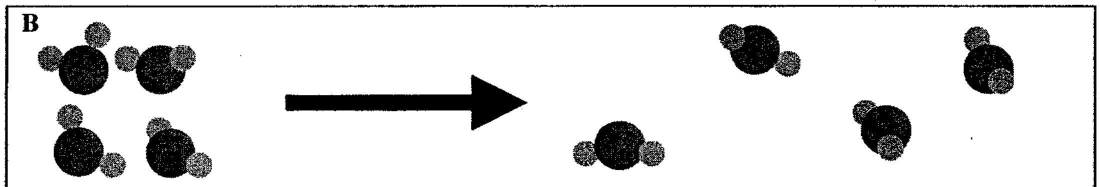
Part 1. Reading about graphical representations

A



Did a chemical reaction occur? **YES**	**Explain your answer. On the left of the yield sign, there are 4 sets of**  **units, but on the right there are different substances; there are 4**  **atoms and 4 units of**  **. So there are different substances on each side, though the numbers of each kind of atom are equal.**
Type of reaction: Decomposition	**Possible symbolic equation:** $4\ AB_2 \longrightarrow 4\ A + 4B_2$ **(A =**  **& B =**  **)**

B



Did a chemical reaction occur? **No**	**Explain your answer. There are 4 units of the material on both sides. Since the composition is the same on both sides, there is no reaction. This likely represents melting (solid to liquid) or maybe sublimation (solid to gas). Clearly the left of the yields sign represents a solid because the units are orderly in nature which represents a solid. The right side has space between the particles; depending on the degree of freedom between them, they may represent the liquid or gaseous state.**
Type of reaction? None	**Possible symbolic equation:** $4\ AB_2 \longrightarrow 4\ AB_2$ **(Same, thus not a reaction)**

Part 2: Writing graphical representations. In your group figure these out & put on whiteboards.
A. Ammonia (NH_3) is an important ingredient in the manufacturing of many commercial products. It is made by the Haber process, and the equation for its formation is: $N_2 + 3\ H_2 \longrightarrow 2\ NH_3$.

In the block below, make a graphical representation of this equation. Also, tell what kind of reaction it is.

Graphical representation:	**Type of reaction:**

B. In 1936, the Hindenburg LZ-129 exploded as it was docking in Lakehurst, New Jersey. A spark caused the buoyant hydrogen in the dirigible to burn with oxygen in the air, sending a fireball into the sky, killing 25 of the 97 people on board. $2H_2 + O_2 \longrightarrow 2\ H_2O$ is the equation for this reaction. Make a graphical representation of this equation and tell what kind of reaction it is.

Graphical representation:	Type of reaction:

C. To get rid of that ugly tarnish (silver sulfide - Ag_2S) on your grandmother's silverware (must be real silver), this cheap but effective method works: Put some soda can pop-top rings (pure aluminum) in a tall glass, fill it up with vinegar and stand the silverware in the cup on top of the rings. Shortly the tarnish will be gone. The equation is: $3Ag_2S + 2Al \longrightarrow Al_2S_3 + 6Ag$. Make a graphical representation of this equation and tell what kind of reaction it is.

Graphical representation:	Type of reaction:

Development Activity III: Conducting and understanding reactions

Part 1: Doing the experiments.

Caution: You must wear goggles from here to the end of this section. Read each of these directions and carefully do the procedures. If you should contact the materials, wash with plenty of water immediately. Answer the questions as they arise.

1. Sand an iron nail's surface with sandpaper till it is shiny. Pour into a small beaker about 2-3 cm of copper (II) sulfate solution, and stand the sanded end of the nail into the solution. Does any-thing happen immediately? ______ Observe what happens over time and record here. ________

____

At the end of this lab, pour the liquids into a bottle labeled "iron nail and copper (II) sulfate solution reaction."

2. Take another iron nail (sand clean) and stand it up in about 2-3 cm of a solution of magnesium sulfate. Does anything happen immediately? ___________ Observe what happens over time and record here. ____

At the end of this lab, pour the liquids into a bottle labeled "iron nail and magnesium sulfate reaction."

3. Place about 2-3 cm of a lead (II) nitrate solution in one test tube and into another test tube place 2-3 cm of a potassium iodide solution. Pour the 2nd test tube's contents into the 1st and describe what happens. ______________________ Let it stand in a test tube rack for about 3 - 5 minutes. What happens? ____ When finished, pour the contents of the test tubes into the bottle labeled "lead (II) nitrate & potassium iodide reaction".

4. Place about 2-3 cm of a sodium chloride solution in one test tube and into another test tube place 2-3 cm of a potassium iodide solution. Pour the 2nd test tube's contents into the 1st and describe what happens. ______________________ Let it stand in a test tube rack for about 3 - 5 minutes. What happens? ____ When finished, pour the contents of the test tubes into the bottle labeled "sodium chloride & potassium iodide reaction".

5. Place a pea-sized amount of sulfur into a metal spoon. IN THE FUME HOOD(!!) hold the spoon over a flame till it catches on fire. Describe what you smell and see. ________________ ________________________________ Now, keep heating in the flame till the sulfur is all gone.
6. Using tongs, hold a nail in a flame for 2 minutes. Does it appear to react? __________ Describe what happens. ____
7. IN THE FUME HOOD (!!) Using tongs, hold a short piece of magnesium strip in the flame till it catches on fire. TRY NOT TO LOOK DIRECTLY AT THE FLAME. Describe what happens here.

____

8. To a dry cell battery, attach a wire to each end, not allowing the two wires touch each other. Put the other ends of the 2 wires into a beaker that has about 20 mL of dilute sulfuric acid. Watch carefully and note here what happens. ____

____

9. Place about 2-3 cm of a hydrochloric acid (HCl) solution in one test tube, and into another test tube place 2-3 cm of a sodium hydroxide (NaOH) solution. Pour the 2nd test tube's contents into the 1st, and describe what happens. ______________________ Feel the outside of the test tube to see if there is a temperature change. What happens? ________________________________ Dispose of the liquids by pouring them into the bottle labeled "hydrochloric acid & sodium hydroxide reaction".
10. Place about 2-3 cm of a magnesium chloride ($MgCl_2$) solution into one test tube and into another test tube place 2-3 cm of a sodium hydroxide (NaOH) solution. Pour the 2nd test tube's contents into the 1st, and describe what happens. ___________________ Let it stand in a test tube rack for about 3 - 5 minutes. What happens? ______________________________________ Dispose of the liquids by pouring them into the bottle labeled "magnesium chloride & sodium hydroxide reaction".

Part 2: Understanding what has happened in #1 - 5
1. In the first activity, by now you should have noticed that the nail got a dark coating on it and the solution became lighter (and may have gone from a light blue to a greenish color). Chemists write the reaction equation as follows:

$$CuSO_4 + Fe \longrightarrow FeSO_4 + Cu$$

$CuSO_4$ is "copper (II) sulfate" and Fe is "iron." The "SO_4" is a group of 5 atoms joined together (1 is sulfur and 4 are oxygen) to make an ion called <u>sulfate</u>. The "(II)" is a way to represent the charge of the copper, but we will ignore it here. Basically, there are 2 ions joined together: copper and sulfate; together they make a compound called copper sulfate (like Allen-Betty). It should be noticed that iron is by itself (like Carl), which means it is an element. No doubt, you know that both copper and iron are metals (though copper does not appear to be a metal here because it is in a combined state with a sulfate ion).
An obvious change to the nail indicates a reaction is occurring here. The iron atom is able to replace the copper ion that was with the sulfate ion, much like Carl is able to push Allen aside to take Betty from him. The copper that was with the sulfate now leaves the solution and sticks to the iron nail (the dark coating on the nail). Interestingly copper ions appear cyan (bluish-green) in solution while iron ions appears yellow. As more copper leaves the solution, the solution gets less cyan, and as more iron enters the solution (to be with the sulfate), the solution becomes more yellow. Before the reaction reaches completion, there are some of both ions in solution, making the solution have a greenish color (combination of cyan and yellow colors). We say that this is a <u>single-replacement</u> reaction.

2. In the 2nd reaction above, nothing happened. Though similar to the 1st reaction, iron was unable to replace magnesium (which was in a compound with the sulfate). As noted at the beginning of this lesson, we saw several items that could offer evidence for a chemical reaction. None of these are present in this reaction. We would write this chemical equation as:

$MgSO_4$ + Fe ⟶ NR (No Reaction)

Another way of looking at this reaction is to say, SO_4 prefers to remain with Mg rather than be with Fe. Why this is the case is beyond what we are studying here.

3. The reaction in #3 above was unexpected! Two colorless solutions were poured together and produced a yellow solid which settled (precipitated) in the solution, just as dust settles in the air. Though this reaction is unbalanced, we write the equation:

$$Pb(NO_3)_2 + KI \longrightarrow PbI + KNO_3$$

Here Pb (lead) and NO_3 (nitrate - there are 2 of them joined to the lead ion) together. This compound is like the compound Allen-Betty. K (potassium) and I (iodide) form a compound potassium iodide like Carl and Debby form the compound Carl-Debby. Notice that they simply swap partners on the right side. Further study reveals that PbI is a yellow, insoluble substance in water.

4. The partners don't swap in the 4th reaction, so we write it: NaCl + KI ⟶ NR (No Reaction)

5. In the 5th reaction, some sulfur was ignited, and it smoked as it burned. Eventually it was all gone. Here, we come to understand that a yellow powder (solid) joined with oxygen (gas in the air) as it burned to form a gas called sulfur dioxide. We represent it as:

$$S + O_2 \longrightarrow SO_2$$

If you noticed carefully, there was a brownish vapor coming from the spoon also. This is some sulfur that simple didn't react. Some of the yellow solid melted, then some of it began to escape into the air as a gas. This part is simply a physical change since there was a change of solid sulfur to liquid sulfur to gaseous sulfur. The strong odor, however was the smell of SO_2, a new substance that was formed in the reaction.

We see that there is a different substance after the reaction than there was before the reaction. This is ALWAYS the case when a chemical reaction occurs.

Development Activity IV: Categorize experiments #6-10

6. Nail in fire

___ Precipitate?	___ Gas formed?	___ Odor change?	____ Color change?
___ Energy change?	___ Reaction? (Y/N) If so, what type?		
___ A + B ⟶ AB (Composition)		____ AB ⟶ A + B (Decomposition)	
___ AB + C ⟶ CB + A (S. Rep.)		____ AB + CD ⟶ AD + CB (D. Rep.)	

7. Mg burned

___ Precipitate?	___ Gas formed?	___ Odor change?	____ Color change?
___ Energy change?	___ Reaction? (Y/N) If so, what type?		
___ A + B ⟶ AB (Composition)		____ AB ⟶ A + B (Decomposition)	
___ AB + C ⟶ CB + A (S. Rep.)		____ AB + CD ⟶ AD + CB (D. Rep.)	

8. Dry cell

___ Precipitate? ___ Gas formed? ___ Odor change? ____ Color change?
___ Energy change? ___ Reaction? (Y/N) If so, what type?
___ $A + B \rightarrow AB$ (Composition) ____ $AB \rightarrow A + B$ (Decomposition)
___ $AB + C \rightarrow CB + A$ (S. Rep.) ____ $AB + CD \rightarrow AD + CB$ (D. Rep.)

9. HCl & NaOH

___ Precipitate? ___ Gas formed? ___ Odor change? ____ Color change?
___ Energy change? ___ Reaction? (Y/N) If so, what type?
___ $A + B \rightarrow AB$ (Composition) ____ $AB \rightarrow A + B$ (Decomposition)
___ $AB + C \rightarrow CB + A$ (S. Rep.) ____ $AB + CD \rightarrow AD + CB$ (D. Rep.)

10. $MgCl_2$ & NaOH

___ Precipitate? ___ Gas formed? ___ Odor change? ____ Color change?
___ Energy change? ___ Reaction? (Y/N) If so, what type?
___ $A + B \rightarrow AB$ (Composition) ____ $AB \rightarrow A + B$ (Decomposition)
___ $AB + C \rightarrow CB + A$ (S. Rep.) ____ $AB + CD \rightarrow AD + CB$ (D. Rep.)

When finished, clean up your area and participate in a class discussion of the lab.

APPENDIX P

Post-course Quiz via Email

Physical Science (PSCI 1030) Post-Course Quiz

Last 4 digits of your SSN: Date:

PUT YOUR ANSWERS IN ALL CAPS LIKE THIS PLEASE.

Density Lab

1. Compare the density of water in a cup and in a bathtub. [Choose only ONE, and give your reason please.]

A. The water in the cup and the water in the bathtub have the same density because

B. The water in the cup has more density than the water in the bathtub because

C. The water in the bathtub has more density than the water in the cup because

2. Describe density (as studied in the lab).

3. Which has lesser density: 2.0 g mass occupying 5.0 cm^3 or a 12.0 g mass occupying 21.0 cm^3? Give your explanation in clear terms so I know how you determined your answer. Don't just guess.

4. A rectangular block of material has the dimensions of: 1 cm x 3 cm x 4 cm and it has a mass of 15.0 g. Would you say the material is Zool (D = 1.88 g/cubic cm), Pretic (D= 1.25 g/cubic cm), Salup (D = 0.80 g/cubic cm), or something else (give density).

Kinetic Theory Lab

1. Suppose you could obtain a very powerful set of eye glasses capable of seeing the particles of air. If you took a snapshot of what you saw, the scientific idea is that you would see tiny dots of particles inside a vessel (such as a balloon or flask). What do you think is between the particles? What leads you to that conclusion?

2. According to the Kinetic Theory, how are solids, liquids and gases different?

3. You may recall that we heated a flask with a balloon over its mouth. Explain why the balloon expanded. Be as specific as possible.

4. When water is boiling in a pan on the stove, what is the makeup of the bubbles in the boiling water?

Chemical Reaction Lab

1. List as many things as you can that indicate the occurrence of a chemical reaction.

A.
B.
C.
D.
E.
F.
MORE???

2. Look at the following diagram. Does it represent a chemical reaction? Why or why not? (Be as specific as possible.)

ABA **ABA** **AA** **BBBB**

ABA → **AA**

ABA **AA** **AA**

3. Three chemical equations are below. Indicate the type (C = Composition, D = Decomposition, SR = Single Replacement and DR = Double Replacement).

__________ A. $Mg + S \rightarrow MgS$

__________ B. $CaCO_3 \rightarrow CaO + CO_2$

__________ C. $Al + Zn(NO_3)_2 \rightarrow Al(NO_3)_3 + Zn$

4. Do these represent chemical reactions? (Yes or No) Then tell why you answered the way you did.

A. Snapping a wooden Popsicle stick into two pieces.

B. Burning wood in a fireplace.

C. Baking soda and vinegar put together.

APPENDIX Q

Permission Letter to Use CPU Diagrams

----- Original Message -----
From: Sharon Bendall
To: Barry Farris
Sent: Monday, January 10, 2005 1:06 PM
Subject: Re: Hello from Barry Farris

Hi Barry,

I'm happy to be helpful. Here it is. Congrats on finishing the dissertation!

Barry Farris has permission from the CPU Project to reproduce and use drawings (and any other parts) of the CPU materials in his dissertation and corresponding publications. Please acknowledge the CPU Project, funded by NSF, in all materials.

Sincerely,
Sharon Bendall
CPU Project Manager
CRMSE/SDSU
6475 Alvarado Road, Suite 206
San Diego, CA 92120