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ABSTRACT

This study investigated the effectiveness of computer animations that simulate laboratory experiments at the microscopic level in general chemistry. The experimental group did simulation activities that focused on the microscopic level, while the control group did simulation activities at the macroscopic level. Three variables were measured in this study: ability to visualize atomic and molecular behaviors, conceptual understanding and attitudes towards activities.

The study showed that dynamic simulations at the microscopic level helped students visualize chemistry representations involving molecular motions. No significant differences were found in students' performance in the examinations. In both groups, students had overall positive attitudes toward computer animations, but there were no differences between the two groups.

CHAPTER I

INTRODUCTION

Background of the Study

A true understanding of chemistry conceptions and chemical processes requires an ability to explain chemical phenomena observed in the laboratory by using atomic and molecular behavior and representing that behavior symbolically (Johnstone, 1993). In meeting that goal chemical educators have developed instructional materials and strategies to promote students' effective learning of chemistry. In recent years, the adoption of computers in education has resulted in the implementation of computer-based animations and simulations as educational aids.

According to Wikipedia (<http://en.wikipedia.org>), the definition of animation is “the rapid display of a sequence of images of 2-D or 3-D artwork or model positions in order to create an illusion of movement”. Simulation is “the imitation of some real thing, state of affairs, or process”. Animation can be based on either real or fictional things. The critical feature is a series of images or cartoons. Simulation is a model based on real objects or processes and does not have to involve pictures. A computer simulation is a program using pre-set and/or input variables to calculate or imitate a real system or

process. It must be built mathematically and the results can be represented by animations. Many computerized learning materials consist of both simulation and animation. Thus, the terms of computer animations and computer simulations in this study are sometimes interchangeable.

Chemistry educators started to think about applying computer simulations in chemical education when using a computer in a classroom or a laboratory became possible. Since the electronic analog computer played a very important role in the 1950s and 1960s (Bissell, 2004), and was considerably less expensive than the digital computer, early simulations were carried out on analog computers. Even four or five decades ago, these pioneers already realized that computers had created and would continue to create fundamental changes in all fields of science, including science education. (Osburn, 1961; Wilkins & Klopfenstein, 1966; Griswold & Haugh, 1968).

Presently, the computer is an integral part of chemistry. For chemical education, countless computer simulations and animations are available online and in CD-ROMs accompanying textbooks (Sanger, 2009). Computer simulations have been proven to help students visualize abstract chemistry models, understand chemistry concepts, improve performance in tests, and form positive attitudes to chemistry (Williamson & Abraham, 1995; Wu, Krajcik, & Soloway, 2001; Yeziarski & Birk, 2006; Abraham, Gelder, & Haines, 2001; Tasker, 2005; Ben-Zvi, Eylon, & Silberstein, 1986; Ealy, 1999).

Purpose of the Study

The purpose of this study is to investigate the effect of using computer animations to represent chemical phenomena at the microscopic or atomic and molecular level on the visualization of particulate behavior in general chemistry. Specifically, we will study the effects of computer animations that model chemistry laboratory experiments at the microscopic level.

Variables and Questions to Be Investigated

The first variable addressed by this study is students' ability to visualize atomic and molecular behaviors and how that ability is affected by animated simulations of chemical interactions. The second variable is how students' conceptual understanding is affected by animated simulations of chemical interactions. The third variable is how students' attitudes toward instruction are affected by these instructional materials and methods. Specifically, this study will explore the following research questions:

1. Will students develop better visualization of atomic and molecular behavior with simulation and animation activities at the microscopic level?
2. Will students learn concepts related to chemical kinetics and chemical equilibrium better with simulation and animation activities at the microscopic level?
3. Will students have different attitudes toward microscopic and macroscopic level computer simulation activities?

Significance of the Study

This study proposes to implement and evaluate computer-based simulation activities that model laboratory experiments at the microscopic level. It is important to know whether and how students benefit from this type of simulations, since computerized simulations are becoming widely used. It is also important to know what features of these simulations are effective. Finally, it is interesting to know if students have different attitudes toward different types of computer activities. Therefore, the results of this work might provide suggestions on how to design effective computer simulations.

CHAPTER II

CURRENT LITERATURE

There is an extensive literature concerning computer animations and simulations in chemical education. In this chapter, the theoretical basis for this study will be introduced first. Then currently available computer animations and simulations will be discussed. Finally, research on these learning materials will be reviewed, focusing on the effectiveness and the limitations of computer animations and simulations.

Theory Basis for Using Computer Animations and Simulations

Paivio's Dual Coding Theory

Paivio's theory assumes that learners use two different coding systems to receive information and store the information in their long-term memory. One system deals with verbal representations, the other deals with imaginal or pictorial representations. These two systems can function alone or coordinate with each other in a cognitive process. In this theory, when learners are exposed to pictures, they will provide verbal explanations to the pictures. On the other hand, they do not naturally provide pictures to words. Meaningful learning occurs when both coding systems are utilized (Paivio, 1986).

Mayer's Cognitive Theory of Multimedia Learning

Similar to Paivio's Dual Coding Theory, Mayer's theory assumes that students learn better when words and pictures are presented simultaneously than when one of them is presented alone. Thus, multimedia learning plays an important role in education. Based on his research, Mayer suggested that using animation and narration together could help students learn effectively. He also stated that animations should exclude any unnecessary materials (Mayer & Sims, 1994; Mayer, 2001). Taken together, Paivio and Mayer provide a theoretical base for simulations that include multiple types of presentation.

Piaget's Model of Intellectual Development

Piaget's theory proposes that there are four stages of cognitive development. They are sensorimotor, preoperational, concrete operational, and formal operational. Every person develops from the first stage to the fourth one as the person matures. Although theoretically students in upper high school and beginning college should be in the formal operational stage, many of these students are in the concrete operational stage of intellectual development. The most important aspect during this stage is that mental operations can be carried out only if those operations are performed with actual experiences. Students in this stage of development have not developed the ability to think abstractly. During the formal operational stage, children develop the ability to think conceptually and abstractly, so that they can work with conceptual ideas, without having to see or handle actual objects (Marek & Cavallo, 1997; Nurrenbern, 2001).

Chemical concepts at the molecular level are abstract because atoms and molecules cannot be seen or touched. Thus, these concepts are formal operational and concrete

operational students have difficulty understanding them. Computer animations at the molecular level are able to provide concrete representations of these formal operational concepts to concrete operational students (Herron, 1975).

Johnstone's Three Representations of Matter

To learn chemistry well, students need to understand representations at three different levels: *macroscopic*, *symbolic*, and *microscopic*. Macroscopic representation includes real chemicals, equipment, and observable phenomena. Symbolic representation includes atomic and molecular formulae, chemical equations, and mathematical representations. Microscopic representation includes models of molecules, atoms, and subatomic particles and all processes involving these particles. Lectures and exams typically focus on the symbolic level. Students learn macroscopic representations from laboratories, demonstrations, and real life. To learn at the microscopic level, students need to use models and imaginations (Johnstone, 1993). Linking these three levels of representations of chemical phenomena is a skill used by experts and a desirable target of chemical education for students. Educational materials that allow students to visualize chemical phenomena at all the three levels simultaneously have the potential to improve chemistry instruction (Wu, Krajcik, & Soloway, 2001; Abraham, Gelder, & Haines, 2001; Tasker, 2005).

Summary

As introduced above, learning chemistry requires students to understand representations in macroscopic, symbolic, and microscopic levels. However, students

often have difficulty understanding abstract phenomena like behaviors of atoms and molecules. This is because subatomic particles cannot be viewed or experienced directly and hence the concepts are abstract. Meanwhile, many of these students' intellectual development is at the concrete operational stage (Herron, 1975; Goodstein & Howe, 1978a, 1978b; Abraham, Williamson, & Westbrook, 1994). As a result, students need some concrete analogies, which can be felt, touched, or visualized, to aid them in learning concepts using atoms and molecules.

The ability to visualize molecular behavior and think at the atomic and molecular level in three dimensions (3D) is essential for understanding chemistry concepts. Therefore, helping students visualize particulate phenomena is an important goal of chemical education. There are different ways to illustrate particulate representations in chemistry, including two-dimensional (2D) drawings, hand-held models, and computer simulations (Shaw, Hyde, Jackson, & Woods, 1995; Pribyl & Bodner, 1987; Rochford, 1987; Carter, LaRussa, & Bodner, 1987; Gabel, 1993; Coleman & Gotch, 1998). Among these three, computer simulations have become widely used in recent years.

Usage and Trends for Computer Simulations in Chemistry

In recent times, computer simulations and animations have become more widely used in chemical education. Many recent chemistry textbooks include CDs containing computer simulations and animations. In addition, there are numerous resources available online that chemistry students and instructors can access. The Multimedia Educational Resources for Learning and Online Teaching (MERLOT) website

(<http://chemistry.merlot.org/materials.html>) has a collection of more than 100 simulations and animations in chemistry. The Journal of Chemical Education (JCE) website has a collection of many computer programs called *JCE WebWare* (<http://www.jce.divched.org/jcedlib/webware/>). These programs were developed by chemistry educators from all over the world, and contain Java applets, QuickTime, Flash movies, and Excel based tools. JCE software collections are also available on CD-ROMs. In addition, there are some websites containing simulations specifically designed for high school and middle school chemistry, such as <http://cse.edc.org/products/simulations/catalog.asp>.

Furthermore, computer simulations and animations can be found on some chemical education and research groups' websites. Examples are Abraham/Gelder's animations (<http://genchem1.chem.okstate.edu/CCLI/Startup.html>), Greenbowe's animations (<http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm>), and Tasker's animations (<http://bcs.whfreeman.com/chemicalprinciples4e>).

There are three trends in developing and utilizing computer animations and simulations: direct interaction with existing computer programs, students' construction of their own animations, and using computational tools to simulate chemical phenomena with real data. In recent years, educators and software experts began to bring 3D techniques and virtual reality (VR) into computer simulations in chemistry. These applications require complex techniques and advanced software for development.

Linn (1989) stated that there were three stages in the relationship between science education and information technology. Stage one is simply simulating experiments. In stage two, students use research tools to obtain real time data. In stage three, educators,

researchers and computer experts cooperate and develop new technological tools for education (as cited in Williamson, 1992, p. 25).

In the early days of applying computer simulations in education, one approach was to ask students to build their own interactive simulations. Osburn (1961), Griswold and Haugh (1968) used an electronic analog computer to simulate problems in chemical kinetics, such as first order reactions. Based on the equations of the reactions, they set up analogous electronic circuits. The output or solution was in the form of time-voltage curves, which mirror the time-concentration curves for the chemical reaction. Osburn (1961) asked the students to set up their own problems. Students could change coefficients and initial conditions to see the effect. However, analog computers were expensive at that time, and a single computer was not practical because of the class size and the time been taken. To solve this problem, they used *auxiliary plugboards*, which were analog forms of computer terminals (Wilkins & Klopfenstein, 1966)

Because applying 3D visualizations of molecular phenomena is an important goal of instruction in chemistry, it is useful for students to generate real 3D models or to form mental models with 3D pictures. Barak and Dori (2005) asked students to actively construct their own 3D molecular models, not just view static ones on paper or on computers. By constructing models, students not only learned chemistry concepts, but also understood chemical processes. Wu, Krajcik and Soloway (2001) introduced a type of visualizing software called *eChem*. By using eChem, students could construct 3D molecular models. They viewed and compared symbolic, macroscopic and molecular representations simultaneously. This was reported to help students build mental models, link between different chemical representations, analyze questions, and understand

chemical concepts. These authors also mentioned some other molecular modeling tools that could be downloaded from the Internet, such as the *Chime2* plug-in, and *TINKER*-molecular modeling software (Wu, Krajcik, & Soloway, 2001).

Besides interactive Computer Models, student-generated drawings and animations show features of interactivity. Williamson and José (2009) reviewed some recent studies of these kinds of activities. The authors concluded that letting students make their own drawings and/or animations not only increases students' involvement, but also gives feedbacks concerning students' understanding.

Computational chemistry uses tools such as molecular mechanics (MM) and molecular dynamics (MD) to calculate molecular structures. It computes the positions, motions, and energies of an ensemble of atoms. It then generates graphic representations based on the data from the computations. Two decades ago, computational chemistry was only used for research purpose, since it required high performance computers at that time. This is because of the complex mathematics behind computations and the large amount of data used in processing the calculations. With the development of the microcomputer (or personal computer) in the early 1990's, computational chemistry began to be used in education settings (Ealy, 1999; Xie & Tinker, 2006). Ealy reported a molecular modeling program utilized by first year college chemistry students. This program is called *Spartan*. It can simulate real data, such as bond length and bond angle. Therefore, students are able to build 3D visualizations of atomic and molecular structures and manipulate these models. Some textbooks have been published with specifically designed workbooks, which can be used with the *Spartan* software produced by Wavefunction Inc. (Hehre, Shusterman, & Nelson, 1998, 2004).

Some universities or colleges have introduced computational chemistry during either general or organic chemistry, and continued to use it throughout the chemistry curriculum (Martin, 1998; Jones, 2001). Others introduced molecular modeling as a computer skill, along with data processing, internet usage, and presentation techniques, to help students learn chemistry better (Kantardjieff, Hardinger, & Willis, 1999). Molecular modeling has also been used as part of traditional wet organic laboratory experiments (Martin, 1998; Jones, 2001; Cook & Kreeger, 2000; Hessley, 2000; Hull, 2001; Klassen, Graham, & Muldoon, 1999; Poon, Bodolosky, & Norris, 1999; Graham, Skoglund, Schaller, & Muldoon, 2000). In addition, it is a powerful way to show students why certain parts of a molecule are more reactive than other parts (Hull, 2001; Graham, et al., 2000; Crouch, Holden, & Samet, 1996). Molecular modeling activities can increase students' interest and engagement, and can help students deeply understand chemistry concepts (Shaw, Hyde, Jackson, & Woods, 1995).

Students often have difficulty in understanding the existence of dynamic processes or mechanisms behind a chemical equation. They hold misconceptions concerning such concepts because they are not exposed to microscopic level representations of such systems (Painarbasi & Canpolat, 2003; Cole & Todd, 2003; Gabel, 1993; Bodner, 1991; Freasier, Collins, & Newitt, 2003; Nakhleh, Samarapungavan, & Saglam, 2005; Haidar, 1997). With the development of computer technology, accurately simulating molecular behaviors and interactions in liquids or solutions becomes possible. Serrano, Santos, Flávia and Greca (2004) asked students to perform Monte Carlo simulations to calculate the structure of liquid water with and without Na^+ , Cl^- , and Ar on personal computers. The author stated that when developing simulations, it is good to apply scientific research

routines and methods in education. These research routines provide accurate data and real models. The teaching community applies such simulations and may adapt it for educational purposes. The research community, in turn, interacts with the teaching community by developing new software that can be used for education. Processing real data can aid students' understanding of complex phenomena in chemistry. (Kelly & Jones, 2007, 2008).

Speer, Wengerter and Taylor (2004) believed that both theory and techniques in computational chemistry should be introduced to undergraduate students in physical chemistry. In their laboratory experiments, students performed MD simulations by using a package of molecular simulation programs called Assisted Model Building with Energy Refinement (*Amber*) to study the molecular structures of some liquids, such as ethanol.

Other technologies related to computers can also be effectively used in teaching and learning, although they were not originally designed for instruction purposes. These technologies include word processors, spreadsheets and mail/communication software. They are cheap and are bundled with most personal computers. Most students are familiar with these technologies even before they enter colleges. Among these, Microsoft Excel is the most commonly used spreadsheet that is able to simulate some chemical processes. For example, Lim (2006, 2005) asked students use Excel spreadsheet to simulate the effect of anharmonicity on diatomic vibration, which is one of the simulations in JCE WebWare.

Coleman, Reich, Vitz and Zielinski (2009) introduced JCE WebWare in a review. The author discussed the software tools in JCE WebWare. Most of the interactive spreadsheets used are Excel spreadsheets. These spreadsheets are interactive and

dynamic. Students can create and study plots or graphs under various conditions. An example spreadsheet simulates titration curves. Students can explore how titration curves change with a change in pK_a values of a polyprotic acid. Students can also use Java applets to visualize organic reaction mechanisms by using web-based interactive animation technologies. Finally, another simulation studied vibrational motion using Flash and shockwave animations.

Cass, Hii and Rzepa (2006) reported the animations created by using Jmol applets in JCE WebWare. Students can view dynamic intramolecular atom exchange processes and learn the mechanisms of fluxional behavior. Gil and Paiva (2006a, 2006b) discussed a salt solubility simulation in JCE WebWare.

Coleman, Reich, Vitz and Zielinski (2009) also introduced another program on JCE website, JCE LivText (<http://www.jce.divched.org/jcedlib/livtexts/>). The idea of JCE LivText is that it combines traditional textbook and digital materials. Hence it has the same range and breadth of a traditional textbook, and can serve as traditional classroom instructional materials. In addition, it is able to contain movies and simulations. For example, *Quantum States of Atoms and Molecules* allows students to visualize electromagnetic waves by changing the parameters and variables in the wave function.

Beside these free accessible software tools, JCE also provides collections of programs that can be ordered online. One is called the *General Chemistry Collection*. It contains software focusing on topics such as the periodic table, equilibrium, acids and bases, etc. Another is called *The Advanced Chemistry Collection*, and includes software focusing on topics such as spectroscopy, NMR, chromatography, quantum chemistry, and so on. These can be found on

<http://www.jce.divched.org/JCESoft/Programs/Collections/GCC/contents.html> and
<http://www.jce.divched.org/JCESoft/Programs/Collections/ACC/contents.html>.

Applying virtual reality (VR) in education is a new trend in computer simulations. L. J. Ausburn and F. B. Ausburn (2004, para. 4) defined VR as “basically a way of simulating or replicating an environment and giving the user a sense of being there, taking control, and personally interacting with that environment with his/her own body”. It ranges “from simple environments presented on a desktop computer to fully immersive multisensory environments experienced through complex headgear and bodysuits”. Immersive VR is usually used in military and industry applications. Because of the expense and technology, non-immersive or desktop VR will be more widely used than immersive VR in most fields, including education, in the near future. Instead of complex equipment such as headgear and bodysuits, non-immersive VR uses everyday device like mouse, joystick, or sensorball.

VR may include the following characteristics: (a) 3D pictures – accurate objects and environment can be simulated, and it is possible for students to navigate these objects and environment in any directions, (b) combining educational activities, video games and tests, (c) control of the environment by students with the physical senses involved during the activities. (Vogel, Greenwood-Ericksen, Cannon-Bowers, & Bowers, 2006; L. J. Ausburn & F. B. Ausburn, 2004)

The most common example of the application of VR in chemical education is the virtual lab. Virtual labs are now available online or in CD-ROMs. Woodfield introduced a series of virtual labs called *Virtual ChemLab*. They include Inorganic Qualitative Analysis, Organic Synthesis and Organic Qualitative Analysis, and Fundamental

Experiments in Quantum Chemistry. These virtual labs were developed by Woodfield and Asplund at Brigham Young University. The laboratory rooms are quite similar to real chemistry lab rooms. A typical room in the software has doors, windows, floors, exit signs, lights, a fire extinguisher, benches, tables, drawers, a chalkboard, a periodic table, a lab book, gas cylinders, balances, centrifuges, test tubes, disposal bucket, bottles of chemicals, etc. When students start to use this software, they can find almost everything that is in a real chemistry lab. They can also observe real-life visual phenomena including the processes and the results of chemical reactions. Therefore, the virtual lab is ideal for distance education or online learning. In addition, The Virtual ChemLab provides numerous open-ended opportunities for students to experiment. For example, the inorganic version of this software can produce numerous outcomes due to the combinations of different chemicals. Students are able to try any experiments they want, without worrying about safety issues (Woodfield, Andrus, et al., 2005; Woodfield, Catlin, et al., 2004). This Virtual ChemLab software comes on a CD, which is part of some textbook packages (Woodfield & Asplund, 2006; Brown, Lemay, & Bursten, 2006).

Resources, costs, time, and class size sometimes make hands-on labs impractical. This becomes a problem especially for some advanced courses, such as physical chemistry and analytical chemistry. Computer simulations can solve this problem. In virtual labs, teachers and students do not have to worry about the limiting resources of equipment like GC and HPLC (Stone, 2007). Neither do they have to worry about the preparation time of equipment before a lab (Haddad, Shaw, Madden, & Dicoski, 2004). They also do not worry about wasting chemicals. Students can repeat as many times as they want, and can try any chemicals in the simulations. Because students know their

glassware will not be contaminated and they will obtain reproducible results, they trust the results and are confident in drawing conclusions. Computer simulations are safe. Students will not be nervous about toxic chemicals and dangerous or unexpected reactions (Woodfield, et al., 2005; Woodfield, et al., 2004).

Computer virtual laboratory simulations usually take less time to complete than hands-on laboratories do. That means students perform a large number of experiments with a broad range of conditions or parameters in a typical lab period (Lim & Coleman, 2005; Stone, 2007; Haddad, Shaw, Madden, & Dicoski, 2004).

More chemistry virtual laboratories can be found on websites such as <http://www.chem.ox.ac.uk/vrchemistry/> and <http://chemistrygeek.com/3d.htm>. Students can do these activities online. Some virtual labs can be downloaded from: <http://www.chemcollective.org/applets/vlab.php>.

Effectiveness of Computer Simulations in Chemistry

Chemistry phenomena are often explained in terms of atoms and molecules. Because atoms and molecules are invisible and untouchable, such explanations are very abstract. Thus, to learn chemistry concepts, understanding the particulate nature of matter is critical. Unable to build proper mental models of the particulate nature of matter leads to misconceptions or lack of conceptual understanding. With computer technology, dynamic animations provide rich and dynamic visual representations, thus aiding students in forming concrete mental models of particle behaviors in chemical processes. (Williamson & Abraham, 1995; Aldahmash, 1995; Aldahmash & Abraham, in press; Sanger &

Greenbowe, 1997; Cole & Todd, 2003; Yeziarski & Birk, 2006; Xie & Tinker, 2006; Cass, Hii, & Rzepa, 2006; Gil & Paiva, 2006a, 2006b; Ealy, 1999).

Sanger (2006, 2009) reviewed a series of research studies on the use of computer animations in chemistry. These studies showed that (a) students improved their conceptual understanding and performed better in exams after viewing computer animations, (b) students who viewed computer animations at the microscopic level had fewer misconceptions than students who only received traditional instruction, and (c) compared to students who only viewed static pictures, students who were exposed to computer animations understood conceptions at the microscopic, macroscopic and symbolic levels more completely. In general, these researches demonstrated that computer simulations had positive effect at the microscopic level.

Ben-Zvi, Eylon, and Silberstein (1986) showed that if the differences between subatomic particles and macroscopic matter were not emphasized, student would have difficulty distinguishing the properties between these two. For example, students might think atoms have colors and are malleable. In other words, students considered atoms or molecules as small parts of matter. This commonly happens in middle school, when such topics need to be simplified. As a consequence, these types of misconceptions have the potential to hinder students from understanding subsequent concepts, such as the composition and the interaction between atoms and molecules. To change these kinds of misconceptions, correctly visualizing atoms and molecules and hence forming correct mental pictures is important.

Williamson and Abraham (1995) explored the effects of computer animations on college students' understanding of certain chemistry concepts. Three dependent variables

were investigated in the study: conceptual understanding, course achievement, and attitude toward instruction. Students were asked to demonstrate their understanding by using drawings and explanations. This study showed that the three groups were similar in their reasoning abilities. However, when the authors used the *Particulate Nature of Matter Evaluation Test* (PNMET) to measure students' understanding of concepts, the results were quite different between the control and the two treatment groups. From the results, they found that (a) animations increased conceptual understanding of abstract phenomena, such as atomic and molecular models, and (b) dynamic animations are more effective than static ones. Therefore, compared to static visuals, such as pictures in textbooks, computer animations are more helpful for college students in understanding chemistry concepts at the particulate level (Williamson & Abraham, 1995).

Sanger and Greenbowe (1997) found that many students in freshman-level chemistry courses had misconceptions concerning electrochemistry. Students in the study viewed computer animations of electrochemical cells at the microscopic level. They were then asked to answer three questions about electrons flow in aqueous solutions. The results showed that computer animations enhanced students' visual abilities, which reduced their misconceptions in electrochemistry.

Yeziarski and Birk (2006) investigated the effectiveness of computer animations in changing students' misconceptions about the particulate nature of matter, especially those related to phases and phase changes. The treatment group watched several animations, which lasted about 25 minutes. The animations demonstrated the three phases of water, and the changes among these phases. After watching the animations, the students were asked questions related to the animations. The control group spent 25 minutes answering

a series of worksheet questions. The concepts in these questions were similar to those in the animations. The students then discussed and shared their answers with partners. The authors developed an instrument, the *Particulate Nature of Matter Assessment* (ParNoMA), to determine the effects of the treatment. By analyzing the pretest and posttest scores of ParNoMA, they found the treatment group scored significantly higher than the control group did. The results indicated that animations at the atomic and molecular level aided the students in forming better mental models and to develop conceptual understanding of particle properties and behaviors.

Wu, Krajcik, and Soloway (2001) investigated how computer-based models support students' learning in chemistry classrooms and how these models help students develop their representational skills. The participants were students in the 11th grade. Wu, et al. (2001) collected various sources of data over the 6-week experimental period. These data include video recordings of classroom and computer activities, pre- and posttests about the conceptual understanding of chemical representations/properties and molecular structures, and case studies. They found many students had difficulties in learning chemical representations such as chemical formulas. First, most secondary school students found it difficult to correctly understand the chemical meanings of these representations. Second, students had difficulties in thinking about or providing analogies for a chemical representation. Third, students had difficulties in transferring between representations at macroscopic, symbolic and microscopic levels, or between 2D and 3D dimensions. They concluded that students needed to "have substantial conceptual knowledge and visual-spatial abilities because chemical representations are conceptual constructs as well as visual displays" (Wu, Krajcik, & Soloway, 2001, p. 824). By

comparing the pre- and posttests scores, the authors concluded that students significantly improved their understanding of chemical representations after having been exposed to the computerized representations.

Ealy (1999) asked first-year college students to use the Spartan software to do a number of activities, and then evaluated their molecular modeling computer experience. The activities included: periodic trends in atoms, the structure of molecules such as bond angle and bond length comparisons, electronic structure of molecules such as MO and valence bond theory comparisons for the same molecules, and properties of organic molecules. The author found that students who viewed atomic and molecular representations scored higher on questions related to the numbers, properties, and behaviors of atoms and molecules in the final exam. Most students (approximately 72%) had positive opinions about the use of the software. The study also showed that computer simulations were helpful for the development of 3D visualization. They enhanced students' geometric ability and conceptual understanding. In addition, it showed most students thought the resources and the activities were effective and would choose to use them again.

Barak and Dori (2005) studied the effects of the integration of Project-Based Learning (PBL) in an Information Technologies (IT) environment. The subjects were students who took undergraduate chemistry courses in Israel Institute of Technology. Students in the experimental group used two computer graphics packages, *Computerized Molecular Modeling* (CMM), to build molecular models and solve chemical problems. Students in the control group only answered traditional problems. The authors found that this IT-enhanced PBL improved students' learning abilities, including spatial

understanding, the understanding of conceptions of molecules, and the ability to mentally transfer between levels of macroscopic, symbolic, microscopic, and process in chemistry. Students who used PBL performed significantly better in the posttests and the final exam.

Stone (2007), Woodfield, Andrus, et al. (2005) and Woodfield, Catlin, et al., (2004) investigated the effects of virtual labs. Their studies showed that most students have positive attitude to virtual labs. Students who did the virtual lab understood the course content better, and they significantly increased the scores on quizzes and exams more than students who did not do the virtual labs. Woodfield, et al. (2004) also found performance was positively related to attitude, and virtual labs helped students think at a higher cognitive level.

In summary, computer simulations and animations in chemistry help student connect representations of chemical phenomena in the macroscopic, symbolic, and microscopic levels; they help students build more correct mental models of chemical concepts; and they help students improve conceptual understanding. Dynamic simulations are able to show chemical processes and mechanisms; rich visualization and interactive content make students engage in study and form positive attitudes. Simulations save time and money, and are environment friendly.

Problems in Computer Simulations and Design Principles

Although computer simulations have advantages, there are also many potential problems that have been noticed and discussed by educators and researchers. These problems include: (a) computer activities can be too time consuming, (b) repeated

measurements make computer activities tedious, (c) computer activities are considered as extra work, (d) computer activities may not integrate well with lectures, (e) computer activities are considered to have nothing to do with exams, (f) activity instructions or exercises can be difficult and unclear, (g) computer activities can be so complex that special training is needed, (h) students are uncomfortable with computers, and (i) a large investment of time and cost is needed to develop computer activities. (Ealy, 1999; Sanger, 2006; Ausburn, L. J. & Ausburn, F. B., 2004; Simpson & Clem, 2008; Woodfield, Andrus, et al., 2005; Woodfield, Catlin, et al., 2004; Stone, 2007; Sanger, 2009). As a result, some research studies reported no effect or even negative effect when using computer simulations.

In his review of the effectiveness of animations in instruction, Rieber (1990) summarized a series of problems. Some animations are not closely related to the contents, or are poorly designed, so they have no effect or negative effect. If animations are too easy, they are not effective, or the effect cannot be detected when comparing to the control groups, because of the ceiling effects. If animations are too complex, and students do not have enough time to explore them, they will feel frustrated and give up. Students new to animations (even easy ones) need clear instructions. Students in different ages vary in relying on pictures and animations to help their learning. Young children may need more pictorial aid than older students do. He proposed three design recommendations: (a) content and animation should be properly integrated; the goal of animation should be coincident with the content, (b) when students are new in the content part, they need to be provided with clear instructions and enough cues, and (c) interactivity and dynamics are two most important features of animations (Rieber, 1990).

Liu, Andre and Greenbowe (2008) studied how students with different prior knowledge levels solve problems when using computer simulations in electrochemistry. They found that a single computer simulation is usually not suitable for every student. Students with a high prior knowledge level use more equations and formulas to solve problems and rely less on computer simulations. The simulations are used by these students to confirm their answers during the activities. On the other hand, low prior knowledge level students mainly use computer simulations to answer questions, and need more instructions to understand the animations and to accomplish the tasks.

Other problems include: simple simulations vs. complicated simulations, 2D simulations vs. 3D simulations, and simulations at the microscopic level vs. simulations at the macroscopic level. Using which type depends on the requirement of the courses and the purpose of the simulations. For example, 2D displays are usually easier to design, view, understand and analyze than 3D displays. However, 2D pictures cannot simulate interactions and mechanisms determined by 3D structures (Xie & Tinker, 2006). Haidar and Abraham (1991) warned that when designing computer simulations in chemistry, there should be a balance between (a) microscopic and macroscopic observations, (b) model and reality, and (c) theory and applied knowledge. They stated that “instruction in chemistry commonly uses instructional devices and analogies which attempt to simplify the students’ task of understanding chemical models” (Haidar & Abraham, 1991, p. 926). However, such simplification can easily cause students to misinterpret the simulations and to develop alternative conceptions. Thus, designers and instructors should be aware of when to use analogies in simulations.

Velázquez-Marcano, et al. (2004) used two different types of visualizations and investigated whether they assisted students in understanding the concepts of dynamic fluid equilibrium. One type of visualization was a video demonstration with macroscopic features; the other was an animation at the microscopic level. They found that the video by itself did not significantly help students' conceptual understanding, neither did the animation. However, when both types of visualizations were conducted in sequence, students improved their performance. This work indicated that when designing or using computer activities, the combination of different types of visualizations is important.

Tasker (2005) introduced a series of animations called *VisChem*. The author focused on the theory base of using multimedia in chemical education and the principles of molecular-level animation design, *VisChem Learning Design*. In these principles, the processes of before, during, and after viewing animations are integrated parts of a learning experience. In other words, when designing an animation at the molecular level, the designers and the educators should consider the learning activities related to that animation, rather than the animation alone. Before students view an animation, they may observe a chemical phenomenon during a lab activity or demonstration. Students are asked to describe the phenomenon in words and draw representations at the molecular level. Next, they discuss their descriptions and drawings with their partners, with the help of the instructor. After viewing the animation, students discuss the relation between their representations and the animation with the partners and the instructor. Then they connect the representations in macroscopic, symbolic, and microscopic levels. Finally, students use their mental model to explain new chemical phenomena.

In summary, a successful computer simulation means: (a) applying proper and consistent principles and procedures to design computer simulations, (b) using students' feedback and the revision based on the feedback, (c) using clear instruction and concise and attractive interface(s), and (d) employing instructors who have the abilities to guide and help students during simulation activities.

CHAPTER III

METHODOLOGY

Subjects

The subjects of this study were students enrolled in the second General Chemistry course at a large Midwestern comprehensive university in the spring semester of 2008. Five hundred and eleven students were enrolled in the course at the beginning of the semester. The lecture portion of this course met three times a week. Each meeting was 50 minutes. There were two lecture sections taught by two different professors. Each section had almost the same number of students. Both professors were experienced in teaching General Chemistry and taught with a common text, syllabus, and gave common examinations. Because students were able to choose either section when enrolled, we assumed these two groups of students were equivalent in academic background.

All the students in these two lecture sections were required to enroll in one of the 24 laboratory/recitation sections. Each section met for a 3-hour chemistry laboratory and an 80-minute recitation each week. Every section had a maximum of 24 students and was taught by an experienced graduate teaching assistant (TA). Similar to the lecture sections, students were freely and randomly enrolled in the laboratory/recitation section, thus all

the sections were assumed to be equivalent. Twenty of the 24 were taught by ten TAs; each TA taught two sections. We assigned half of these TAs' sections as experimental groups, and the other half as control groups. Sections taught by the same TA were in the same group, except for two sections. The TA who taught these two sections assigned one section to the experimental group, and the other to the control group. In the end, 11 sections were assigned to control groups, and nine sections were in experimental groups.

Students were asked to volunteer to participate in the study. They could also quit the study at any time. Therefore, it is possible for some students to participate in one set of assessments, but not in the other ones. In comparing the results of two assessments, we excluded the students who took only one set of the assessments. As a consequence, different measurements include different numbers of subjects.

Treatment

The treatments took place during the second and third weeks of the semester. Both the experimental and the control groups did computer-based laboratory simulations in the recitation sessions during these two weeks. Students answered questions that were part of the activities accompanied the simulations. TAs collected the paper work as students' reports at the end of each recitation.

Experimental Group

The simulation activities that the experimental group did were from *Molecular Laboratory Experiments* (MoLEs) (Abraham, Gelder, & Haines, 2001). MoLEs are a

collection of computer simulations available online and are designed for introductory chemistry. The topics of these simulations include stoichiometry, gas laws, molecular structures, kinetics, equilibrium, acids and bases, etc. (Abraham, Gelder, & Greenbowe, 2008, 2009). Each MoLE simulation is interactive and dynamic and is accompanied by guided-inquiry and open-inquiry activities. The manual containing the activities is based on the learning cycle approach. It guides students to interact with the simulations, collect data, and answer questions. A typical interface or window of a MoLE simulation consists of three regions: the *Sample Region*, the *Control Bar Region*, and the *Module Display Region*. Figure 1 is an interface example of a MoLE.

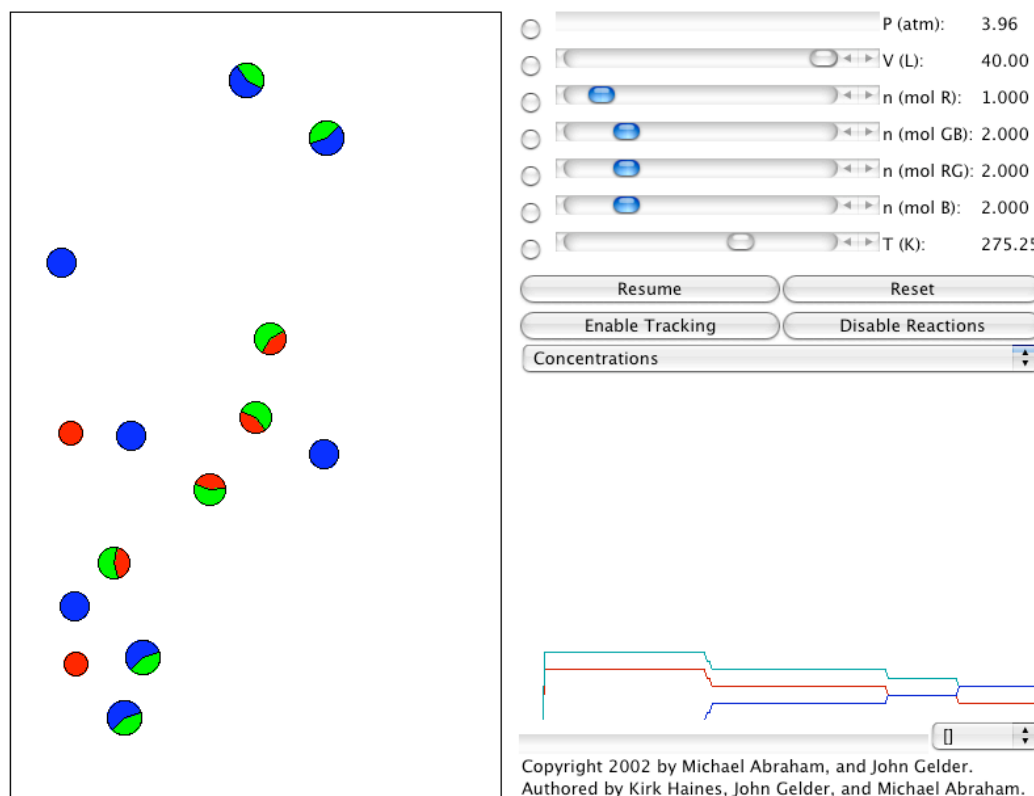


Figure 1. *Mechanisms of A Chemical Reaction* simulation interface.

The Sample Region is a container with atoms and molecules in different colors. These particles can move, collide and react in the container. The Control Bar Region allows students to change parameters such as temperatures and pressures during experiments and to control the interaction of the sample. The Module Display Region shows data in graphs or in tables to display the experimental results. The actions of the three regions are linked so that changes in one region are reflected in the others.

The first MoLE simulation used in this study was *Mechanisms of A Chemical Reaction*. It took place during the second week recitation period. This activity was designed to expose students to chemical reactions associated with chemical kinetics. Students were taught how a chemical reaction occurs between two molecules in the gas phase. Factors such as speed and orientation that affect the results of molecular collisions were explored. Additionally, students were taught how multiple-step reactions occur.

During the third week recitation, students did the *Shifting Reaction A* and *Shifting Reaction B* simulations. Both introduce concepts of chemical equilibrium in the gas phase. *Shifting Reaction A* emphasizes the dynamic nature of chemical reactions and invents the idea that chemical reactions can be reversible. *Shifting Reaction B* simulates how concentration changes influence a chemical equilibrium and invents Le Châtelier's principle.

Control Group

The activities that the control group did were from *Laboratory Simulations*, which were developed by Thomas Greenbowe and his group (Greenbowe, 2003). Laboratory Simulations include a wide range of topics in college chemistry and focus on General

Chemistry. There are also some animations and tutorial materials in the collections of Laboratory Simulations. Similar to MoLEs, the inquiry activities of the Laboratory Simulations are based on the learning cycle approach. A Laboratory Simulation window usually has the *Macroscopic Region* only, as shown in Figure 2. Simulations of laboratory apparatus or glassware are shown in this Region. Students can also read measurement from the equipment or glassware, change variables in experiments, and view chemical phenomena like color change.

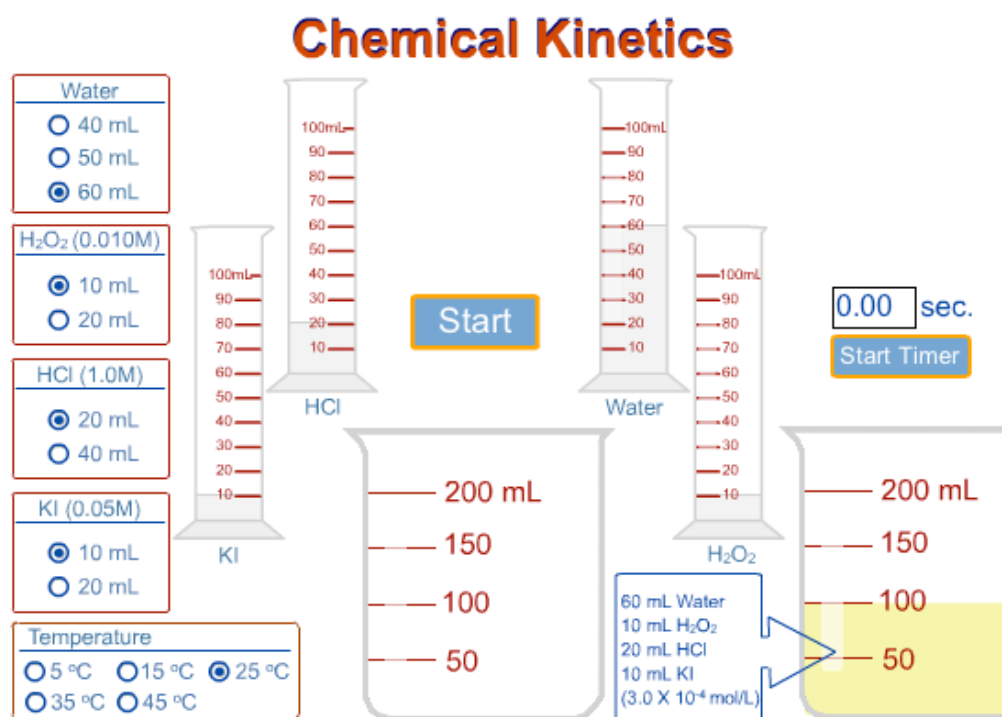


Figure 2. Concentration/Temperature Effects simulation interface.

Students did the *Concentration/Temperature Effects* activity during the second week of recitation. This activity was a macroscopic simulation of a kinetics experiment. In this

simulation, students set different amount of chemicals and different temperature, and then record the time that each reaction completes to find the rate of the reaction.

During the third week recitation, the simulations were *Decomposition of H₂O₂* and *Acid/Base pH*. In the *Decomposition of H₂O₂* simulation, students choose different amount of KI, KCl, and FeCl₃ in each trial in order to find how they affect the decomposition rate of H₂O₂. Thus, they are guided to learn the concept of how catalysts influence the rate of a chemical reaction. *Acid/Base pH* asks students to explore the relationship between the concentrations of acids/bases and the concentrations of H⁺/OH⁻ in order to allow students learn what factors determine an acid/base to be strong or weak.

As introduced above, MoLEs focus on the microscopic level, while Laboratory Simulations chosen in this study has more macroscopic features. The activities for all the computer simulations in the treatments are in Appendices A.1 – A.6.

Instruments

Particulate Nature of Matter Assessment (ParNoMA)

ParNoMA is a validated instrument to assess students' conceptual understanding in the particulate nature of matter (Yeziarski & Birk, 2006). We used the second version of ParNoMA as both a pretest and posttest in our study. ParNoMA is not directly related to kinetics or equilibrium concepts. Thus it was used as a general measure of understanding of the particulate nature of matter.

The design of the ParNoMA was based on five concepts. Items or questions were constructed about (a) size of particles, (b) weight of particles, (c) compositions of

particles, (d) phases and phase changes, and (e) energy of particles. The questions included for each of the five concepts are listed in Table 1.

Table 1

Category of concepts in ParNoMA

Concept	Name	Question	Number of questions
a	Size	3,14	2
b	Weight	6,19	2
c	Composition	4,7,8,9,11,15	6
d	Phase change	1,2,10,13,16,17,20	7
e	Energy	5, 12,18	3

An example question of each concept is also listed below:

(a) Size:

3. Which of the following processes will make water molecules larger?

- A. freezing
- B. melting
- C. evaporation
- D. condensation
- E. none of the above

(b) Weight:

6. A water molecule in the gas phase is _____ a water molecule in the solid phase.

- A. smaller than
- B. lighter than
- C. heavier than
- D. larger than
- E. the same weight as

(c) Composition:

7. When water is vaporized, it is changed to
- A. hydrogen and oxygen
 - B. hydrogen only
 - C. gaseous water
 - D. air, hydrogen, and oxygen
 - E. oxygen only

(d) Phase and phase change:

10. Consider three samples of water in three phases. The first is solid water (ice) at 0°C , the second is liquid water at 24°C , and the third is gaseous water at 100°C . The water molecules in the liquid phase _____ the water molecules in the solid phase.

- A. move faster than
- B. move slower than
- C. move at the same speed as
- D. move less randomly than
- E. travel in the same direction as

(e) Energy:

12. Which of the following processes does **NOT** require heat energy?
- A. evaporating water
 - B. melting ice
 - C. boiling water
 - D. vaporizing water
 - E. condensing water

The pretest was held before the treatment, while the posttest was carried out six weeks after the treatment. The interval between the treatment and the posttest was relatively long because we anticipated that students would not be able to recall the specific questions they answered in the pretest. The effects of the treatment were expected to be measured by comparing students' performance in both tests. In addition, ParNoMA scores in the pretest could also be used to evaluate the equivalence of the experimental and the control groups. The second version of ParNoMA is in Appendix B.

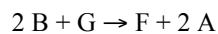
One general chemistry professor and two general chemistry TAs reviewed ParNoMA and took the assessment independently before this research. The answers had 100% agreement among them. These answers were used as the answer key to grade the students' responses in ParNoMA.

Examinations

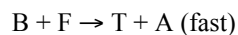
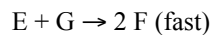
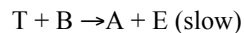
After the treatment, all the students took two exams. The first exam was held one week after the treatment; the second was four weeks after the first exam. They were the first two of the monthly examinations in the course. Both exams consisted of 10 multiple-choice questions in the kinetics unit and 10 multiple-choice questions in the equilibrium unit. The second exam was a retest opportunity for students who were dissatisfied with their scores in the first exam. The two exams are in Appendices C.1 and C.2. Only the two units involved in this research are included in the appendix. The exams were constructed by the instructor of the course and only some questions were directly related to the contents of the simulations. Two example questions are shown below:

Kinetics:

1. The reaction



is known to follow the mechanism

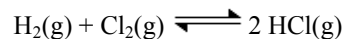


From this, we know that

- A. E and T are both intermediates
- B. E is an intermediate and T is a catalyst
- C. The rate for the reaction is $\text{rate} = k [\text{B}]^2 [\text{G}]$
- D. The rate for the reaction is $\text{rate} = k [\text{E}] [\text{T}]$
- E. E and T are both catalysts

Equilibrium:

11. Suppose the following reaction is at equilibrium at a given temperature and pressure. The pressure is then increased at constant temperature, by compressing the reaction mixture, and the mixture is allowed to re-establish equilibrium. At the new equilibrium _____.



- A. there is more hydrogen chloride than there was originally
- B. there is less hydrogen chloride than there was originally
- C. there is the same amount of hydrogen chloride as there was originally
- D. the hydrogen and chloride are completely used up
- E. the amount of hydrogen chloride may be either larger or smaller than it was originally, depending on the value of K

Conceptual quiz

Students in both groups took a conceptual quiz 10 weeks after the treatment. This quiz was optional and there was no credit for students to take it. The quiz contains two open-ended questions and is in Appendix D.

The first question was about a reversible chemical reaction. There was a graph representing the concentration of all chemicals in a reversible chemical reaction versus time (Figure 3). At time=2, more D is added to the system. Students were asked to answer three sub-questions:

- Write an equation describing the reaction that is taking place in the system.
- Is the reaction ever at equilibrium during the time monitored? If so, draw a box around any such regions of the graph.
- Explain, in your own words, why the concentrations of [A], [B], [C] change as they do at time=2.

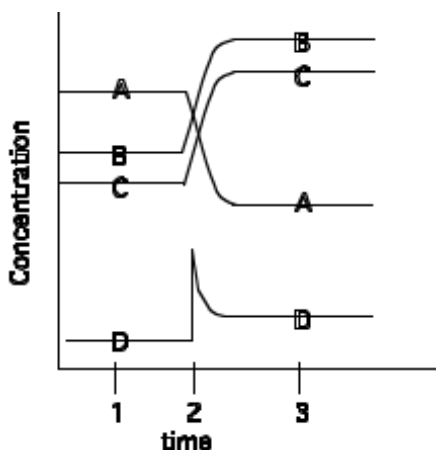
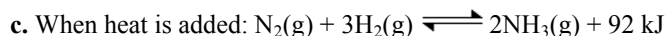
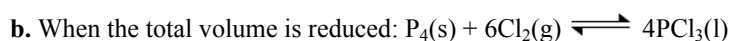
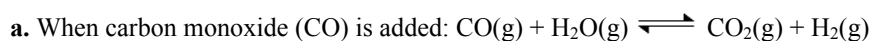


Figure 3. Graph of concentration versus time in the conceptual quiz.

Similar graphs showing concentration vs. time can be found in the textbook used in the course (Silberberg, 2003, p. 718, 738). In other words, students in both groups were exposed to a similar graph in their classes.

The second question asked students to predict equilibrium shifting when stresses are added to chemical reactions and to explain their prediction at the particulate level. The reactions and the stresses were:



Attitude

During the same week of the posttest, a semantic differential survey regarding students' attitudes toward the computer activities was conducted. The instrument is called the Birnie-Abraham-Renner Quick Attitude Differential (BAR) (Abraham & Renner, 1983, 1986). This inventory measures the student's attitude toward a specific science lesson. The construct validity of the BAR has been established by using factor analysis. There are two factors in the BAR: a contentment factor, which measures the student's satisfaction towards the lesson; and a comprehension factor, which measures student's confidence in their learning. We put the BAR online so that we could obtain students' responses directly from a database, which was connected to the website. We used a version of the BAR that was slightly different from the original one. This version of the BAR was reported in Williamson's (1992) and Amiot's (2007) dissertations. It has 12 questions or items compared to 13 questions in the original one. The orders of the

questions in these two versions are a little different. The two factors of this version of the BAR and the questions included are listed in Table 2.

Table 2

Summary of Factor Questions in BAR

Comprehension factor		Contentment factor	
Question	Measurement	Question	Measurement
3	Not confused	1	Pleased
5	Easy	2	Satisfied
7	Question understood	4	Enthusiastic
9	Words understood	6	Activities in order
10	Solve problems	8	Like the topic
11	Nothing new		
12	Too slowly		

The BAR uses a seven-point semantic differential scale. That is, each question has seven choices, from 1 to 7. The higher the number chosen by a student, the more positive attitude a response is, except for Question 12. The BAR used in this study is in Appendix E.

Timeline

The timeline of this research is in Table 3. It summarizes the conducting time of each activity.

Table 3

Timeline of Research

Activity	Pretest	Treatment	1st Exam	2nd Exam	Posttest	Bar	Open-ended
Week	1	2-3	4	8	9	9	13

Note: Both the pretest and posttest are ParNoMA

Data Analysis

All statistical analyses were carried out by using Statistical Analysis Software (SAS). A t-test was used to compare the mean scores statistically between the experimental and the control groups. These scores include (1) the scores of ParNoMA, (2) the scores of each factor in ParNoMA, (3) the scores of unit one and unit two in the first examination, (4) the scores of the BAR, and (5) the scores of each factor in the BAR. The differences of the gain scores between the two groups were also analyzed.

Factor analysis was used to determine the factors in ParNoMA and in the BAR. Pearson's chi-square (X^2) test was used to find the differences in the proportions of students' responses in the conceptual quiz between the two groups.

CHAPTER IV

RESULTS

ParNoMA

Average Scores

The second version of ParNoMA contains 20 multiple-choice questions about particulate actions focusing on water molecules. One point was assigned to a student if this student chose the correct answer to a question; otherwise, zero points were assigned to that question. Therefore, the total scores for ParNoMA are between 0 and 20 points.

Every subject's ParNoMA score of each question along with the total score is listed in Appendix F. Only students who took both ParNoMA assessments and could be identified are included.

Table 4 shows the mean scores of each group in the pre- and post- tests.

Table 4

Descriptive Data of ParNoMA

Group	Pretest			Posttest		
	M	SD	n	M	SD	n
Control	14.25	4.45	114	13.68	5.36	114
Experiment	13.59	4.38	56	14.41	3.94	56

A t-test in Table 5 indicated that there was no significant difference between the experimental and control groups either in the pretest or in the posttest.

Table 5

t-test for the Average Scores of ParNoMA

ParNoMA	df	t	p
Pretest	168	0.91	0.3649
Posttest	143	-1.01	0.3139

Although the scores in the ParNoMA of the two groups were not significantly different, we noticed that the experimental group increased 0.82 points (SD = 3.34) from the pretest to the posttest, while the control group decreased 0.57 points (SD = 4.48). Table 6 lists the differences of the scores between the pretest and the posttest.

Table 6

Gain Scores in ParNoMA

Group	M	SD	n
Control	-0.57	4.48	114
Experiment	0.82	3.34	56

A t-test of the changes of the ParNoMA scores (or gain scores) found a significant difference between the two groups, $t(142) = -2.27$, $p = 0.0246$. The results of the t-test are shown in Table 7.

Table 7

t-test of the Gain Scores in ParNoMA

ParNoMA	df	t	p
Gain	142	-2.27*	0.0246

Note. *p < 0.05.

Factor Analysis

As discussed in Chapter III, the questions or items in ParNoMA were originally constructed by Yeziarski and Birk with five parameters or concepts. In order to test this construction and to understand the patterns of our students' responses, we did a factor analysis of these 20 questions. We wanted to see whether there existed groups of questions and whether each group of questions would share some common features. The factor analysis identified three factors, or three groups of questions. Each factor contained four to nine questions. Each of the 20 questions with the loading on each factor is listed in Table 8.

The criterion 0.30 was used as the cutoff of the factor loadings. In other words, a question was categorized to a factor if that factor loading was greater than 0.30 (shaded cells in Table 8). For example, the first question had a loading 0.3689 in factor 2 and therefore it was assigned to factor 2. There were four questions that had loadings greater than 0.30 on two factors. In this case, we assigned the question to the group that had the higher factor loading.

Table 8

Rotated Factor Pattern of ParNoMA Questions

Question	Factor 1	Factor 2	Factor 3
1	0.06068	0.36891	0.09900
2	0.08192	0.37098	0.13199
3	0.31459	0.13215	0.56673
4	0.46745	0.17384	0.30795
5	0.62442	0.18606	0.30143
6	0.39466	0.20067	0.66168
7	0.76081	0.03205	0.18409
8	0.74809	0.07722	0.15509
9	0.57923	0.18716	0.15748
10	0.05711	0.31917	0.12081
11	0.61225	0.23895	0.15652
12	0.22399	0.51327	-0.07459
13	0.11229	0.57923	0.18480
14	0.22350	0.13599	0.76796
15	0.69646	0.12419	0.18526
16	-0.04450	0.54171	0.11186
17	0.09318	0.63347	0.10214
18	0.17002	0.44737	-0.15325
19	0.27190	0.19547	0.68219
20	0.19188	0.46691	0.16816

Note. Extraction Method: prinit
Rotation Method: varimax

By looking at the characteristics of each question in ParNoMA, we derived three concepts associated with each factor or each set of questions. Each factor contained a group of questions with the same concept(s). Questions in factor 1 were all about compositions of molecules. Questions in factor 2 were about the movement of particles and energies needed during phase changes. Questions in factor 3 were about the sizes of atoms and molecules. Table 9 summarizes the groups of questions and the name of each factor.

Table 9

Factors of ParNoMA from factor analysis

Factor	Name	Question	Number of questions
1	Composition	4,5,7,8,9,11,15	7
2	Motion-Energy	1,2,10,13,16,17,20,12,18	9
3	Size	3,6,14,19	4

The statistics of each factor from the factor analysis are discussed below.

Factor 1 (Composition factor).

The descriptive data of the average scores of the Composition factor and the t-test results are listed in Table 10 and Table 11, respectively. The data of the gain scores of the this factor and the statistics are listed in Table 12. The t-test results showed that there was no significant difference between the experimental and the control groups either in the pretest or in the posttest when comparing the average scores, nor was there any difference between the two groups when the gain scores were considered.

Table 10

Average scores of Composition factor in ParNoMA

Group	Pretest			Posttest		
	M	SD	n	M	SD	n
Control	3.88	2.67	114	3.81	2.56	114
Experiment	3.84	2.48	56	3.96	2.41	56

Table 11

t-test for the Average Scores of Composition Factor in ParNoMA

ParNoMA	df	t	p
Pretest	168	0.09	0.9292
Posttest	168	-0.38	0.7017

Table 12

Gain Scores of Composition Factor in ParNoMA

Group	M	SD	n	df	t	p
Control	-0.07	2.13	114	168	-0.56	0.5780
Experiment	0.13	2.17	56			

Factor 2 (Motion-Energy factor).

The descriptive data of the average scores of the Motion-Energy factor and the t-test results are listed in Table 13 and Table 14, respectively. The data of the gain scores and the statistics are listed in Table 15. The t-test results showed that there was a significant difference of the posttest scores between the experimental group ($M = 8.00$, $SD = 1.16$) and the control group ($M = 7.41$, $SD = 2.34$), $t(168) = -2.19$, $p = 0.0298$. The average score in the posttest of the experimental group was higher than that of the control group. There was also a significant difference between the two groups when the gain scores were considered, $t(143) = -3.06$, $p = 0.0027$. The experimental group ($M = 0.32$, $SD = 1.55$) gained more than the control group ($M = -0.55$, $SD = 2.10$) did in the Motion-Energy factor.

Table 13

Average Scores of Motion-Energy Factor in ParNoMA

Group	Pretest			Posttest		
	M	SD	n	M	SD	n
Control	7.96	1.12	114	7.41	2.34	114
Experiment	7.68	1.65	56	8.00	1.16	56

Table 14

t-test for the Average Scores of Motion-Energy Factor in ParNoMA

ParNoMA	df	t	p
Pretest	168	1.33	0.1866
Posttest	168	-2.19*	0.0298

Note. *p < 0.05

Table 15

Gain Scores of Motion-Energy Factor in ParNoMA

Group	M	SD	n	df	t	p
Control	-0.55	2.10	114	143	-3.06*	0.0027
Experiment	0.32	1.55	56			

Note. *p < 0.05

Factor 3 (Size factor).

The descriptive data of the average scores of the Size factor and the t-test results are listed in Table 16 and Table 17, respectively. The data of the gain scores and the statistics are listed in Table 18. Similar to the Composition factor, there were no significant differences of the average scores or the gain scores between the experimental and the control groups in the pretest and in the posttest.

Table 16

Average Scores of Size Factor in ParNoMA

Group	Pretest			Posttest		
	M	SD	n	M	SD	n
Control	2.40	1.58	114	2.46	1.61	114
Experiment	2.07	1.74	56	2.45	1.58	56

Table 17

t-test for the Average Scores of Size Factor in ParNoMA

ParNoMA	df	t	p
Pretest	168	1.25	0.2410
Posttest	168	0.04	0.9704

Table 18

Gain Scores of Size Factor in ParNoMA

Group	M	SD	n	df	t	p
Control	0.05	1.60	114	168	-1.20	0.2305
Experiment	0.38	1.72	56			

Summary

There is no difference in either the first or the second overall ParNoMA scores between the experimental group and the control group. The gain scores are significantly different between the two groups. The factor analysis categorized the items in ParNoMA into three groups or factors. Each factor corresponds to a chemical concept. The relation between these factors and the groups of questions designed by Yeziarski et al. will be discussed in Chapter V. The scores of the Motion-Energy factor are significantly

different between the two groups and so are the gain scores. There are no significant differences in the other two factors, either the scores or the gain scores.

Examinations

There were four monthly examinations in this general chemistry course. The two topics in this study, kinetics (Unit 1) and equilibrium (Unit 2) were tested in the first two exams. The first exam only included units 1 and 2; the second exam included these two units plus two other units covered since the first exam. The questions in units 1 and 2 of the second exam were parallel to those in the first exam. Each unit contained 10 multiple-choice questions. Five points were assigned to a student if this student chose the correct answer to a question; otherwise, zero points were assigned to that question. Therefore, the total scores of each unit were between 0 and 50 points.

Students were free to retake one, two, or none of the Unit 1 and Unit 2 in the second exam. Because the reason why students retook these two units might be different, we decided not to compare the average scores of the second exam. In spite of this, we were still interested in the comparison of the gain scores between the two groups. Every subject's score of each unit in the two exams is listed in Appendix G. Only students who took both the exams are included.

The the average scores and the gain scores of each group in Unit 1 and Unit 2, including the descriptive data and the t-test results, are listed in Tables 19 through 22.

Table 19

Average scores of Unit 1 in Exam 1

Group	M	SD	n	df	t	p
Control	27.44	10.52	80	228	1.04	0.2990
Experiment	25.90	10.75	150			

Table 20

Gain Scores of Unit 1 in Exams

Group	M	SD	n	df	t	p
Control	-4.00	14.11	80	228	-0.75	0.4530
Experiment	-2.57	13.60	150			

Table 21

Average Scores of Unit 2 in Exam 1

Group	M	SD	n	df	t	p
Control	27.86	9.07	112	260	1.31	0.1908
Experiment	26.37	9.12	150			

Table 22

Gain Scores of Unit 2 in Exams

Group	M	SD	n	df	t	p
Control	0.49	15.83	112	260	-1.15	0.2493
Experiment	2.63	14.09	150			

In summary, there were no significant differences of the average scores between the experimental and control groups in the first exam, either Unit 1 or unit 2, and there was no difference of the gain scores between the two groups, either.

Conceptual Quiz

In the experimental group, 160 students answered the two open-ended questions in the conceptual quiz, while 69 students in the control group took this quiz. When answering the two open-ended questions, the experimental and the control groups showed a similar pattern in writing chemical equations or explaining chemical phenomena using their own words. In both groups, most students were able to write chemical equations and predict shifts of equilibriums correctly; most students used a single arrow (\rightarrow) instead of a double arrow (\rightleftharpoons) when they wrote the chemical equation in Question 1.a. (see Chapter III and Appendix D); very few students were willing to explain their reasons at the atomic and the molecular level, as they were asked to do (Question 2. and Question 1.c.).

However, we found some interesting differences between the two groups by looking at how students drew boxes on the graph in Question 1.b. When asked to draw boxes at equilibrium, 76.88% of experimental group students correctly drew boxes at Time 1 or Time 3, or both, which is correct, as shown in Figure 4. Only 49.28% of the control group students drew them correctly. On the other hand, 30.43% of the control group students drew a box incorrectly at Time 2 as in Figure 5. For the experimental group, only 11.25% students drew a box at Time 2.

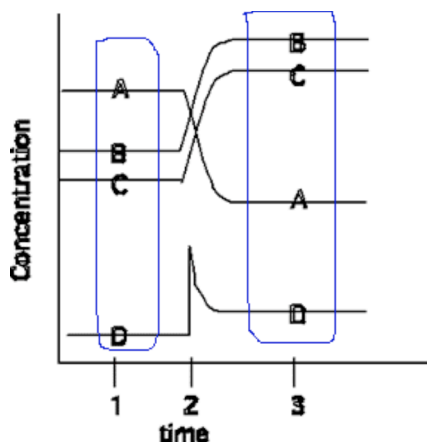


Figure 4. Draw boxes correctly on the graph in the conceptual quiz

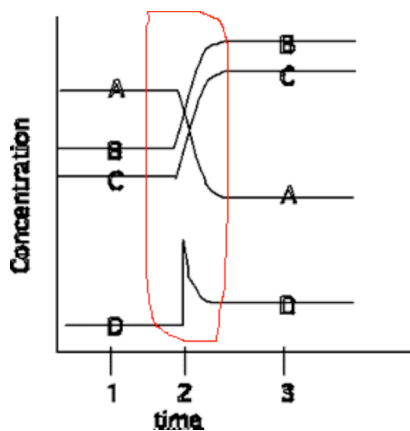


Figure 5. Incorrectly draw boxes at time 2 on the graph in the conceptual quiz.

The numbers and ratios of students who drew one box or two boxes correctly are listed in Table 23. The results of Pearson's chi-square (X^2) test are listed in Table 24. The numbers and ratios of the students who drew one or more boxes at Time 2 and the statistical results are listed in Table 25. The Pearson's chi-square test showed significant

differences between the experimental and the control groups in both situations. The ratios are also shown in Figure 6 and Figure 7, respectively.

Table 23

Numbers and ratios of students drawing boxes correctly in the conceptual quiz

Group	Total	two boxes	one box
Control	69	17 (24.63%)	17 (24.63%)
Experiment	160	48 (30.00%)	75 (46.88%)

Table 24

Pearson's chi-square test of students drawing boxes correctly

	Yes	No	Qp	p (of Qp)
Control	34 (49.28%)	35 (50.72%)	17.0365*	<0.0001
Experiment	123 (76.88%)	37 (23.12%)		

Note. Qp = Pearson chi-square (X^2). *p < 0.05

Table 25

Numbers and ratios of students drawing boxes at Time 2 in the conceptual quiz

	Yes	No	Qp	p (of Qp)
Control	21 (30.43%)	48 (69.57%)	11.2364*	0.0008
Experiment	18 (11.25%)	142 (88.75%)		

Note. Qp = Pearson chi-square (X^2). *p < 0.05

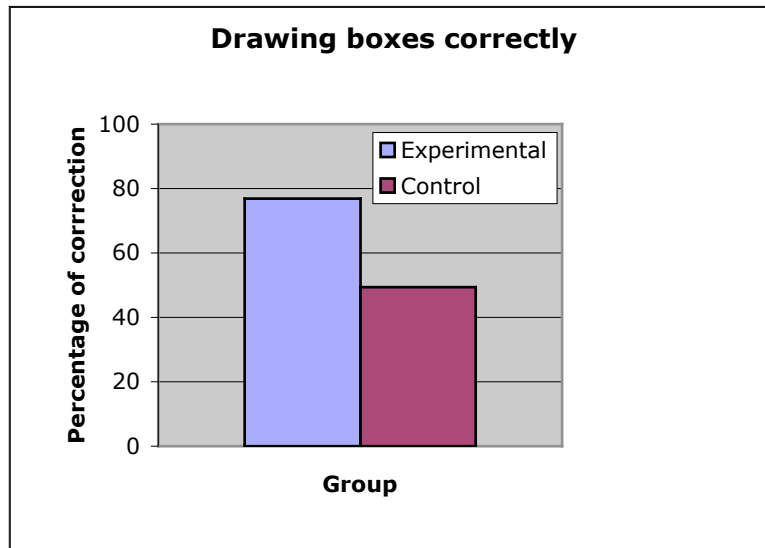


Figure 6. Ratios (%) of students drawing boxes correctly in the conceptual quiz.

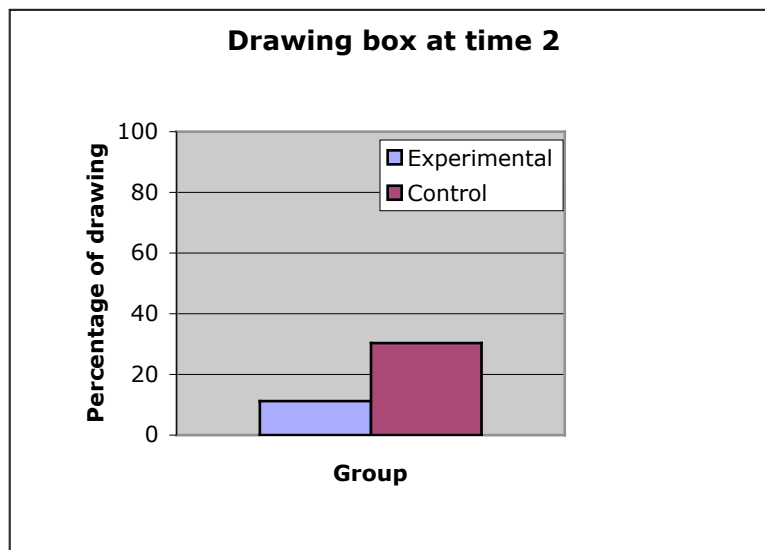


Figure 7. Ratios (%) of Students Drawing Boxes at Time 2 in the Conceptual Quiz

In summary, students in the two groups performed similarly when answering verbal questions in the conceptual quiz, e.g., when they wrote chemical equations or gave explanations in their own words. But the experimental group understood and answered the graphic questions significantly better than the control group did.

Attitude – BAR

Seventy-three students in the experimental group and 114 students in the control group took the BAR survey. Every subject's choice of each question in the BAR is listed in Appendix H. Their comments are not included in the appendix.

The overall scores of each group in the BAR and the statistics are shown in Table 26. The t-test indicated that there was no significant difference between the experimental and the control groups. The overall scores of both groups are equal to or above 53.50. That means the average score for each of the 12 questions is about 4.5. Because 4 is the median of the seven-point scale, the responses in both groups can be considered slightly positive.

Table 26

Overall scores of BAR

Group	M	SD	n	df	t	p
Control	53.50	11.68	114	185	-0.20	0.8412
Experiment	53.88	13.74	73			

We did a factor analysis of the 12 questions in BAR to understand the patterns of our students' responses. The statistics identified three factors, or three groups of questions.

The first factor contained four questions; the second factor contained six questions; the third factor contained two questions. Each of the 12 questions with the loading on each factor is listed in Table 27. The criterion 0.30 was used as the cutoff of the factor loadings. In other words, a question was categorized to a factor if that factor loading was greater than 0.30 (shaded cells in Table 27). There are two questions (questions 6 and 11) that had loadings greater than 0.30 in two factors. In this case, we chose the higher factor loadings. These two questions, along with question 12, will be discussed later in this chapter and the next chapter.

Table 27

Rotated Factor Pattern of BAR Questions

Question	Factor1	Factor2	Factor3
1	0.9330	0.1131	0.0177
2	0.9177	0.1284	-0.0240
3	0.3488	0.6242	0.0265
4	0.7374	0.1666	0.0217
5	0.0469	0.7434	0.1700
6	0.4955	0.5614	-0.0100
7	0.2542	0.6113	0.1540
8	0.5594	0.2393	0.1818
9	0.1545	0.6394	0.2849
10	0.1478	0.7007	0.2961
11	-0.1508	0.4176	0.4796
12	0.1538	0.2269	0.8417

Note. Extraction Method: prinit
Rotation Method: varimax

By looking at the characteristic of each question in BAR, we derived three different kinds of attitude associated with each factor or each set of questions. Each factor contained a group of questions with the same concept(s). Questions in factor 1 were about students' contentment or satisfaction, that is, how students felt about the activities.

For example, question 1 – pleased, and question 2 – satisfied. Questions in factor 2 were all about comprehension, that is, how students felt about their understanding of the activities. For example, question 5 – work is easy, and question 7 – I understand the question. Questions in factor 3 could be considered as neutral items, because question 11 asked whether the contents of the activities were old or new; question 12 asked whether the activities moved too quickly or too slowly. Table 28 summarizes the group of questions and the name of each factor.

Table 28

Summary of Factors in BAR

Factor	Name	Question	Number of questions
1	Contentment	1,2,4,8	4
2	Comprehension	3,5,6,7,9,10	6
3	Neutral	11,12	2

The factor loadings of question 6 (whether activities were in order or mix up) in both the Contentment factor and the Comprehensive factor are close to 0.5. This indicates that question 6 could be assigned to both of these two factors. Similarly, question 11 (whether activities were new or old) could be assigned to both the Comprehensive factor and the Neutral factor. Williamson (1992) regarded question 12 (whether activities moved too fast or slowly) as contributing to both Contentment and Comprehensive factors. Therefore, the results of the factor analysis in this study are consistent with the previous work.

The average scores of each factor in the BAR and the statistics are shown in Tables 29, 30, and 31, respectively. The t-test indicated that there were no significant differences between the experimental and the control groups in any factor.

Table 29

Average scores of Contentment factor in BAR

Group	M	SD	n	df	t	p
Control	17.06	5.80	114	185	0.67	0.5064
Experiment	16.47	6.22	73			

Table 30

Average scores of Comprehensive factor in BAR

Group	M	SD	n	df	t	p
Control	28.82	6.86	114	185	-0.26	0.7975
Experiment	29.10	7.88	73			

Table 31

Average scores of Neutral factor in BAR

Group	M	SD	n	df	t	p
Control	7.62	2.46	114	185	-1.85	0.0661
Experiment	8.32	2.56	73			

In summary, students' attitudes toward both computer activities were positive. The factor analysis extracted three factors from students' responses in this study. These three factors agreed with previous work.

CHAPTER V

DISCUSSION AND CONCLUSIONS

ParNoMA

As shown in Chapter IV, there is no difference in the first ParNoMA scores between the experimental group and the control group. This supports the assumption that the two groups were equivalent in their abilities to understand the particulate nature of matter before the treatment. The overall mean scores on the pretest and the posttest were 13.92 and 14.05, respectively (N = 170). In the research of Yeziarski, et al (2006), the overall mean scores were 10.31 on the pretest and 12.85 on the posttest when the participants consisted of students in middle school, high school and college general chemistry, while the mean score was 15.2 in a pilot study when the subjects were at the beginning of a second semester general chemistry. Therefore, the results in our research are reasonable. In addition, compared to the significant increase from 10.31 to 12.85 in Yeziarski's study, the change of the mean scores in our research was very small. The reason might be that if college students had already taken first semester general chemistry, it would be difficult to improve their basic understanding of particulate nature of matter measured by an assessment such as ParNoMA.

On the other hand, the gain scores of ParNoMA in our study showed a significant difference between the experimental the control groups. The factor analysis indicated that this difference came from the understanding of the concepts of particulate motion and energies needed during phase changes.

Recall that when Yeziarski et al. (2006) designed ParNoMA, they intended to evaluate these concepts: sizes of atoms and molecules, weights of atoms and molecules, compositions of molecules, phase changes, and energies in phase change. We found through the factor analysis that weight can be combined with size, perhaps because both weight and size describe physical properties of substances; while phase changes, including energies involved during phase changes, can be considered phenomena related to molecular motion. Therefore, the concepts that the factor analysis identified matched that of Yeziarski. We also recognized that the composition and size factors are associated with static phenomena of atoms and molecules, while motion and energy factors are associated with the dynamic nature of particles. Because there were no differences in the two static concepts, but the dynamic concept favored the experimental group, the results of ParNoMA imply that animations at the molecular level, such that the experimental group experienced, helped students visualize dynamic chemical phenomena.

The factor analysis method discussed above is one of two basic exploratory factor analysis approaches. The other is called principal components analysis. The difference between these two approaches is that principal components analysis “assumes that each variable is equally as important as the others and has the same amount of interrelatedness with the other variables”; while factor analysis utilizes the idea that “in most cases, some variables are more important than others, have stronger relationships with the variables in

the analysis than others, or are measured with less error than others” (Cody & Smith, 2006, p. 331). This is the reason why some researchers do not think principal components analysis is equivalent to factor analysis. When performing factor analysis in SAS, an extra statement, *priors smc*, needs to be added to the *proc factor* procedure used by principal components analysis. This means the communalities on the main diagonal will be less than one in factor analysis, while all the communalities used in principal components analysis are ones (Cody & Smith, 2006).

We performed a principal components analysis and obtained the five factors listed in Table 32.

Table 32

Rotated factor pattern of ParNoMA questions by using principal components analysis

Question	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	0.07108	0.07329	0.37591	0.08363	0.10837
2	0.08206	0.11266	0.38108	0.07923	0.21989
3	0.31373	0.56885	0.14064	0.00995	-0.08352
4	0.50115	0.29596	0.18249	0.04545	-0.26217
5	0.64801	0.27021	0.21580	0.01253	-0.01668
6	0.39342	0.65149	0.21266	0.02047	-0.00245
7	0.77456	0.17910	0.02692	0.03329	-0.07727
8	0.73558	0.16599	0.05066	0.07752	0.13871
9	0.57322	0.17219	0.13070	0.13782	0.38841
10	0.08870	0.08019	0.35945	0.02883	-0.13334
11	0.62084	0.15406	0.21486	0.11555	-0.05634
12	0.13595	0.05354	0.24501	0.65280	0.07218
13	0.11088	0.16957	0.56830	0.17128	0.19013
14	0.19310	0.80842	0.13298	0.00498	0.08870
15	0.65960	0.23728	0.03260	0.19049	0.10303
16	-0.00095	0.02892	0.64841	0.02293	-0.05625
17	0.10206	0.10318	0.57396	0.28200	-0.18546
18	0.08615	-0.03058	0.17101	0.66225	-0.00952
19	0.24889	0.70786	0.17538	0.05893	0.06277
20	0.18487	0.18528	0.39311	0.22625	-0.01378

Note. Extraction Method: prinit
Rotation Method: varimax

Because only one factor loading in the fifth factor is greater than 0.3, and the factor loading on the first factor for the same question is 0.57, we discarded this factor. The questions included in each of the four factors are listed in Table 33.

Table 33

Summary of factors from principal components analysis

Factor	Name	Question	Number of questions
1	Composition	4,5,7,8,9,11,15	7
2	Size	3,6,14,19	4
3	Motion	1,2,10,13,16,17,20	7
4	Energy	12,18	2

Compared to the results given by the factor analysis, the principal components analysis separated the energy and the motion factors (concepts). Otherwise the two analyses are the same.

Research on the effectiveness of animated over static graphics has shown that students exposed to computer animations performed significantly better in the exams and demonstrated better conceptual understanding than students who only viewed computerized static representations (Williamson & Abraham, 1995; Aldahmash, 1995; Kelly, Rhelps & Sanger, 2004). However, Tversky, Morrison and Betrancourt (2002) have argued that in studies concluding animations superior to static representations, the animated graphics and the static ones were not comparable. On the other hand, animations were ineffective in other studies because the animations did not obey design principles.

This research has suggested that viewing animated representations of chemical phenomena aids students' abilities to visualize atomic and molecular actions.

Examinations

For both Unit 1 and Unit 2, there were no significant differences for the average scores between the experimental and the control groups in the first content exam. Although the gain scores of the experimental group were always higher than that of the control group (Table 20 and Table 22), the differences were not significant.

As mentioned in Chapter I, we were interested in both students' performance and conceptual understanding as shown in exams. However, the computer activities in the experimental and control treatments focused on how students described their understanding of chemical conceptions, and most of the questions in the activities were open-ended (Appendices A.1 – A.6). However, all the unit examinations were multiple-choice questions, and calculations were involved in most of these questions (Appendices C.1 and C.2). Thus, the unit examinations probably did not provide a suitable platform to assess students' conceptual understanding.

College students can solve abstract problems in general chemistry by memorizing and by using their arithmetic abilities. In other words, it is possible for students to solve algorithmic problems without understanding chemical concepts (Painarbasi & Canpolat, 2003; Williamson, 1992, p. 70). Conversely, understanding conceptions is believed to be critical to problem solving. When students learn conceptions well, they are often able to better problem solvers (Herron, 1996, p. 103-104). Kozma and Russell (1997) have

suggested that in addition to multiple-choice problems, assessments should require open-ended questions that ask students to transform their conceptual understanding from symbolic forms to linguistic forms.

Conceptual Quiz

As discussed in Chapter III, the textbook used in both experimental and control classes had graphics showing the relationship between concentration and time that were similar to the time-concentration graphic in the first question of the conceptual quiz (see Figure 3). These graphic representations were also covered in their lecture classes. However, students in the experimental group were exposed to dynamic representations of the graphics, whereas the control group only saw static ones. The ParNoMA results discussed in Chapter IV suggested that animations of chemical phenomena might help students' visualization. This may explain why more experimental group students correctly drew the boxes on the graph in question 1.b. in the conceptual quiz than did the control group students.

Among these students, 50% in the control group and 60% in the experimental group only drew one box (Table 23). Most of them drew a box at Time 3 instead of at both Times 1 and 3. Eight students in the experimental group only drew a box at Time 1, and none of the control group student did so. This may be because of a misconception that there was no reaction at Time 1 until the stress is added. For example, question 1.c. asks "why do the concentrations of [A], [B], [C] change as they do at time=2". When answering this question, a student who drew one box at Time 3 circling all the chemicals

(A, B, C, and D) explained “(because) the reaction has started (at time=2)”. Perhaps this is the reasoning of other students who did not circle the graph at time=1.

The importance of students’ graphing skills in scientific education has been addressed in the last two decades. Graphing skills include visualizing graphs, interpreting graphs, constructing graphs, and connect graphs with other forms of representation. Real-time graphing during laboratories, including computerized laboratories or computer animations, improves students’ abilities to visualize representations and to understand concepts. It is especially effective when the laboratories are inquiry-based and graphs are dynamically displayed (Dori & Sasson, 2008).

Compared to algebraic skills, students’ graphic skills are often deficient. Lack of graphic abilities impedes students’ performance in chemistry learning. Therefore, these two skills should be connected in science teaching. Teachers should cultivate students’ graphic skills and motivate students to apply the skills to disciplines such as chemistry (Potgieter, Harding, & Engelbrecht, 2008).

Attitude – BAR

The Contentment and Comprehensive factors of the BAR in this study (Tables 27 and 28) were consistent with the factors identified in previous work (Abraham & Renner, 1983, 1986; Williamson, 1992; Amiot, 2007). We also performed a principal components analysis and obtained two factors. The factor loadings are listed in Table 34. The questions in each factor are summarized in Table 35.

Table 34

Rotated Factor Pattern of BAR Questions by using principal component analysis

Question	Factor1	Factor2
1	0.07765	0.94681
2	0.08489	0.90812
3	0.59921	0.35850
4	0.16756	0.73423
5	0.77274	0.09841
6	0.49317	0.51657
7	0.63008	0.23043
8	0.25271	0.62662
9	0.69376	0.14822
10	0.73429	0.17388
11	0.58769	-0.05300
12	0.49161	0.20365

Note. Extraction Method: prinit
Rotation Method: varimax

Table 35

Summary of Factors in BAR from principal component analysis

Factor	Name	Question	Number of questions
1	Comprehension	3,5,7,9,10,11,12	7
2	Contentment	1,2,4,6,8	5

As we can see, these two factors are identical as the factors in Chapter III. The results are also consistent with previous work (Williamson, 1992; Abraham & Renner, 1983, 1986).

The results in Chapter IV show that most students' attitudes toward the computer activities were either neutral or positive when we looked at their choices, and students in the two groups had a similar pattern of selecting the answers. Students were also asked to write whether they liked or dislike the computer activities including the reasons and what aspects of the activities they liked or disliked. In the experimental group, many students

stated that the computer activities helped them visualize chemical representatives (at the molecular level). Here are some comments from some experimental group students:

Student 2: I liked using the computer labs more so I can visualize what is going on in the molecular level.

Student 29: I liked being able to see the models of the reactions in the computer labs. It helped me to visualize what was going on in reactions.

Student 38: Concerning computer lab activities I liked the simulations best.

Student 51: The animations helped me to better understand what was actually going on in the reaction.

Student 57: I liked that it was nice to see reactions happening.

Student 65: I liked that it was visual.

Students 73: I like working on these computer lab activities and it presents the material in a different sort of way that is easy to grasp the concept and understand.

Although some students in the control group also mentioned visualization when they explained why they liked the computer activities, the most frequent reason stated was because they thought the activities were interesting and easy or not difficult:

Student 8: The unit seemed very interesting.

Student 9: The computer labs are easy activities. They are a lot more helpful than labs.

Student 34: Some things were interesting.

Student 54: I liked that these computer activities were not very difficult.

Student 65: Easy to understand than chemical lab.

Student 68: I liked best that it was not that hard.

When students listed some aspects of the computer activities that they liked, almost every student in both groups would also write one or more negative comments. Some students did not like the math/calculation part in the activities; some thought the computer activities were not connected to the exams. The most common complaints were that the time spent on the activities was too long and the activities were repetitive and tedious. Some experimental group students wrote:

Student 29: I disliked the repetitiveness of some of the exercises.

Student 45: The unit was very long and had to be split up to finish in time. I don't understand why it must take a long time to illustrate a concept.

Student 61: The computer activities can be too long and tedious sometimes. It's best when they are short and to the point.

Student 62: The computer activities can be too long and tedious sometimes.

Student 65: I disliked the length of the assignments.

Here are some comments from the control group:

Student 52: I least liked the tedious busy work that the computer labs seemed to entail; they are long and drawn out.

Student 54: I disliked the fact that they're extremely tedious.

Student 65: Sometimes very redundant.

In summary, many students in the experimental group suggested that the computer models helped them visualize what happened to the molecules in chemical reactions. This agrees with the results of ParNoMA in this research. That is, the experimental group gained more from the computer animations than the control group did when considering the dynamic nature of the representations.

Compared to the experimental group, more students in the control group thought the computer animations were interesting and of only moderate difficulty. This may be because of the interfaces and the nature of questions in the animations. These laboratory simulations are more like a real chemistry laboratory than the MoLEs are. The former simulated apparatus and chemicals, as well as chemical/physical changes such as colors and sizes. There are also very few questions that students had to answer at the microscopic level.

Conclusions

1. By measuring students' understanding of the particulate nature of matter, this study showed that dynamic simulations at the microscopic level helped students visualize chemistry representations involving molecular motions.

2. The computer animations did not influence students' performance in the examinations. That means that students did not learn concepts related to chemical kinetics and chemical equilibrium better with simulation and animation activities at the microscopic level in this study. However, this might be because of a disconnection between the content of the simulations and the items in the exams.

3. In both groups, most students had positive or non-negative attitudes toward computer animations. Students who did computer activities that focused on the microscopic level concluded that the animations aided them in visualizing chemistry phenomena; while students who did computer activities that focused on the macroscopic level thought the animations were interesting.

Suggestions for Future Research

1. Study the effects of two different types of computer animations on students' understanding of chemistry concepts. One type of animations is dynamic and the other is static. Both are either at the microscopic level or at the macroscopic level. These two types of animations should simulate the same concepts and have the similar questionnaires.

2. More open-ended questions should be designed to evaluate students' understanding of particulate nature of matter. Some questions would be directly related to the computer animations, some would not but only be associated with the studied conceptions.

3. To deeply investigate how students understand chemical concepts, interviews of selected subjects are necessary for further research.

4. Study the effectiveness of computer animations with other concepts in General Chemistry and other chemistry courses such as Physical Chemistry.

5. Study the effect of long-term exposure to computer animations and simulations in chemistry.

6. Study whether visualization in one content area can be transferred to other areas.

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APPENDICES

Appendix A.1

Mechanisms of a Chemical Reaction

Mechanisms of a Chemical Reaction

Name _____ Lab Section _____

Log on to the Internet. Type the following address into the location-input line of your browser:

<http://cheminfo.chem.ou.edu/~mra/CCL12004/KRGBM.htm>

This will load a Particulate Simulation. Once you have the simulation running your screen will look like what is shown in Figure 1 below. If you haven't already done so, read the Particulate Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

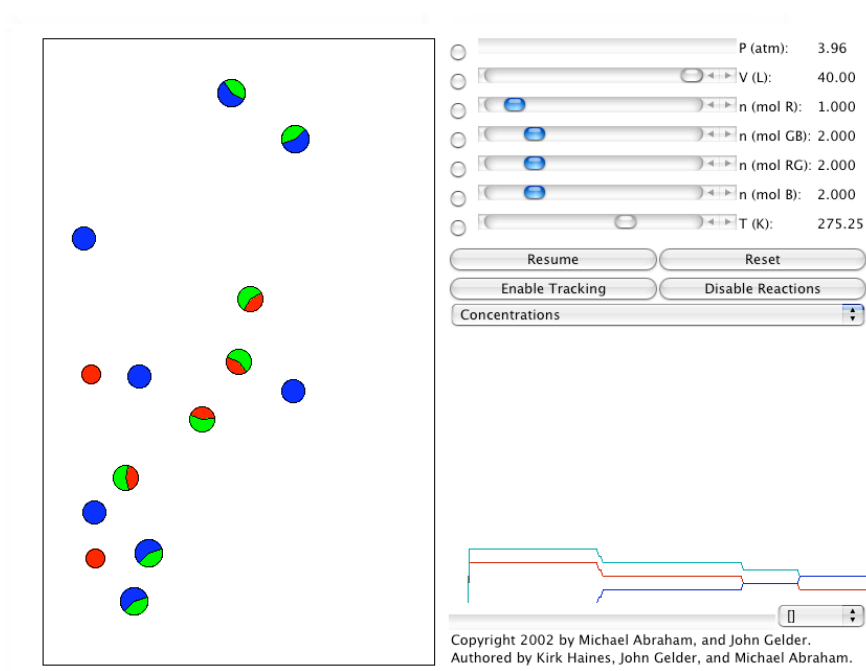


Figure 1.

Problem Statement: How does a chemical reaction proceed from reactants to products?

I. Data Collection:

Open the molecular simulation KRGBM:

<http://cheminfo.chem.ou.edu/~mra/CCLI2004/KRGBM.htm>

A. Based on what you observe in the sample region and control bar region of the screen, record the number and the concentration of R, BG, B, and RG particles in the table below.

	R	BG	B	RG
# of Particles				
Concentration (M)				

B. Click on the Resume button and then the Enable Reactions button and allow the simulation to run. Record your observations of what is happening. Use some or all of the following terms in your description: atom, molecule, particle, collision, effective collision, speed, energy, orientation, reactants, and products.

C. Allow the simulation to run until no more changes occur. Click on the Pause button and record your observations. Record the number and concentration of each kind of particle.

	R	BG	B	RG
# of Particles				
Concentration (M)				

II. Data Analysis and Interpretation:

A. Write a balanced equation for the reaction you have observed in this simulation.

B. Draw and label the appearance of the strip chart. Identify each kind of particle on the strip chart and explain what is happening to each over time.

C. What criteria did you use to decide the reaction was finished?

III. Data Collection:

Reset the simulation. Then click on the Resume and Enable Reactions buttons. Systematically observe multiple collisions between each of the possible combinations of pairs of the reactant and product particles (see the table below). Note when pairs of collisions result in a change. Use the following table to guide and record your observations. In order to aid your observations you can do the following: (a) change the amounts of the reactant and product particles, (b) use the Enable Tracking button with different particles, (c) use the replay option, (d) change the volume of the container, and (e) change the temperature of the sample.

Collisions Between					
Particle 1	Particle 2	Result	Speed	Orientation	Comments
R	R	No reaction	--	--	--
R	BG				
R	B				
R	RG				
BG	B				
BG	BG				
BG	RG				
B	B				
B	RG				
RG	RG				

IV. Data Analysis and Interpretation:

- A. Use the data from the table to write a balanced equation to represent your observations. Compare this equation with the one you wrote for section IIA.

- B. Even those collisions between particles that can result in a change don't do so 100% of the time. From your observations can you propose at least two different reasons why some collisions result in a change and others don't.

V. Conclusions:

In the boxes below draw pictures showing how a possible collision between reactant molecules might form product molecules for the KRGBM reaction. Make sure the orientation of the collision supports the arrangement of the atoms in the reactant and product molecules.

Reactants	Collision	Products

VI. Data Collection:

Open the molecular simulation K2GBM:

<http://cheminfo.chem.ou.edu/~mra/CCL12004/K2GBM.htm>

A. Based on what you observe in the sample region and control bar region of the screen, record the number and the concentration of R, BG, B, and RG particles in the table below.

	G	B	G ₂	GB	G ₂ B	B ₂
# of Particles						
Concentration (M)						

B. Click on the Resume button and then the Enable Reactions button and allow the simulation to run. Record your observations of what is happening.

- C. Allow the simulation to run until no more changes occur. Click on the Pause button and record your observations. Record the number and concentration of each kind of particle.

	G	B	G ₂	GB	G ₂ B	B ₂
# of Particles						
Concentration (M)						

VII. Data Analysis and Interpretation:

- A. Write an overall balanced equation to represent your observations.
- B. Draw and label the appearance of the strip chart. Identify each kind of particle on the strip chart and label what is happening to the particles at each change in the chart.
- C. What criteria did you use to decide the reaction was finished?

VIII. Data Collection:

- A. Use the simulation to design and carry out experiments to explore all of the possible collisions between reactant particles. In order to aid your observations you can do the following: (a) change the amounts of the reactant and product particles, (b) use the Enable Tracking button with different particles, (c) use the replay option, (d) change the volume of the container, and (e) change the temperature of the sample. Use the following table to guide and record your observations.

Reactant 1	Reactant 2	Result	Comments
B	B		
B	G		
G	G		

Describe the experiments you carried out.

Write the chemical equation(s) to summarize the experiments.

- B. In a manner similar to section VIII, A. design and carry out additional experiments to explore further all of the possible collisions between the product molecule(s) you identified from section VII. A. with the other reactant particles. Design and construct a table to record your observations.

Describe the experiments you carried out.

Write the chemical equation(s) to summarize the experiments.

IX. Conclusions

- A. Using the data you collected in part VIII, propose a step-by-step process (mechanism) showing how the reaction in the molecular simulation K2GBM proceeds from reactants to final products.
- B. An alternate possible mechanism for the reaction in the molecular simulation K2GBM is a one step process described by the following: $2G + B \rightarrow G_2B$. Why is this mechanism less likely than the one you proposed?

Appendix A.2

Shift Reaction A

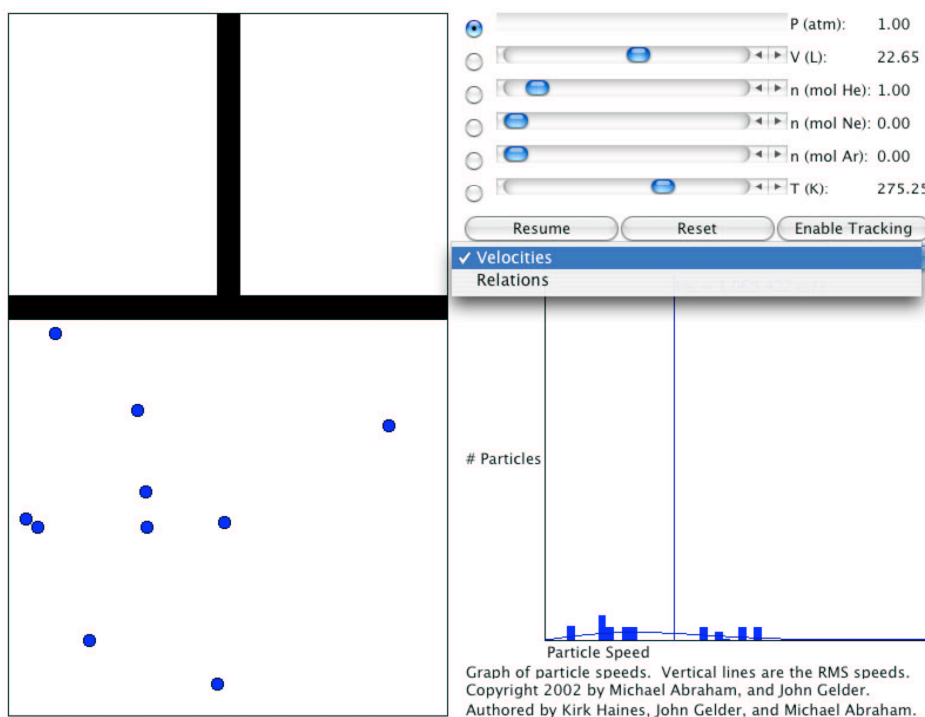
Shifting Reactions A

Name _____ Lab Section _____

Log on to the Internet. Type the following address into the location-input line of your browser:

<http://cheminfo.chem.ou.edu/~mra/CCLI2004/ERGBM.htm>

This will load a Particulate Simulation. Once you have the simulation running your screen will look like what is shown in Figure 1 below. If you haven't already done so, read the Particulate Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.



Problem Statement: What are the characteristics of a hypothetical chemical reaction?

I. Data Collection:

A. Open the Particulate Simulation. Use the pause button in the Control Bar region to stop the action of the particles. In the diagram below record the conditions of your sample as shown in the simulation.

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B. Use the reset button to refresh the screen. Determine the concentration (mol liter^{-1}) of each substance in the control bar region. (Show your work.) Click on the pause button to stop the motion of the particles. In the Control Bar region, change the number of moles of one of the substances present by adding one half a mole to the amount already there. Resume motion and describe what you observe in the strip chart and the Sample Window.

- C. Use the reset button to refresh the screen. Click on the Enable Reactions button. After a short period of time has elapsed click the Pause button. In the space below draw a picture of the strip chart. Label the lines of the strip chart with their identity (R, GB, RG, and B).
- D. Resume the action. Observe how the concentrations of the particles in the sample change over time. How can you tell when the reaction is completed? What particles are present when the reaction is completed?
- E. Use the reset button to refresh the screen. Use the pull down menu to change the graphical representation to the replay function. Click the Enable Reaction button to begin the reaction. Allow the reaction to proceed for a short period of time (10 sec – 20 sec). Click the Pause button. Scroll the time index bar back to the point where only the reactant particles are present. Click on the forward arrow to roll the reaction forward in a step-wise manner to the point where the first new particle appears. Explain, in detail, the nature of that interaction. Include drawings and specify the orientation of all of the atoms in the interaction.

II. Data Analysis:

Write a chemical equation representing the chemical interaction you observed.

III. Data Collection:

A. Use the reset button to refresh the screen and the pause button to stop the action. Using the controls in the Control Bar region, fix the amounts of R and GB at zero, of RG at 3, and B at 4. Set the graphics display to Concentrations, and resume the interaction. Calculate the concentrations of the particles. Calculate the initial concentrations of all the substances (R, GB, RG and B).

B. Click on the Enable Reactions button. When the reaction is complete, click on the Pause button. Calculate and record the final concentrations of all of the substances.

- C. Use the reset button to refresh the screen. Using the controls in the Control Bar region, fix the amounts of R and GB at zero, of RG at 3, and B at 4. Use the pull down menu to change the graphical representation to the replay function. Click the Enable Reaction button to begin the reaction. Allow the reaction to proceed for a short period of time (10 sec – 20 sec). Click the Pause button. Scroll the time index bar back to the point where only the reactant particles are present. Click on the forward arrow to roll the reaction forward in a step-wise manner to the point where the first new particle appears. Explain, in detail, the nature of that interaction. Include drawings and specify the orientation of all of the atoms in the interaction.

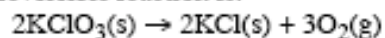
IV. Data Analysis:

- A. Write a chemical equation representing the chemical interaction you observed
- B. Compare and contrast the two equations you wrote in sections II. and IV. A.

V. Interpretation and Conclusions:

- A. Chemists refer to the type of reaction you have been investigating as a reversible reaction. Using the chemical system you investigated explain what is meant by reversible reaction.

- B. An example of a non-reversible reaction is:



What is meant when the term non-reversible is used to describe this reaction?

- C. When viewed at the macroscopic level in the laboratory, chemical reactions seem to stop after a period of time. How does this compare to your molecular observations in this activity? How do your observations at the molecular level explain what happens at the macroscopic level?

D. Mental Modeling: Using the Particulate Simulation program see if you can observe both chemical reactions studied in this activity to occur in the same window. Illustrate your observation by drawing a sequence of interactions that result in both reactions occurring sequentially.

E. Summarize in a few statements what are the characteristics of chemical reactions of the type studied in this activity.

Appendix A.3
Shift Reactions B

Shifting Reactions B

Name _____ Lab Section _____

Log on to the Internet. Type the following address into the location-input line of your browser:

<http://cheminfo.chem.ou.edu/~mra/CCLI2004/ERGBN.htm>

This will load a Graphics Simulation. Once you have the simulation running your screen will look like what is shown in Figure 1 below. If you haven't already done so, read the Graphics Simulation section of the Introduction to MoLEs Activities to learn how to use the simulation.

Control Panel:

- P (atm): 67.94
- V (L): 1.00
- n (mol R): 0.60
- n (mol BG): 0.70
- n (mol RG): 0.80
- n (mol B): 0.90
- T (K): 275.25

Buttons: Pause/Resume, Reset, Enable Reactions

Reaction Viewer: R + BG -> RG + B

Reactants: R, BG

Products: RG, B

Activation Energy: E act (kJ / mol) 5.00

Base Angle: Reactant A, Reactant B, Product A, Product B

Tolerance: Reactant A, Reactant B, Product A, Product B

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Authored by Kirk Haines, John Gelder, and Michael Abraham.

Figure 1.

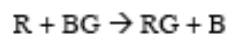
Name _____ Lab Section _____

Problem Statement: How can concentration changes affect a chemical reaction?

I. Data Collection:

- A. Open the Graphics Simulation program. Using the data from the Control Bar Region, enter the initial concentration of each substance in the equation, along with the initial pressure, volume and temperature into the table below.

EXPERIMENT #1:



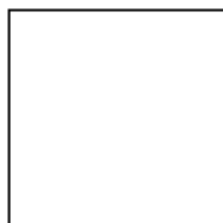
Initial Concentration – I	_____	_____	_____	_____
Concentration Change – C	_____	_____	_____	_____
Ending Concentration – E	_____	_____	_____	_____
Pressure	_____			
Volume	_____			
Temperature	_____			

- B. Click on the Resume and then the Enable Reactions button to begin the reaction. When the reaction appears to be complete, click Pause to stop the action. Record the values of the ending concentrations in the table in Section 1A. Calculate the change in concentration of each of the substances in the reaction. In the space below, draw the appearance of the strip chart and label the axes. If necessary, use the scrollbar located under the strip chart to move the chart back to the beginning of the reaction. Identify the chemical substance that corresponds to each of the colored lines.

II. Data Analysis and Interpretation:

- A. Mental Modeling: In the following boxes, draw pictures at the level of atoms and

molecules that represents the initial and ending states of the reaction?



Initial



Ending

B. Explain what is happening to each of the reactant and product substances over time. How does the strip chart illustrate the changes you observe?

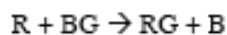
B. How can you tell when the reaction is complete? What substances are present when the reaction appears to be complete?

C. Considering the substances that are present when the reaction appears to be complete, why do the concentrations of the substances cease to change?

III. Data Collection:

- A. If necessary click Pause to stop the action. If you moved the strip chart scrollbar in the previous section, shift it back to as far to the right as it will go. Use the ending concentrations of BG, RG and B from Experiment #1 (Section 1A.) as the initial concentrations in this experiment. Enter those values in the table below. In the Control Bar Region add R until its concentration is 2.0 M. Record this initial concentration of R in the table below. Click the Resume button. Observe how the concentrations of the substances change over time. When the reaction appears to be complete click the Pause button. Record the values of the ending concentrations in this table and calculate the change in concentration of each of the substances in the reaction. Draw and label the appearance of the portion of the strip chart for this reaction. (NOTE: If necessary drag the Strip Chart scrollbar to the left.)

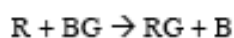
EXPERIMENT #2: Increase reactant R to 2.0 M



Initial Concentration – I	___	___	___	___
Concentration Change – C	___	___	___	___
Ending Concentration – E	___	___	___	___

- B. If you moved the strip chart scrollbar in the previous section, shift it back to as far to the right as it will go. Use the ending concentrations of R, RG and B from Experiment #2 as the initial concentrations in this experiment. Enter those values in the table below. In the Control Bar Region add BG until its concentration is 1.0 M. Record this initial concentration of BG in the table below. Click the Resume button. Observe how the concentrations of the substances change over time. When the reaction appears to be complete click the Pause button. Record the values of the ending concentrations in this table and calculate the change in concentration of each of the substances in the reaction. Draw and label the appearance of the portion of the strip chart for this reaction. (NOTE: If necessary drag the Strip Chart scrollbar to the left.)

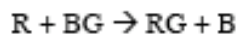
EXPERIMENT #3: Increase reactant BG to 1.0 M



Initial Concentration – I	___	___	___	___
Concentration Change – C	___	___	___	___
Ending Concentration – E	___	___	___	___

- C. In a manner similar to the previous experiments remove R until its concentration equal 0.75 M. Record the new initial conditions of all substances in the table below. Click the Resume button. Observe how the concentrations of the particles in the sample change over time. When the reaction is appears to be complete click the Pause button. Record the values of the ending concentrations in the table and calculate the change in concentration of each of the substances in the reaction. Draw and label the appearance of the portion of the strip chart for this reaction.

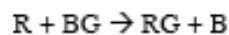
EXPERIMENT #4: Decrease reactant R to 0.75 M



Initial Concentration – I	___	___	___	___
Concentration Change – C	___	___	___	___
Ending Concentration – E	___	___	___	___

D. In a manner similar to the previous experiments add RG until its concentration is 2.0 M. Record the new initial conditions of all substances in the table below.

EXPERIMENT #5: Increase product RG to 2.0 M



Initial Concentration – I	___	___	___	___
Concentration Change – C	___	___	___	___
Ending Concentration – E	___	___	___	___

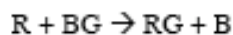
Before initiating the reaction draw what you think the Strip Chart Region will look like during this reaction in the box labeled Your Prediction.

Your Prediction:	Observation:
------------------	--------------

Click the Resume button. Observe how the concentrations of the particles in the sample change over time. When the reaction is appears to be complete click the Pause button. Record the values of the ending concentrations in the ICE table (above) and calculate the change in concentration of each of the substances in the reaction. Draw and label the appearance of the portion of the strip chart for this reaction in the Your Observation box.

- E. In a manner similar to the previous experiments remove RG until its concentration is 1.0 M. Record the new initial conditions of all substances in the table below.

EXPERIMENT #6: Decrease product RG to 1.0 M



Initial Concentration – I ___ ___ ___ ___

Concentration Change – C ___ ___ ___ ___

Ending Concentration – E ___ ___ ___ ___

Before initiating the reaction draw what you think the Strip Chart Region will look like during this reaction in the box labeled Your Prediction.

Your Prediction:	Observation:
------------------	--------------

Click the Resume button. Observe how the concentrations of the particles in the sample change over time. When the reaction is appears to be complete click the Pause button. Record the values of the ending concentrations in the ICE table (above) and calculate the change in concentration of each of the substances in the reaction. Draw and label the appearance of the portion of the strip chart for this reaction in the Your Observation box.

IV. Data Analysis and Interpretation:

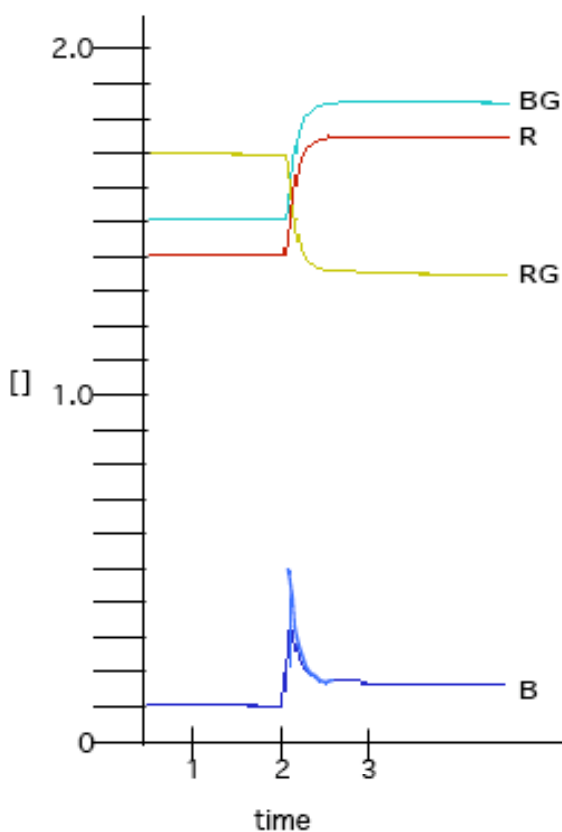
A. Summarize your observations of Experiments #3 - #6 by completing the table below. As an example, the entries for Experiment #2 have been done for you.

Experiment	Stress	Change in [Reactants]	Change in [Products]	Reaction shift
#2	Add reactant [R]	Concentrations decreased	Concentrations increased	Left to Right
#3				
#4				
#5				
#6				

B. Consider the strip chart recording on the right for a hypothetical experiment.

What was the stress placed on the reaction at time 2?

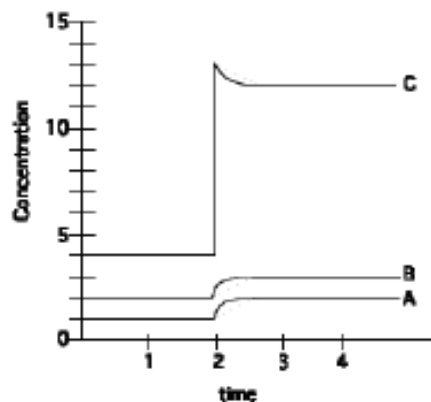
Write an equation to describe this reaction, then set up and complete all the entries in an ICE table.



V. Conclusions:

A. Review the summary of your experimental observations that you prepared in Section IVA. Write a statement(s) that generalizes how stressing a reaction by adding or removing a reactant or product shifts the chemical reaction.

B. Mental Modeling: Consider the strip chart recording on the right for a hypothetical experiment. Write an equation to describe this reaction, then set up and complete all the entries in an ICE table.



In the following boxes, draw pictures at the level of atoms and molecules that represents the progress of the hypothetical experiment from $t=1$ to $t=2$ to $t=3$. Indicate those particles that are added or subtracted from the sample as a result of the stress placed on the system.

time = 1	time = 2	time = 3

If you were to make a drawing for time = 4, how would it be similar to the drawing you made for time = 3? How would it be different?

Appendix A.4

Concentration/Temperature Effects

Concentration/Temperature Effects

Name _____ Lab Section _____

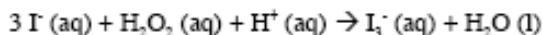
Problem Statement: How do concentration and temperature influence the rate of a chemical reaction?

I. Data Collection:

- A. Go to <http://cheminfo.chem.ou.edu/~mra/home.html> and open the Concentration/Temperature Effects Simulation. Your screen should look like the figure.

The reaction to be investigated occurs in the beaker when four colorless solutions from four graduated cylinders are mixed. Different amounts of the solutions can be added together at different specified temperatures. Radio buttons control these amounts and the temperature. A timer can be used to monitor how long it takes for the chemical reaction to proceed to the same level of completeness as the standard solution contained in a second beaker.

The chemical interactions that takes place is:



The reactant solutions are colorless. The product, I_3^- , is colored. As the reaction proceeds, the intensity of the color increases, indicating that the concentration of the products is increasing. The reaction is slow enough so that the time it takes to get to predetermined color intensity, and therefore a specific I_3^- concentration, can be conveniently timed. A standardized solution is available so that the colors can be matched.

- B. If necessary, use the buttons to adjust the volume of the reactant solution to the amounts shown in the following table. Notice that the volume of water is adjusted so that sum of all the solutions when combined equals 100 mL. Make sure the temperature is set at 25°C. Click on the start button. When the last solution is added, Click to start the timer. Pause the timer when the reaction solution changes to a color that matches the color of the standard solution. Record your data.

Trial	H ₂ O (l)	0.010 M H ₂ O ₂ (aq)	1.0 M HCl (aq)	0.050 M KI (aq)	Time @ 25 °C
1	60 mL	10 mL	20 mL	10 mL	
2					
3					
4					
5					
6					
7					
8					

- C. Design trials to test the effect that changing the concentration of each of the reactants has on the rate of the reaction by varying the amounts of the reactants. Try and minimize the number of trials tried. Record the conditions of each trial in the table above. Remember to adjust the amount of water so that each trial has 100 mL of total solution. Enter the parameters of each trial in the simulation and determine the amount of time it takes for each trial to reach the standard color. Record your data in the above table.

II. Data Analysis and Interpretation

- A. From the data you collected in the table from section I. B. calculate the molar concentrations of H_2O_2 , $[\text{H}_2\text{O}_2]$, H^+ , $[\text{H}^+]$, and I^- , $[\text{I}^-]$, for each trial and record your results in the following table.

Trial	$[\text{H}_2\text{O}_2]$	$[\text{H}^+]$	$[\text{I}^-]$	Rate @ 25 °C
1				
2				
3				
4				
5				
6				
7				
8				

- B. The rate of a chemical reaction is inversely proportional to the amount of time it takes for the reaction to happen. (If it takes half the amount of time its rate is twice as big.) Calculate the average rate of each trial (time^{-1}) and record your results in the preceding table.
- C. Relate the change in $[\text{H}_2\text{O}_2]$ to the change in average rate. How are they related? Are the changes directly proportional? What trials did you use to come to your conclusions?
- D. Relate the change in $[\text{H}^+]$ to the change in average rate. How are they related? Are the changes directly proportional? What trials did you use to come to your conclusions?

- E. Relate the change in $[I^-]$ to the change in average rate. How are they related? Are the changes directly proportional? What trials did you use to come to your conclusions?

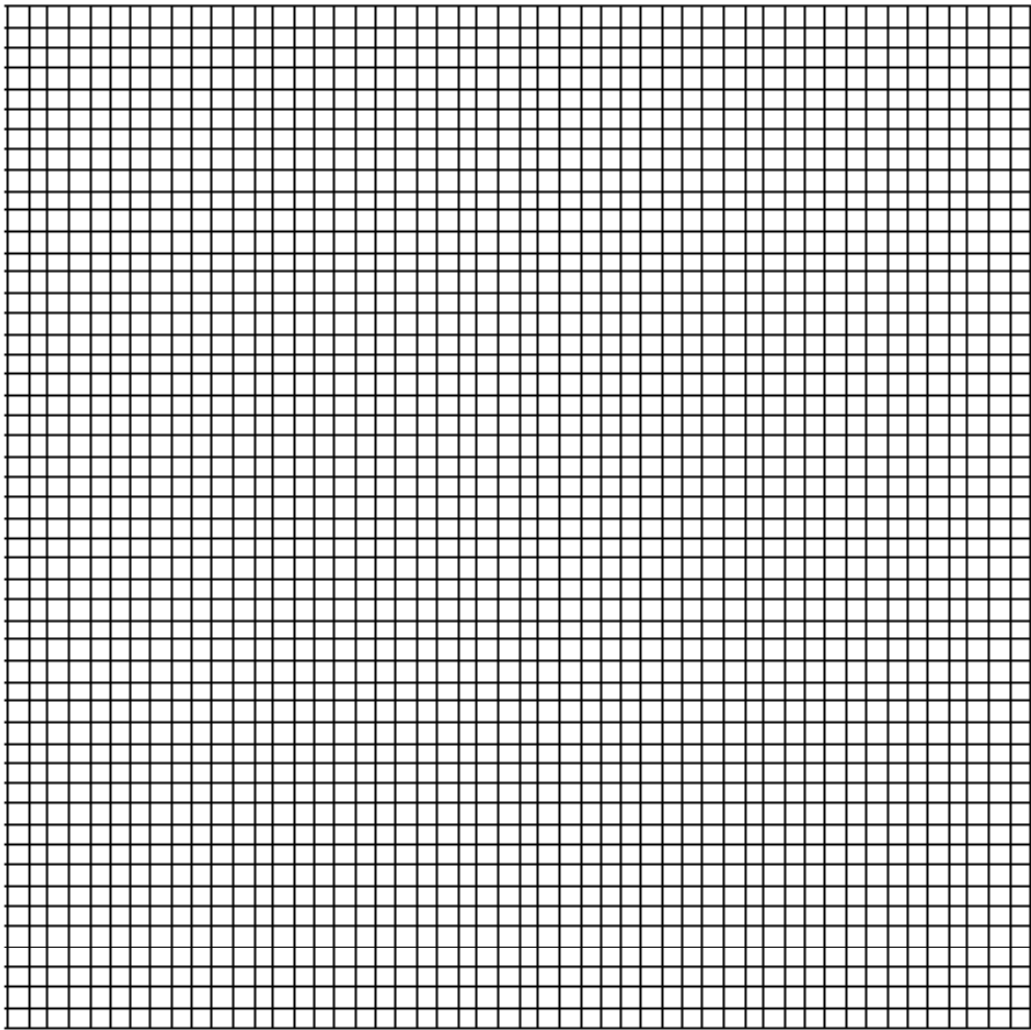
III. Data Collection:

Using the concentrations of trial 1 from section I. B. copy the rate for 25 °C into the following table. Repeat the experiment using the trial 1 concentrations at each of the specified temperatures. Calculate and record the rates in the following table.

Trial	$[H_2O_2]$	$[H^+]$	$[I^-]$	Rate @ 5 °C	Rate @ 15 °C	Rate @ 25 °C	Rate @ 35 °C	Rate @ 45 °C
1								

IV. Data Analysis and Interpretation

On the following graph, or using a graphing program, plot the relationship between the temperature of the reactants and the rate of the reaction in trial 1. What happens to the rate of a chemical reaction as the temperature changes? What is the nature of this relationship? Are the changes directly proportional? (Optional. How are they related mathematically? Using a graphing program plot the amount of rate vs. the temperature. Then use the curve fitting function of your graphing program to draw the best line through all of the points. Try each of the available functions and see which gives you the best fit. Record the equation of your best-fit line.)



V. Conclusions

A. Make a generalization of how concentration changes affect the rate of a chemical reaction.

B. Make a generalization of how temperature changes affect the rate of a chemical reaction.

Appendix A.5

Decomposition of H_2O_2

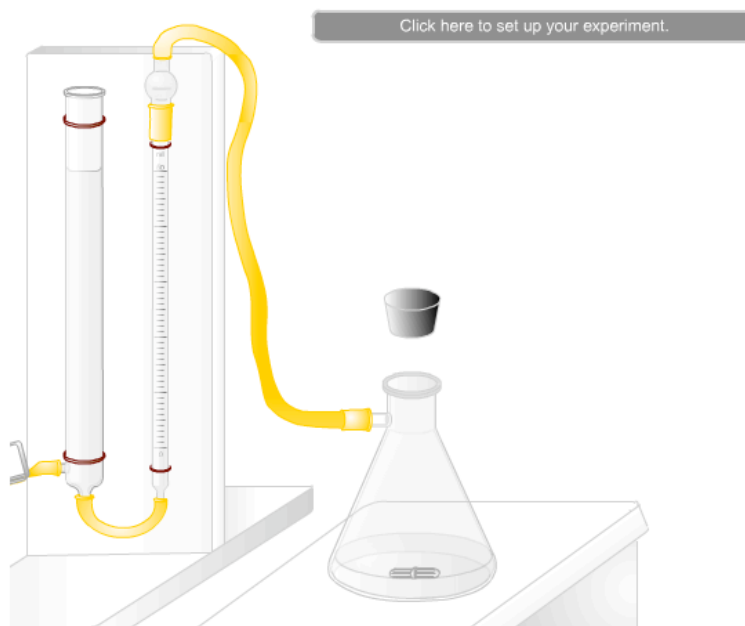
Decomposition of H₂O₂

Name _____ Lab Section _____

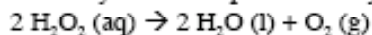
Problem Statement: How do catalysts influence the rate of a chemical reaction?

I. Data Collection:

- A. Go to <http://cheminfo.chem.ou.edu/~mra/home.html> and open the Decomposition of H₂O₂ Simulation. Your screen should look like the figure.



The apparatus is used to study the decomposition of hydrogen peroxide:



A flask is attached to a gas-measuring device that monitors the generation of oxygen gas. The rate at which oxygen gas is produced by the chemical reaction is a measure of the rate of the chemical reaction. Click on the gray rectangle to set up the reaction conditions. You will be asked to specify the amount of 3% H₂O₂, what potential catalyst you will try, and the amount of catalyst. Radio buttons control the amounts. Water is automatically added to make all of the solutions have equal total volumes. When you click on the start button, a magnified view of the graduated gas-measuring device allows you to see how

much gas is being collected over time. You can also click onto graphs that plot the generation of O_2 gas or the consumption of H_2O_2 solution. Try this out to see how this works.

- B. Reset the apparatus. Measure the rate of the dissociation of 5.0 mL of uncatalyzed H_2O_2 .

To do this click on the set up rectangle, choose 5 mL of H_2O_2 , choose 0.5 M KI, and choose 0 mL.

You have several options for timing the reaction: (1) Use a stopwatch to time how long it takes for a specified amount of O_2 gas to be produced. Express this as an average rate (in mL per second). Click on the start button and start the stopwatch at zero gas and stop the stopwatch at the specified volume. (2) Use the O_2 plot to see how long it takes to generate a specified amount of O_2 gas. Click on the Plot O_2 button to view the graph. Use the graph to determine the average rate by determining the slope of a straight line drawn between zero and the specified volume of gas. Record your data in the following table.

	Rate with KI (mL/sec)		Rate with KCl (mL/sec)		Rate with $FeCl_3$ (mL/sec)	
	0 mL	2mL	0 mL	2mL	0 mL	2mL
5 mL H_2O_2						
10 mL H_2O_2						

- C. Repeat the experiment for all of the conditions specified in the above table and record your results. Sketch the plot for the generation of O_2 when 2 mL of KI is added to 5 mL of H_2O_2 .

II. Data Analysis and Interpretation

- A. Use the plot from section I. C. to describe what happens to the rate of this reaction as the reaction proceeds.
- B. Relate the change in $[H_2O_2]$ to the change in average rate. How are they related? Are the changes directly proportional?
- C. Which of the substances you added to H_2O_2 acted as a catalyst? Which was the best catalyst? What ion (ions) was (were) responsible for the catalytic effect? How did you eliminate other ions?

Appendix A.6

Acid/Base pH

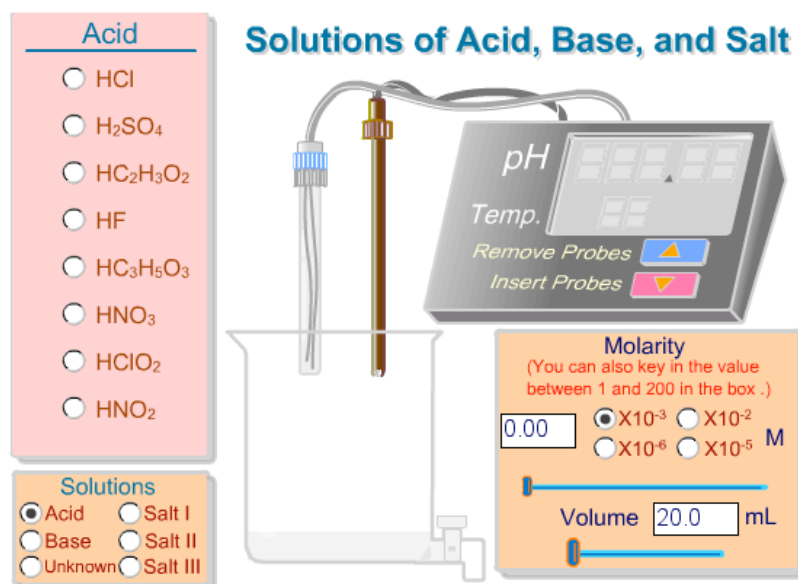
Acid/Base pH

Name _____ Lab Section _____

Problem Statement: What are the acid and base properties of solutions?

I. Data Collection:

- A. Go to <http://cheminfo.chem.ou.edu/~mra/home.html> and open the Acid/Base pH Simulation. Your screen should look like the figure.



This simulation contains a pH meter. You can test the pH of strong and weak acid, base and salt solutions of different concentrations. You will set up the conditions of each measurement using the radio buttons and then insert the pH probes into the solution to obtain the pH of the solution.

- B. Under the acid solutions, choose HCl. Set the concentration of the solution at 1.00×10^{-2} M (use the slider bar or key in 1.00 and then the radio button). Set the volume at 100 mL (use the slider bar). Click on the Insert Probes button on the pH meter. Enter your pH data in the following table.

Solution	Concentration (M)	pH	$[H^+]$
HCl (aq)	1.00×10^{-2}		
HCl (aq)	1.00×10^{-3}		
HCl (aq)	1.00×10^{-5}		
HCl (aq)	1.00×10^{-6}		

- C. Remove the probes. Adjust the conditions of your measurements and measure the pH of each of the concentrations for the HCl solutions in the above table and enter the pH data you obtain.

II. Data Analysis and Interpretation

- A. pH is defined by the equation: $pH = -\log [H^+]$. Calculate the $[H^+]$ for each of the conditions in the table in the previous section and record your results in the table.
- B. Compare the $[H^+]$ with the original concentration of HCl. What does this tell you about the amount of HCl present in the solution? What is the percentage of HCl that has reacted when it is dissolved in water? (Acids that have this characteristic are called strong acids.)
- C. Write an equation representing the reaction when HCl is dissolved in water.

III. Data Collection:

- A. Under the acid solutions, choose $\text{HC}_2\text{H}_3\text{O}_2$. Set the concentration of the solution at 1.00×10^{-2} M (use the slider bar or key in 1.00 and then the radio button). Set the volume at 100 mL (use the slider bar). Click on the Insert Probes button on the pH meter. Enter your pH data in the following table.

Solution	Concentration (M)	pH	$[\text{H}^+]$
$\text{HC}_2\text{H}_3\text{O}_2$ (aq)	1.00×10^{-2}		
$\text{HC}_2\text{H}_3\text{O}_2$ (aq)	1.00×10^{-3}		
$\text{HC}_2\text{H}_3\text{O}_2$ (aq)	1.00×10^{-5}		
$\text{HC}_2\text{H}_3\text{O}_2$ (aq)	1.00×10^{-6}		

- B. Remove the probes. Adjust the conditions of your measurements and measure the pH of each of the concentrations for the $\text{HC}_2\text{H}_3\text{O}_2$ solutions in the above table and enter the pH data you obtain.

IV. Data Analysis and Interpretation

- A. Calculate the $[\text{H}^+]$ for each of the conditions in the table in the previous section and record your results in the table.
- B. Compare the $[\text{H}^+]$ with the original concentration of $\text{HC}_2\text{H}_3\text{O}_2$. What does this tell you about the amount of $\text{HC}_2\text{H}_3\text{O}_2$ present in the solution? What is the percentage of $\text{HC}_2\text{H}_3\text{O}_2$ that has reacted when it is dissolved in water? (Acids that have this characteristic are called weak acids.)
- C. Write an equation representing the reaction when $\text{HC}_2\text{H}_3\text{O}_2$ is dissolved in water.

V. Data Collection:

- A. Under the acid solutions, choose H_2SO_4 . Set the concentration of the solution at 1.00×10^{-2} M (use the slider bar or key in 1.00 and then the radio button). Set the volume at 100 mL (use the slider bar). Click on the Insert Probes button on the pH meter. Enter your pH data in the following table.

Solution	Concentration (M)	pH	$[\text{H}^+]$
H_2SO_4 (aq)	1.00×10^{-2}		
H_2SO_4 (aq)	1.00×10^{-3}		
H_2SO_4 (aq)	1.00×10^{-5}		
H_2SO_4 (aq)	1.00×10^{-6}		

- B. Remove the probes. Adjust the conditions of your measurements and measure the pH of each of the concentrations for the H_2SO_4 solutions in the above table and enter the pH data you obtain.

VI Data Analysis and Interpretation

- A. Calculate the $[\text{H}^+]$ for each of the conditions in the table in the previous section and record your results in the table.
- B. Compare the $[\text{H}^+]$ with the original concentration of H_2SO_4 . What does this tell you about the amount of H_2SO_4 present in the solution? What is the percentage of H_2SO_4 that has reacted when it is dissolved in water? Is H_2SO_4 a strong or weak acid?

C. Write an equation representing the reaction when H_2SO_4 is dissolved in water.

VII. Data Collection and Analysis:

A. Using the procedure of the previous sections, measure the pH of $1.00 \times 10^{-2} \text{ M}$ concentrations of each of the acids in the list. Record your findings in the following table.

Solution	Concentration (M)	pH	$[\text{H}^+]$	Strong/Weak
HCl (aq)	1.00×10^{-2}			
H_2SO_4 (aq)	1.00×10^{-2}			
$\text{HC}_2\text{H}_3\text{O}_2$ (aq)	1.00×10^{-2}			
HF (aq)	1.00×10^{-2}			
$\text{HC}_3\text{H}_5\text{O}_3$ (aq)	1.00×10^{-2}			
HNO_2 (aq)	1.00×10^{-2}			
HClO_2 (aq)	1.00×10^{-2}			
HNO_3 (aq)	1.00×10^{-2}			

B. Calculate the $[\text{H}^+]$ of each solution and classify each acid as weak or strong. Enter your findings in the previous table.

VIII. Data Collection:

A. Under the base solutions, choose NaOH. Set the concentration of the solution at $1.00 \times 10^{-2} \text{ M}$ (use the slider bar or key in 1.00 and then the radio button). Set the volume at 100 mL (use the slider bar). Click on the Insert Probes button on the pH meter. Enter your pH data in the following table.

Solution	Concentration (M)	pH	$[\text{H}^+]$	$[\text{OH}^-]$
NaOH (aq)	1.00×10^{-2}			
NaOH (aq)	1.00×10^{-3}			
NaOH (aq)	1.00×10^{-5}			
NaOH (aq)	1.00×10^{-6}			

B. Remove the probes. Adjust the conditions of your measurements and measure the pH of each of the concentrations for the NaOH solutions in the above table and enter the pH data you obtain.

IX. Data Analysis and Interpretation

- A. Calculate the $[H^+]$ for each of the conditions in the table in the previous section and record your results in the table.

- B. In a water solution the $[H^+]$ is related to the $[OH^-]$ by the following equation:

$$10^{-14} = [H^+][OH^-]$$

Use this equation to calculate the $[OH^-]$ of the NaOH solutions. Enter your results in the previous table.

- C. Compare the $[OH^-]$ with the original concentration of NaOH. What does this tell you about the amount of NaOH present in the solution? What is the percentage of NaOH that has reacted when it is dissolved in water? Is NaOH a strong or weak base?

- D. Write a chemical equation to represent what happens when NaOH dissolves in water.

X. Data Collection and Analysis:

- A. Using the procedure of the previous sections, measure the pH of $1.00 \times 10^{-2} \text{ M}$ concentrations of each of the bases in the list. Record your findings in the following table.

Solution	Concentration (M)	pH	$[\text{H}^+]$	$[\text{OH}^-]$	Strong/Weak
NaOH (aq)	1.00×10^{-2}				
KOH (aq)	1.00×10^{-2}				
NH_3 (aq)	1.00×10^{-2}				
$\text{Ca}(\text{OH})_2$ (aq)	1.00×10^{-2}				
$(\text{CH}_3)_2\text{NH}$ (aq)	1.00×10^{-2}				
$\text{C}_2\text{H}_5\text{NH}_2$ (aq)	1.00×10^{-2}				
HONH_2 (aq)	1.00×10^{-2}				

- B. Calculate the $[\text{H}^+]$ and $[\text{OH}^-]$ of each solution and classify each base as weak or strong. Enter your findings in the previous table.

Appendix B

Particulate Nature of Matter Assessment (ParNoMA), 2nd Version

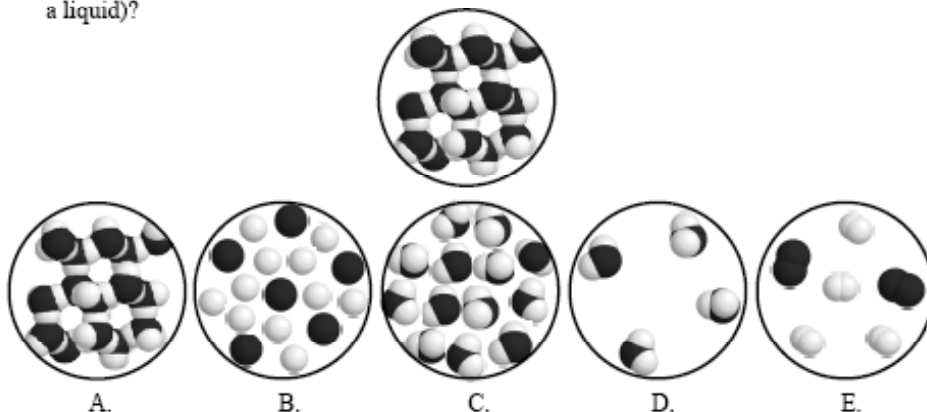
**Particulate Nature of Matter Assessment (ParNoMA)
Version 2**

Instructions:

Carefully read each question and choose the best answer.

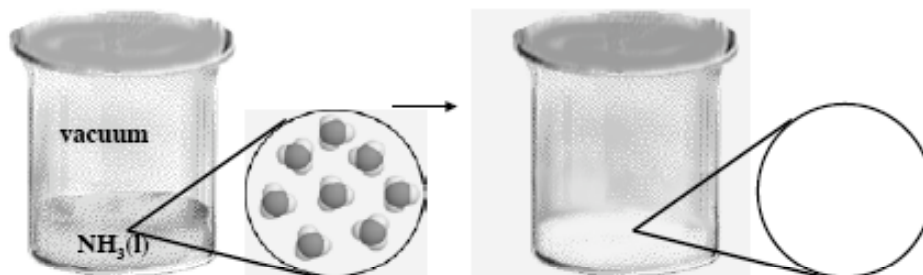
1. A diagram representing water molecules in the solid phase (ice) is shown below.

Which of these diagrams best shows what water would look like after it melts (changes to a liquid)?

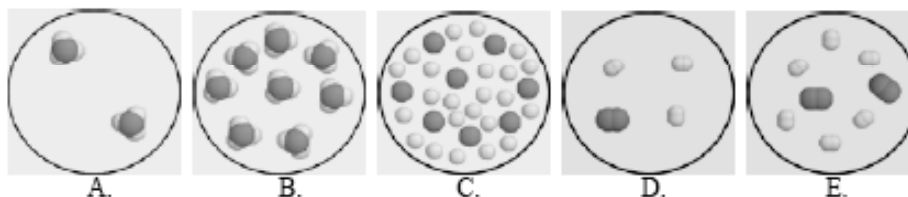


2. Consider three samples of water in three phases. The first is solid water (ice) at 0°C , the second is liquid water at 24°C , and the third is gaseous water at 100°C . The water molecules in the liquid phase _____ the water molecules in the gaseous phase.
- A. move faster than
 - B. move slower than
 - C. move at the same speed as
 - D. move more randomly than
 - E. travel in the same direction as
3. Which of the following processes will make water molecules larger?
- A. freezing
 - B. melting
 - C. evaporation
 - D. condensation
 - E. none of the above

4. A sample of liquid ammonia (NH_3) is completely evaporated (changed to a gas) in a closed container as shown:



Which of the following diagrams best represents what you would “see” in the same area of the magnified view of the vapor?



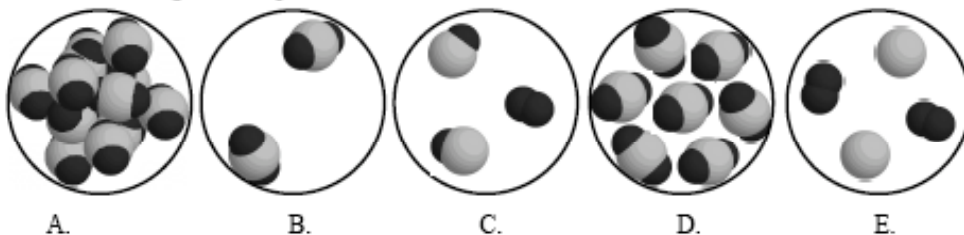
5. When water changes from a liquid to a gas through evaporation or vaporization, energy is required to
- break the bonds between the hydrogen atoms.
 - form new bonds between the atoms.
 - break the bonds between the oxygen and hydrogen atoms in the molecules.
 - break the water molecules away from other water molecules.
 - form new bonds between the molecules.
6. A water molecule in the gas phase is _____ a water molecule in the solid phase.
- smaller than
 - lighter than
 - heavier than
 - larger than
 - the same weight as
7. When water is vaporized, it is changed to
- hydrogen and oxygen
 - hydrogen only
 - gaseous water
 - air, hydrogen, and oxygen
 - oxygen only

8. A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear. What are the bubbles made of?
- A. heat
 - B. air
 - C. gaseous oxygen and hydrogen
 - D. gaseous water
 - E. none of the above
9. A pot of water on a hot stove begins to boil rapidly. A glass lid is placed on the pot and water droplets begin forming on the inside of the lid. What happened?
- A. The lid became sweaty.
 - B. Steam cools and water molecules moved closer together.
 - C. Water from outside leaked into the pot.
 - D. Hydrogen and oxygen combined to form water.
 - E. Steam combined with the air to wet the inside of the lid.
10. Consider three samples of water in three phases. The first is solid water (ice) at 0°C , the second is liquid water at 24°C , and the third is gaseous water at 100°C . The water molecules in the liquid phase _____ the water molecules in the solid phase.
- A. move faster than
 - B. move slower than
 - C. move at the same speed as
 - D. move less randomly than
 - E. travel in the same direction as
11. A wet dinner plate is left on the counter after it has been washed. After awhile it is dry. What happened to the water that didn't drip onto the counter?
- A. It changes to carbon dioxide.
 - B. It just dries up and no longer exists as anything.
 - C. It goes into the air as molecules of water.
 - D. It goes into the plate.
 - E. It changes to oxygen and hydrogen in the air.
12. Which of the following processes does NOT require heat energy?
- A. evaporating water
 - B. melting ice
 - C. boiling water
 - D. vaporizing water
 - E. condensing water

13. When water molecules in the gas phase are heated, the molecules themselves
- expand.
 - move faster.
 - become less massive.
 - change to a liquid.
 - release air.
14. Which of the following processes will make molecules smaller?
- freezing
 - melting
 - evaporation
 - condensation
 - none of the above
15. Oxygen and hydrogen gases may be formed from liquid water through the process of
- vaporization.
 - evaporation.
 - decomposition.
 - freezing.
 - boiling.
16. A diagram representing carbon dioxide molecules in the solid phase, also known as dry ice, is shown below.



Which of these molecular diagrams best shows what dry ice would look like after it melts (changes to a liquid)?



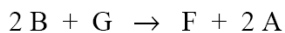
17. When water at 25°C is heated and changes to a gas at 110°C, the water molecules
- A. become more organized.
 - B. move farther apart.
 - C. stop moving.
 - D. move closer together.
 - E. move more slowly.
18. Which of the following processes requires heat energy?
- A. condensation
 - B. freezing
 - C. evaporation
 - D. cooling
 - E. none of the above
19. A water molecule in the liquid phase is _____ a water molecule in the solid phase.
- A. smaller than
 - B. lighter than
 - C. heavier than
 - D. larger than
 - E. the same weight as
20. When water at 24°C is cooled to 0°C and freezes, the water molecules
- A. become less organized.
 - B. move much faster.
 - C. stop moving.
 - D. break apart.
 - E. move much more slowly.

Appendix C.1

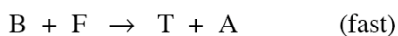
Exam 1

Unit 1 - Kinetics

1. The reaction



is known to follow the mechanism



From this, we know that

- A. E and T are both intermediates
 - B. E is an intermediate and T is a catalyst
 - C. The rate for the reaction is $\text{rate} = k [\text{B}]^2 [\text{G}]$
 - D. The rate for the reaction is $\text{rate} = k [\text{E}][\text{T}]$
 - E. E and T are both catalysts
2. The rate of formation of Z under a given set of conditions is 0.042 M s^{-1} for the reaction



Under the same conditions, what is the rate of loss of A (M s^{-1})?

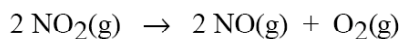
- A. 0.126 B. 0.028 C. 0.014 D. 0.063 E. 0.042
3. The reaction



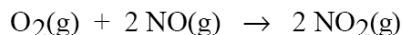
shows a rate of 0.014 M/min when the initial concentrations of both A and B are 0.10 M . When $[\text{A}]_0 = 0.20 \text{ M}$ and $[\text{B}]_0 = 0.10 \text{ M}$, the reaction rate is 0.014 M/min . When $[\text{A}]_0 = 0.10 \text{ M}$ at $[\text{B}]_0 = 0.20 \text{ M}$, the reaction rate is 0.056 M/min . What is the order of this reaction with respect to A and B, respectively?

- A. 0 and 2 B. 0 and 1 C. 1 and 1 D. 1 and 2 E. 2 and 2

4. The reaction

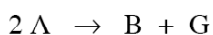


is known to have an activation energy of 82 kJ/mol and a standard change in enthalpy of 28 kJ/mol at some temperature. At the same temperature, what are the ΔH° and E_a values (kJ/mol), respectively, for the reaction below?



- A. 28 and 82 B. -28 and 110 C. 28 and 110 D. -28 and 54 E. 28 and 54

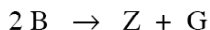
5. The rate constant is 0.0143 M/min for the zero order reaction



If we begin this reaction with $[\text{A}]_0 = 0.200 \text{ M}$, what is the concentration of the reactant (M) after 11.8 min of reaction progress?

- A. 14.1 B. 0.19 C. 0.031 D. 0.17 E. 350

6. The reaction



shows a rate constant of 0.0488 min^{-1} at 36°C when $[\text{B}]_0 = 0.200 \text{ M}$. What is the half-life (hr) of this reaction under these conditions?

- A. 860 B. 0.034 C. 0.24 D. 2.05 E. 14.2

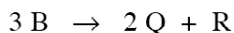
7. The half-life for the second order reaction



is 46.2 days when $[\text{A}]_0 = 0.114 \text{ M}$. How long (d) would be required to reduce an initial concentration of A of 0.0580 M to 20% of this value?

- A. 15 B. 23 C. 108 D. 38 E. 363

8. The reaction



has a rate constant of 0.0683 y^{-1} at 48.6 K. What is the half-life (y) for this reaction at 48.6 K if $[\text{B}]_0 = 0.774 \text{ M}$?

- A. 5.7 B. 3.3 C. 0.693 D. 19 E. 10

9. A reaction is catalyzed by Br_2 at 48°C . In the presence of Br_2 , the rate constant is $4.43 \times 10^{-6} \text{ M s}^{-1}$. In the absence of Br_2 , the rate constant is $1.984 \times 10^{-10} \text{ M s}^{-1}$. If the activation energy for the uncatalyzed reaction is 136 kJ/mol , what is the activation energy (kJ/mol) for the catalyzed reaction?

A. 136 B. 109 C. 140 D. 132 E. 162

10. The first order reaction

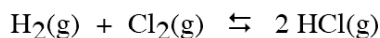


has a half-life of 85.0 min when $[\text{NH}_3]_0 = 0.300 \text{ M}$. Under the same conditions, what is the concentration of $\text{NH}_3(\text{M})$ after 30 min of reaction if $[\text{NH}_3]_0 = 0.803 \text{ M}$?

A. 0.63 B. 0.41 C. 0 D. 25.5 E. 0.039

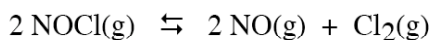
Unit 2 - Equilibrium

11. Suppose the following reaction is at equilibrium at a given temperature and pressure. The pressure is then increased at constant temperature, by compressing the reaction mixture, and the mixture is allowed to re-establish equilibrium. At the new equilibrium _____.



- A. there is more hydrogen chloride than there was originally
B. there is less hydrogen chloride than there was originally
C. there is the same amount of hydrogen chloride as there was originally
D. the hydrogen and chloride are completely used up
E. the amount of hydrogen chloride may be either larger or smaller than it was originally, depending on the value of K

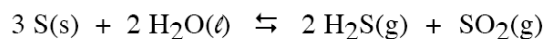
12. Consider the following reaction:



If a sample of $\text{NOCl}(\text{g})$ is allowed to equilibrate in a container, and the equilibrium concentrations of $\text{NOCl}(\text{g})$, $\text{NO}(\text{g})$, and $\text{Cl}_2(\text{g})$ are 0.968 mol/L , 0.0318 mol/L , and 0.0159 mol/L , respectively, what is the value of K_c for this reaction?

- A. 5.40×10^{-4} B. 5.22×10^{-4} C. 1.85×10^3
D. 1.72×10^{-5} E. 2.70×10^{-4}

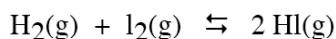
13. For the reaction:



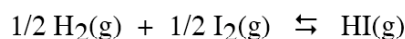
which of the following is the accepted expression for the equilibrium constant K_c ?

- A. $[\text{H}_2\text{S}]^2 [\text{SO}_2]$ B. $\frac{[\text{H}_2\text{S}]^2 [\text{SO}_2]}{[\text{S}]^3 [\text{H}_2\text{O}]}$ C. $\frac{[\text{H}_2\text{S}]^2}{[\text{SO}_2] [\text{H}_2\text{O}]}$ D. $[\text{H}_2\text{S}] [\text{SO}_2]$ E. $\frac{[\text{H}_2\text{S}]^2 [\text{SO}_2]}{[\text{H}_2\text{O}]}$

14. The value of K_c for the equilibrium



is 794 at 25°C. At this temperature, what is the value of K_c for

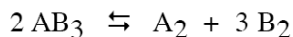


- A. 397 B. 0.035 C. 1588 D. 28 E. 0.0013
15. The value of K_c for the following reaction is 1.10 at 25.0°C. What is the value of K_p for this reaction?

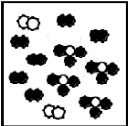
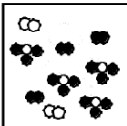
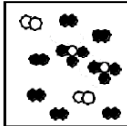
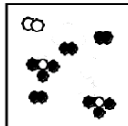
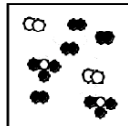


- A. 658 B. 37.2 C. 26.9 D. 4.63 E. 1.52×10^{-3}

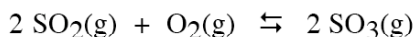
16. Consider the following hypothetical reaction:



Initially 6 molecules of AB_3 are placed in a reaction vessel. After a period of time, 2 molecules of A_2 are found in the vessel. Which of the following diagrams represents this final state?

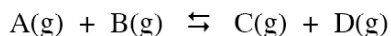
- A.  B.  C.  D.  E. 

17. The equilibrium constant for the reaction



is 11.7 at 1100 K. A mixture of SO_2 , O_2 and SO_3 , each with a concentration of 0.015 M, was introduced into a container at 1100 K. Which of the following is true?

- A. $[\text{SO}_3(\text{g})]$ will increase until equilibrium is reached.
 - B. $[\text{SO}_2(\text{g})]$ and $[\text{O}_2(\text{g})]$ will increase until equilibrium is reached.
 - C. $[\text{SO}_3] = 0.045 \text{ M}$ at equilibrium.
 - D. $[\text{SO}_3] = 0.015 \text{ M}$ at equilibrium.
 - E. $[\text{SO}_3] - [\text{SO}_2] - [\text{O}_2]$ at equilibrium.
18. The initial concentrations at 35°C in a reversible chemical reaction:



are: $[\text{A}] = [\text{B}] = 1.00 \text{ mol/L}$, and $[\text{C}] = [\text{D}] = 0 \text{ mol/L}$. After equilibrium is reached, the concentrations are : $[\text{A}] = [\text{B}] = 0.15 \text{ mol/L}$.

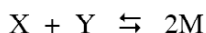
If the initial concentrations at 35°C were: $[\text{A}] = [\text{B}] = 0 \text{ mol/L}$ and $[\text{C}] = [\text{D}] = 1.00 \text{ mol/L}$, what would be the concentrations of A and B after equilibrium is reached?

- A. $[\text{A}] = [\text{B}] = 0.85 \text{ mol/L}$
 - B. $[\text{A}] = [\text{B}] = 0.15 \text{ mol/L}$
 - C. $[\text{A}] = [\text{B}] = 1.0 \text{ mol/L}$
 - D. $[\text{A}] = [\text{B}] = 0.00 \text{ mol/L}$
 - E. $[\text{A}] = [\text{B}] = 0.35 \text{ mol/L}$
19. Calculate the equilibrium partial pressure (atm) of BCl_3 in a 2.00 L container that was evacuated, then charged with 4.29 g of PH_3BCl_3 and allowed to come to equilibrium.



- A. 0.026
- B. 4.4
- C. 0.10
- D. 0.032
- E. 0.23

20. The reaction



has $K_c = 0.89$ at 672 K. At equilibrium, _____.

- A. products predominate substantially
- B. reactants predominate substantially
- C. roughly equal molar amounts of products and reactants are present
- D. only products exist
- E. only reactants exist

Appendix C.2

Exam 2

Unit 1 -- Kinetics

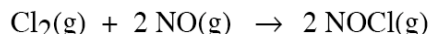
1. For a particular second order reaction, the rate constant, k , was determined at a variety of temperatures (k = rate constant, $^{\circ}\text{C}$ = temperature in Celsius, K = temperature in Kelvins). To obtain a linear graph, one should plot

A. k vs. $^{\circ}\text{C}$ B. $\log k$ vs. $^{\circ}\text{C}$ C. $\ln k$ vs. $1/\text{K}$
D. $\ln k$ vs. $1/^{\circ}\text{C}$ E. k vs. $1/\text{K}$

2. For a given second order reaction, the rate of the reaction is $0.300 \text{ mol}/(\text{L}\cdot\text{s})$ when the concentration of the reactant is 0.200 M . What is the rate constant ($\text{L}/(\text{mol}\cdot\text{s})$) for this reaction under these conditions?

A. 7.5 B. 3.0 C. 2.2 D. 1.5 E. 0.67

3. The reaction of chlorine and nitric oxide produces nitrosyl chloride:

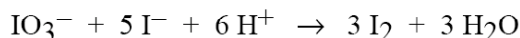


The following initial rates were obtained for this reaction at 89°C . What is the rate law for this reaction?

Exp't.	$[\text{NO}]_0, \text{M}$	$[\text{Cl}_2]_0, \text{M}$	Init. Rxn Rate $\text{M}\cdot\text{hr}^{-1}$
1	0.25	0.25	2.21
2	0.25	0.50	8.83
3	0.50	0.50	17.5

- A. rate = $k [\text{NO}][\text{Cl}_2]^2$ B. rate = $k [\text{NO}]^2[\text{Cl}_2]^2$
C. rate = $k [\text{NO}][\text{Cl}_2]$ D. rate = $k [\text{NO}]^2[\text{Cl}_2]$
E. rate = $k [\text{NO}]^{1/2}[\text{Cl}_2]$

4. For the aqueous reaction



the rate of disappearance of I^- under some unspecified conditions is $3.0 \times 10^{-3} \text{ M min}^{-1}$.

What is the rate of formation of I_2 (M min^{-1}) under the same conditions?

A. 6.0×10^{-4} B. 1.5×10^{-2} C. 1.8×10^{-3} D. 9.0×10^{-3} E. 1.0×10^{-3}

5. The radioactive isotope ^{188}W decays in a first order process with a rate constant of $1.00 \times 10^{-2} \text{ d}^{-1}$. How long (d) will it take to reduce an initial 3.84 mg sample of this isotope by 70.0%?

A. 150 B. 120 C. 90 D. 69 E. 36

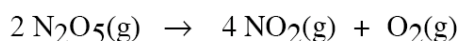
6. The rate for a chemical reaction is

$$\text{rate} = k [\text{ClO}_3^-][\text{I}^-][\text{H}^+]^2$$

If the time is measured in seconds, what are the appropriate units for k for this reaction?

A. $\text{mol} / (\text{L} \cdot \text{s})$ B. $\text{mol}^4 / (\text{L}^4 \cdot \text{s})$ C. $\text{L}^3 / (\text{mol}^3 \cdot \text{s})$
D. $\text{L}^4 / (\text{mol}^4 \cdot \text{s})$ E. $\text{L} / (\text{mol} \cdot \text{s})$

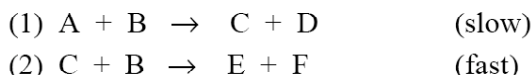
7. For the first order process



the rate constant of the reaction is given as $k = 1.5 \times 10^{-3} \text{ s}^{-1}$ at 55°C . We begin this reaction with 10.0 g of N_2O_5 in container 1 and 5.00 g of N_2O_5 in container 2. The containers are initially at the same temperature (55°C) and the same pressure. How much time is required to decompose one-half the original amount of N_2O_5 in each container?

A. container 1 requires twice as much time as container 2.
B. container 2 requires twice as much time as container 1.
C. container 1 requires three times as much time as container 2.
D. container 1 requires four times as much time as container 2.
E. container 1 requires the same amount of time as container 2.

8. A chemical reaction is known to be consistent with the two step mechanism:



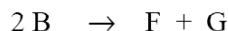
From this we know that the chemical reaction is:

A. $\text{A} + 2 \text{B} \rightarrow \text{D} + \text{E} + \text{F}$ B. $\text{A} + \text{C} \rightarrow \text{E} + \text{F}$
C. $\text{A} + \text{B} + \text{C} \rightarrow \text{D} + \text{E} + \text{F}$ D. $\text{A} + \text{B} \rightarrow \text{D} + \text{E} + \text{F}$
E. $\text{A} + \text{B} \rightarrow \text{C} + \text{D}$

9. For the reaction shown below at 30°C, $k = 5.1 \times 10^6 \text{ s}^{-1}$ and the activation energy is 54.0 kJ. What is the value of E_a (kJ) for the reverse reaction?



- A. 32.8 B. 28.6 C. 54.0 D. 25.4 E. 82.6
10. The zero order reaction

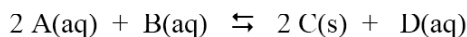


exhibits a 40.0% loss of reactant in 3.62 min when $[\text{B}]_0 = 0.0200 \text{ M}$ at 25°C. At the same temperature, what is the half-life (min) for this reaction if $[\text{B}]_0 = 0.0600 \text{ M}$?

- A. 7.5×10^3 B. 4.53 C. 4.91 D. 13.6 E. 3.14×10^2

Unit 2 -- Equilibrium

11. What is the equilibrium expression for the reaction:



- A. $\frac{[\text{D}]}{[\text{A}]^2[\text{B}]}$ B. $\frac{[\text{D}][\text{C}]}{[\text{A}][\text{B}]}$ C. $\frac{[\text{D}]}{[\text{A}][\text{B}]}$ D. $\frac{[\text{A}]^2[\text{B}]}{[\text{D}]}$ E. $\frac{[\text{D}][\text{C}]^2}{[\text{A}]^2[\text{B}]}$

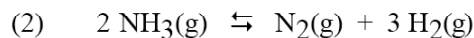
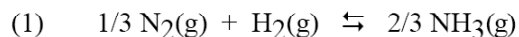
12. The equilibrium constant for the reaction below is 32 at 500 K. A mixture of BrCl,



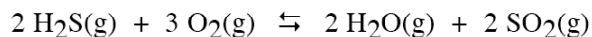
Br₂, and Cl₂ is introduced into a container at 500 K. If the initial concentrations of BrCl, Br₂, and Cl₂ in the container are 0.10, 2.2, and 2.2 M, respectively, which of the following is true?

- A. The reaction will proceed until all BrCl(g) is used up.
B. The reaction will initially proceed to the left, forming more BrCl(g).
C. The concentration of Br₂(g) will remain constant at 2.2 M.
D. The system is at equilibrium and therefore no net change will occur.
E. The reaction will initially proceed to the right, forming more products.

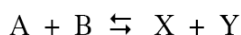
13. The equilibrium constant for reaction (1) is K . What is the equilibrium constant for reaction (2)?



- A. K^3 B. $3K$ C. $K/3$ D. $1/K^3$ E. $-K^3$
14. For the following reaction at 25°C , $K_c = 3.0 \times 10^5$. What is the numerical value of K_p ?



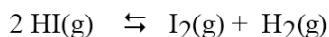
- A. 1.2×10^4 B. 8.2×10^{-5} C. 3.3×10^{-6} D. 3.0×10^5 E. 7.3×10^6
15. The reaction



has $K_c = 997$ at 472 K . At equilibrium, _____.

- A. products predominate.
B. reactants predominate.
C. roughly equal molar amounts of products and reactants are present.
D. only products exist.
E. only reactants exist.
16. For the **gas phase** reaction $\text{SO}_2 + \frac{1}{2} \text{O}_2 \rightleftharpoons \text{SO}_3$, $\Delta H^\circ = -1.6 \times 10^2 \text{ kJ}$ for the forward reaction. In order to increase the yield of SO_3 , the reaction should be run
- A. at high P, high T B. at high P, low T
C. at low P, high T D. at low P, low T
E. at high P, but is independent of T

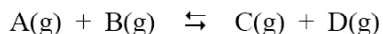
17. For the reaction



$K_c = 0.0198$ at 721 K . What is the concentration of HI (M) at 721 K if we are at equilibrium and $[\text{H}_2] = 0.012 \text{ M}$ and $[\text{I}_2] = 0.015 \text{ M}$?

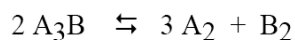
- A. 0.13 B. 0.033 C. 0.095 D. 0.0021 E. 0.0066

18. The initial concentrations at 15°C in a reversible chemical equation are

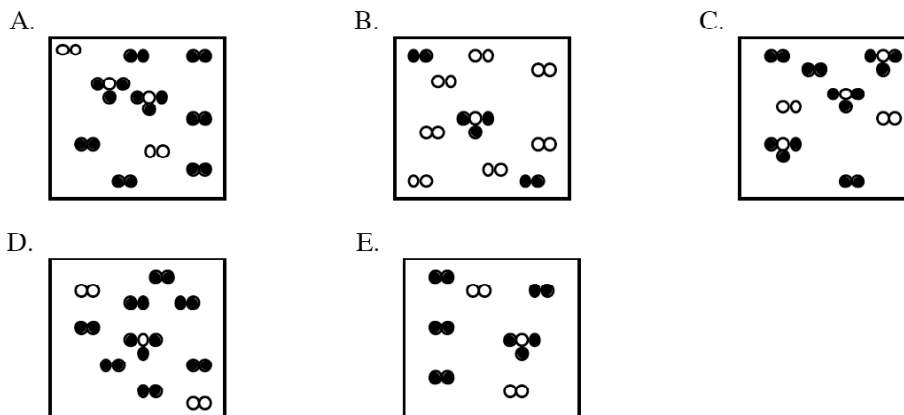


[A] = [B] = 1.00 mol/L, and [C] = [D] = 0 mol/L. After equilibrium is reached, the concentrations are: [A] = [B] = 0.35 mol/L. If initial concentrations at 15°C were [A] = [B] = 3.00 mol/L, and [C] = [D] = 0 mol/L, what would be the concentration of C after equilibrium is reached?

- A. [C] = 0.65 mol/L
 B. [C] = 2.65 mol/L
 C. [C] = 1.95 mol/L
 D. [C] = 1.50 mol/L
 E. [C] = 1.05 mol/L
19. Consider the following hypothetical reaction:



Initially, 5 molecules of A_3B and 1 molecule of A_2 are placed in a reaction vessel. After a period of time, 2 molecules of B_2 are found in the vessel. Which of the following diagrams represents this final state?



20. Consider the following:



For an initial concentration of 0.38 M $COCl_2(g)$, the equilibrium concentration of $Cl_2(g)$ is 0.080 M at 1700 K. Calculate the value of K_c .

- A. 59
 B. 0.017
 C. 0.029
 D. 0.21
 E. 0.021

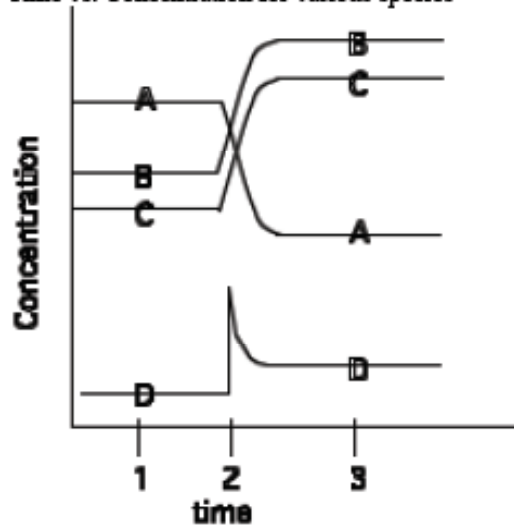
Appendix D

Conceptual quiz: Open-ended Questions

Name:	
Section:	TA code:

1. The following graph represents the concentration of all species in a reversible chemical reaction versus time. At time=2, more D is added to the system.

Time vs. Concentration for various species



a. Write an equation describing the reaction that is taking place in the system.

b. Is the reaction ever at equilibrium during the time monitored? If so, draw a box around any such regions of the graph.

c. Explain, in your own words, why the concentrations of [A], [B], [C] change as they do at time=2.

2. Predict the shift in the equilibrium position that will occur for each of the following reactions when the indicated changes take place. Explain the reasons for your prediction in terms of what is happening at the atomic and molecular level.

a. When carbon monoxide (CO) is added: $\text{CO(g)} + \text{H}_2\text{O(g)} \rightleftharpoons \text{CO}_2\text{(g)} + \text{H}_2\text{(g)}$

b. When the total volume is reduced: $\text{P}_4\text{(s)} + 6\text{Cl}_2\text{(g)} \rightleftharpoons 4\text{PCl}_3\text{(l)}$

c. When heat is added: $\text{N}_2\text{(g)} + 3\text{H}_2\text{(g)} \rightleftharpoons 2\text{NH}_3\text{(g)} + 92 \text{ kJ}$

Appendix E

Birnie-Abraham-Renner Quick Attitude Differential (BAR)

Reduced Copy

BAR Quick Attitude Inventory

You have just completed a lesson in chemistry concerned with _____. We are very interested in student reaction to the approach used in your class. Please take a moment to fill out the following survey.

Sample: Below you will find seven numbers between two words or phrases. You are requested to circle the number which best describes how you feel at this time. For example, if you felt very relaxed you might circle number 2.

relaxed 1 2 3 4 5 6 7 tense

Please tell us your reaction to the unit you have just completed by circling the appropriate number.

- | | | | | | | | | | |
|-----|--------------------------------------|---|---|---|---|---|---|---|------------------------------------|
| 1. | displeased | 1 | 2 | 3 | 4 | 5 | 6 | 7 | pleased |
| 2. | dissatisfied | 1 | 2 | 3 | 4 | 5 | 6 | 7 | satisfied |
| 3. | confused | 1 | 2 | 3 | 4 | 5 | 6 | 7 | not confused |
| 4. | unenthusiastic | 1 | 2 | 3 | 4 | 5 | 6 | 7 | enthusiastic |
| 5. | work is difficult | 1 | 2 | 3 | 4 | 5 | 6 | 7 | work is easy |
| 6. | class activities
seem mixed up | 1 | 2 | 3 | 4 | 5 | 6 | 7 | class activities
seem in order |
| 7. | I have unanswered
questions | 1 | 2 | 3 | 4 | 5 | 6 | 7 | I understand
the questions |
| 8. | I dislike this
topic | 1 | 2 | 3 | 4 | 5 | 6 | 7 | I like this
topic |
| 9. | I don't understand
the words used | 1 | 2 | 3 | 4 | 5 | 6 | 7 | I understand
the words used |
| 10. | I can't solve
the problems | 1 | 2 | 3 | 4 | 5 | 6 | 7 | I am able to solve
the problems |
| 11. | everything is
new to me | 1 | 2 | 3 | 4 | 5 | 6 | 7 | I am learning
nothing new |
| 12. | we are moving
too quickly | 1 | 2 | 3 | 4 | 5 | 6 | 7 | we are moving
too slowly |

On the back of this sheet, write what you liked best AND what you liked least about this unit.

Appendix F

Individual Students' ParNoMA Scores

Table F1

Experimental group in the pretest of ParNoMA

Subject \ Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	1	0
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Table F2

Control group in the pretest of ParNoMA

Subject	Question																			
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59	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
60	1	1	0	1	0	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1
61	1	1	0	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	0	1
62	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
63	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
64	1	1	0	1	0	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1
65	1	1	0	1	0	0	0	0	0	1	1	1	1	0	0	1	1	1	0	1
66	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
67	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
68	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1

69	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
70	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
71	1	1	0	0	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1
72	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
73	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
74	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
75	1	1	1	1	1	1	1	1	1	0	0	1	1	0	1	1	0	1	0	0
76	1	1	1	1	0	1	0	0	1	0	1	1	1	0	1	1	1	1	1	1
77	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
78	1	1	1	1	0	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1
79	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
80	1	1	0	0	0	1	0	1	1	1	1	1	1	0	1	1	0	1	0	0
81	0	1	1	1	0	0	1	0	0	1	1	1	1	1	0	0	1	1	1	1
82	1	1	0	1	0	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1
83	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0	0
84	1	1	0	0	1	0	1	0	0	0	1	1	1	0	0	0	1	1	0	1
85	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
86	1	1	0	0	0	1	1	1	0	1	1	1	1	0	0	1	1	1	0	1
87	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
88	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1
89	1	1	0	0	1	0	0	1	1	1	1	0	1	0	0	1	1	1	1	1
90	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	1	1
91	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
92	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
93	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
94	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	0	1
95	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	1	1	0	1	1
96	1	1	0	0	0	0	0	0	1	1	0	1	1	1	0	1	1	1	1	1
97	1	1	0	0	0	0	0	0	1	1	0	1	1	0	0	1	0	1	0	1
98	1	1	1	0	0	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1
99	1	1	1	0	0	1	0	0	0	1	0	0	1	1	0	1	1	0	0	1
100	1	1	1	1	1	1	0	0	1	1	0	1	1	1	0	1	1	1	1	1
101	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
102	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
103	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
104	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
105	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
106	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	0
107	1	1	0	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1	1
108	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
109	1	1	0	0	0	1	0	0	0	1	0	1	1	0	0	1	1	0	1	1
110	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1
111	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1
112	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	1	0	1
113	0	1	1	1	0	1	0	0	0	1	0	1	0	1	0	1	1	1	1	1
114	0	1	0	1	0	1	1	0	0	1	0	0	1	0	0	1	1	0	0	1

Table F3

Experimental group in the posttest of ParNoMA

Subject	Question																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1
2	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1
3	1	1	0	1	1	1	0	1	0	0	0	1	0	0	0	1	1	1	0	0
4	1	1	0	0	0	0	0	0	1	1	0	1	1	0	0	1	1	1	0	1
5	1	1	0	0	0	1	0	0	0	0	0	1	1	1	0	0	1	1	1	1
6	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1
7	1	1	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1
10	1	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
11	1	1	0	0	0	1	0	0	1	1	1	1	0	0	0	1	1	1	1	0
12	1	1	1	0	0	1	0	0	1	1	0	0	1	1	0	1	1	0	1	1
13	1	1	0	1	0	0	1	0	1	1	1	1	1	0	1	1	1	1	0	1
14	0	1	0	0	0	1	0	0	1	1	0	1	1	1	1	0	1	1	1	1
15	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	1	0	1
16	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
17	1	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
18	1	1	0	1	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0	1
19	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	1	1	1	0	1
20	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	0	1
21	1	1	1	1	1	1	0	0	1	1	1	1	1	1	0	1	1	0	1	1
22	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
23	0	1	0	0	0	0	0	1	0	1	1	1	1	0	0	1	1	1	0	0
24	1	1	0	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1	1
25	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
26	1	1	1	1	0	0	1	0	0	1	1	1	1	0	0	1	1	0	0	1
27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
28	1	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1
29	1	1	0	0	1	1	1	0	0	1	1	0	0	0	0	1	1	1	1	1
30	1	1	1	0	0	0	0	0	0	1	0	1	1	1	0	0	1	1	1	1
31	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
32	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
33	1	1	0	0	0	0	1	1	1	1	1	1	1	0	0	1	1	1	0	1
34	1	1	1	1	0	1	0	0	0	1	1	0	1	1	0	1	1	1	1	1
35	1	1	0	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1	1
36	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
37	1	1	0	1	0	1	0	0	0	1	0	1	1	0	0	1	1	1	1	1
38	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1
39	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	0	0	1
40	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	1	1
41	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1

42	1	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0	0
43	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
44	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
45	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	1	0	1
46	1	1	0	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1	1
47	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	
48	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	
49	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
50	1	1	1	1	1	1	1	0	1	0	1	0	1	1	0	1	1	0	1	
51	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	
52	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	1	1	
53	1	1	1	1	0	1	0	1	0	1	1	0	1	1	0	1	1	1	1	
54	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	
55	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	
56	1	1	0	1	1	1	1	0	0	1	1	0	1	1	0	1	1	0	1	

Table F4

Control group in the posttest of ParNoMA

Question \ Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
3	1	1	0	0	0	1	0	1	1	0	1	0	0	1	0	0	0	0	0	0
4	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0
5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	0	0	1	0	1	1	1	0	1	1	1	0	1	1	1	1	1
8	1	1	0	1	0	1	1	0	0	1	1	0	1	1	0	1	1	0	1	0
9	1	1	0	0	1	0	0	0	0	1	0	1	1	0	0	1	1	1	0	1
10	1	1	1	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	0	1
11	1	1	1	0	0	1	0	0	0	1	1	1	1	1	0	1	1	0	1	1
12	1	1	0	0	1	0	1	1	0	1	1	0	1	0	0	1	1	1	0	1
13	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
14	1	1	0	1	0	1	1	0	1	0	1	1	1	1	0	0	1	1	1	1
15	1	1	0	0	0	0	1	0	1	0	0	1	1	0	0	0	0	0	1	0
16	1	1	0	1	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1	1
17	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	0	1
18	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1	0
19	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1	1	0	0
20	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0
21	1	1	0	0	1	1	0	0	1	1	1	1	1	1	0	1	1	1	1	1
22	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0	1

23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
25	0	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1
26	1	1	0	1	0	0	1	0	0	0	1	0	0	0	0	1	1	0	1
27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
28	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
29	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
30	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	1
31	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1
32	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1
33	1	1	0	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	0
34	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
35	1	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
36	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
37	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
38	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	1	0
39	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
40	1	1	1	1	0	1	0	1	1	1	1	1	1	1	0	1	1	1	1
41	1	1	0	1	0	0	0	0	0	1	1	0	1	1	1	1	1	0	0
42	0	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	1	1
43	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	0	1	0
44	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
45	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1
46	1	1	1	1	1	1	0	0	0	1	1	1	1	1	0	1	1	1	1
47	1	1	0	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1
48	1	1	0	0	0	0	0	0	1	1	0	1	1	0	1	1	1	1	0
49	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
50	1	1	0	1	1	1	1	0	1	1	0	0	1	1	0	1	1	1	1
51	0	1	0	0	0	0	0	0	1	1	0	0	1	0	0	1	1	1	0
52	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
53	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	1	1	0	1
54	1	1	0	0	0	0	0	0	1	0	0	1	1	0	0	1	1	1	0
55	0	1	0	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0
56	1	1	1	1	0	0	0	0	0	1	0	0	1	0	0	1	1	1	1
57	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	0
58	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
59	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
60	1	1	0	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1
61	1	1	0	1	0	1	0	1	0	1	0	1	1	1	0	1	0	0	0
62	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
63	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
64	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
65	1	1	0	0	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1
66	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
67	1	1	0	0	1	0	0	0	0	1	0	1	1	0	0	1	1	1	0
68	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1
69	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1

70	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
71	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	1	1	0	1
72	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
73	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
74	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
75	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	1
76	1	1	0	1	0	1	0	0	1	1	1	1	0	0	1	1	1	0	1
77	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
78	1	1	1	0	0	1	0	0	0	1	0	1	1	0	1	1	1	1	1
79	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
80	1	1	0	0	0	0	0	0	1	1	0	0	1	0	0	1	1	0	0
81	1	1	1	1	0	0	1	1	0	1	1	1	1	0	0	1	1	1	0
82	1	1	0	1	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0
83	1	1	0	0	0	0	0	0	0	1	0	1	1	0	0	1	1	1	0
84	1	1	0	1	1	1	0	0	0	1	1	1	1	0	0	1	1	0	1
85	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1
86	1	1	1	1	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1
87	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
88	1	1	1	0	0	0	0	1	0	1	1	1	1	1	0	1	1	1	0
89	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
90	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
91	0	0	0	1	0	0	1	1	0	1	0	0	0	0	1	0	0	0	0
92	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
93	1	1	1	1	0	1	0	0	1	1	0	1	1	1	0	1	1	1	1
94	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1
95	1	1	0	0	0	0	0	0	1	1	1	1	1	0	0	1	1	1	0
96	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	1	1	1	0
97	1	1	0	1	0	0	0	0	1	1	1	1	1	1	0	1	1	1	0
98	1	1	1	0	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1
99	1	1	1	0	0	0	1	0	0	1	0	0	1	1	0	0	0	0	1
100	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1
101	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
102	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1
103	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	1	0	0
104	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
105	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
106	1	1	0	1	0	0	1	0	0	1	1	1	0	0	0	1	1	1	0
107	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	1
108	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
109	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
110	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
111	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1
112	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1	1	0
113	1	1	1	1	1	0	0	0	0	1	1	1	1	1	0	1	1	1	0
114	1	1	0	0	0	1	0	0	0	1	0	1	1	1	0	1	1	1	1

Appendix G
Individual Students' Exam Scores

Unit 1						Unit 2					
Experiment			Control			Experiment			Control		
Subject	Exam1	Exam2	Subject	Exam1	Exam2	Subject	Exam1	Exam2	Subject	Exam1	Exam2
1	30	30	1	45	15	1	25	10	1	35	10
2	10	5	2	35	10	2	15	50	2	35	35
3	10	10	3	30	40	3	40	30	3	20	30
4	10	25	4	35	25	4	15	5	4	5	35
5	15	5	5	35	5	5	35	35	5	25	40
6	40	30	6	10	5	6	40	45	6	20	10
7	35	10	7	30	40	7	40	50	7	35	30
8	10	5	8	30	30	8	15	25	8	35	15
9	20	0	9	35	35	9	25	20	9	40	35
10	25	20	10	35	15	10	30	40	10	10	10
11	25	25	11	10	15	11	35	30	11	30	35
12	30	15	12	40	15	12	25	35	12	30	5
13	35	20	13	25	20	13	10	25	13	35	15
14	30	20	14	25	25	14	25	15	14	25	45
15	30	45	15	20	15	15	35	25	15	25	5
16	15	30	16	25	20	16	35	35	16	25	40
17	15	10	17	20	25	17	15	25	17	35	35
18	30	15	18	30	10	18	25	40	18	35	40
19	15	10	19	35	10	19	20	25	19	35	45
20	30	40	20	10	40	20	30	30	20	25	35
21	20	25	21	40	50	21	30	30	21	15	15
22	25	15	22	40	25	22	30	35	22	20	45
23	30	20	23	10	10	23	30	10	23	30	30
24	30	35	24	35	15	24	10	20	24	40	40
25	40	30	25	20	20	25	20	25	25	35	35
26	10	15	26	25	40	26	20	40	26	10	15
27	40	40	27	30	5	27	30	45	27	25	20
28	35	0	28	25	35	28	25	50	28	30	15
29	25	15	29	20	20	29	35	45	29	25	35
30	10	5	30	25	10	30	20	20	30	30	10
31	15	15	31	30	30	31	40	20	31	20	45
32	15	10	32	30	35	32	30	5	32	30	35
33	35	10	33	30	15	33	20	20	33	10	20
34	25	25	34	30	25	34	15	30	34	30	15
35	25	5	35	30	15	35	20	10	35	35	40
36	25	15	36	25	45	36	30	5	36	25	50
37	15	0	37	15	35	37	20	20	37	30	35
38	30	30	38	10	15	38	20	20	38	40	0
39	40	45	39	20	15	39	25	45	39	35	20
40	20	20	40	30	35	40	25	10	40	25	35
41	15	40	41	15	20	41	20	20	41	20	15
42	20	30	42	35	40	42	10	35	42	25	45
43	15	25	43	30	15	43	45	25	43	30	10
44	15	25	44	10	5	44	20	15	44	30	45

45	30	15	45	40	30	45	30	35	45	30	50
46	35	15	46	25	35	46	20	30	46	20	10
47	30	40	47	25	15	47	30	40	47	20	5
48	15	20	48	20	5	48	15	35	48	20	25
49	25	15	49	40	40	49	40	25	49	35	15
50	15	30	50	45	40	50	30	25	50	25	35
51	35	35	51	45	15	51	20	25	51	35	35
52	40	15	52	25	35	52	35	20	52	30	15
53	30	15	53	35	20	53	40	20	53	35	40
54	5	5	54	35	10	54	30	15	54	15	45
55	40	40	55	40	15	55	30	45	55	30	20
56	20	15	56	40	15	56	20	25	56	30	45
57	25	45	57	25	30	57	30	25	57	30	50
58	35	30	58	15	20	58	25	35	58	40	45
59	35	20	59	40	40	59	20	35	59	35	35
60	15	10	60	5	10	60	35	40	60	30	40
61	15	15	61	40	45	61	35	15	61	30	35
62	35	25	62	25	25	62	25	20	62	25	35
63	35	45	63	15	10	63	10	15	63	25	45
64	15	5	64	0	10	64	0	35	64	45	40
65	10	15	65	35	20	65	25	25	65	20	45
66	15	15	66	40	10	66	20	30	66	30	15
67	25	20	67	30	35	67	20	20	67	20	40
68	25	30	68	25	50	68	30	10	68	20	10
69	30	25	69	10	20	69	30	35	69	45	0
70	20	30	70	40	20	70	20	35	70	20	40
71	20	25	71	30	25	71	20	15	71	15	35
72	20	35	72	35	20	72	25	20	72	20	25
73	40	0	73	5	25	73	10	20	73	40	15
74	20	10	74	30	50	74	20	45	74	35	30
75	35	5	75	20	10	75	30	35	75	20	15
76	25	10	76	20	25	76	40	30	76	35	45
77	10	10	77	40	40	77	30	45	77	30	40
78	35	25	78	20	25	78	30	10	78	40	40
79	25	25	79	30	25	79	20	40	79	20	25
80	15	30	80	35	20	80	40	30	80	15	10
81	40	15				81	20	45	81	15	30
82	20	40				82	30	35	82	45	40
83	15	20				83	30	15	83	15	35
84	30	30				84	15	25	84	30	10
85	20	20				85	25	20	85	35	45
86	15	0				86	15	25	86	30	20
87	10	20				87	0	45	87	30	40
88	35	45				88	35	25	88	45	0
89	25	40				89	35	45	89	40	35
90	35	30				90	25	5	90	10	25
91	15	10				91	15	40	91	25	20

92	20	40	92	25	40	92	40	35
93	25	40	93	30	40	93	15	40
94	25	15	94	35	40	94	35	10
95	50	50	95	35	25	95	10	40
96	15	25	96	30	35	96	35	30
97	15	10	97	40	30	97	20	10
98	35	35	98	30	20	98	40	35
99	45	15	99	15	35	99	30	25
100	40	10	100	30	40	100	30	30
101	20	15	101	20	20	101	45	25
102	35	35	102	40	15	102	20	10
103	40	35	103	30	40	103	25	30
104	40	30	104	15	30	104	20	25
105	35	15	105	35	15	105	40	15
106	35	35	106	25	35	106	40	45
107	20	20	107	30	30	107	30	35
108	30	40	108	15	40	108	25	5
109	25	25	109	35	35	109	25	35
110	35	40	110	35	40	110	30	35
111	40	45	111	35	40	111	10	5
112	25	20	112	30	15	112	20	40
113	35	30	113	30	25			
114	25	30	114	20	20			
115	40	50	115	20	10			
116	20	25	116	0	15			
117	35	35	117	35	35			
118	35	20	118	30	10			
119	40	15	119	5	25			
120	35	35	120	30	25			
121	35	20	121	30	40			
122	30	20	122	35	35			
123	30	10	123	35	45			
124	45	0	124	10	20			
125	30	45	125	40	5			
126	35	25	126	30	50			
127	0	35	127	25	40			
128	20	25	128	25	20			
129	40	40	129	30	25			
130	35	40	130	30	35			
131	25	15	131	15	45			
132	40	35	132	40	20			
133	35	40	133	30	45			
134	15	20	134	25	25			
135	25	30	135	40	50			
136	30	40	136	35	45			
137	45	15	137	35	40			
138	15	30	138	30	10			

139	30	25	139	35	50
140	15	25	140	20	35
141	40	5	141	15	40
142	10	35	142	30	30
143	10	35	143	20	30
144	40	45	144	35	35
145	5	10	145	40	35
146	15	30	146	35	35
147	40	25	147	30	30
148	5	5	148	30	50
149	35	35	149	20	5
150	0	5	150	20	30

Appendix H

Individual Students' Response of BAR

Table H1

Experimental Group

Question Subject	1	2	3	4	5	6	7	8	9	10	11	12
1	5	5	5	3	3	3	4	2	4	2	2	2
2	3	3	5	1	4	4	3	1	5	5	4	3
3	4	4	4	3	3	3	3	3	3	3	3	3
4	4	5	5	2	4	3	5	2	3	4	6	4
5	4	4	4	4	5	5	4	3	6	5	5	4
6	6	6	6	5	5	4	5	6	6	6	5	2
7	3	3	3	1	2	4	3	2	4	3	4	4
8	6	2	6	5	6	5	5	5	6	6	5	4
9	6	6	6	7	6	7	7	6	6	6	3	4
10	2	2	2	1	4	1	3	1	6	6	1	1
11	5	4	3	3	5	3	3	6	5	5	5	6
12	6	6	5	4	6	3	6	5	6	6	3	3
13	6	6	4	4	4	5	5	5	5	5	4	4
14	5	4	5	5	5	3	4	5	6	3	3	4
15	4	3	3	3	6	3	1	7	6	6	5	6
16	4	4	4	3	4	4	6	4	6	6	4	4
17	5	6	5	5	4	3	6	5	7	6	5	6
18	3	3	3	4	3	2	2	5	5	3	3	3
19	1	1	1	1	1	1	1	1	1	1	1	1
20	3	3	3	3	3	5	4	3	6	5	5	5
21	5	3	7	5	6	6	6	5	6	6	5	3
22	5	5	4	5	6	5	7	7	7	7	2	2
23	6	6	5	4	5	6	6	6	6	6	4	4
24	4	3	4	5	3	3	2	5	7	4	6	4
25	4	4	3	4	3	4	3	4	6	3	3	2
26	5	5	4	5	6	6	6	6	5	6	5	5
27	6	6	6	7	4	6	6	5	6	6	4	4
28	5	5	6	2	6	4	2	2	7	7	2	6
29	1	1	2	2	2	2	2	1	2	1	5	3
30	4	5	2	3	2	3	4	2	7	4	6	5
31	4	5	7	5	5	6	6	5	6	6	5	4
32	7	6	6	7	5	7	5	5	7	5	6	4
33	6	6	4	5	4	7	5	3	6	5	3	3
34	4	4	3	3	3	5	3	3	6	5	3	4
35	7	7	5	1	4	4	4	3	5	5	3	4
36	5	5	4	3	3	4	4	2	4	4	3	4
37	7	7	7	7	7	7	7	7	7	7	7	7
38	1	1	1	1	1	1	1	3	1	1	1	1
39	5	3	7	4	7	7	5	6	7	7	5	4
40	4	5	5	4	6	4	3	6	7	6	3	4
41	6	5	5	6	6	7	6	4	6	6	6	4

42	6	6	7	4	6	7	7	7	7	7	3	4
43	6	6	4	4	6	5	6	6	6	6	4	4
44	4	4	3	1	3	4	4	2	5	4	2	3
45	3	3	4	3	5	3	7	3	7	2	7	4
46	6	6	7	5	6	6	7	5	7	7	6	5
47	5	5	6	5	6	6	6	4	6	6	4	4
48	6	6	5	7	5	6	6	6	6	6	4	4
49	3	3	2	2	3	2	6	3	6	5	5	4
50	5	5	5	5	5	6	7	5	5	5	5	5
51	6	6	6	6	4	7	6	7	7	7	5	4
52	5	6	6	4	6	5	5	7	5	5	6	4
53	1	3	7	2	7	7	7	1	7	5	4	1
54	4	4	4	4	4	4	4	4	4	4	4	4
55	1	1	7	1	7	7	7	1	7	7	7	1
56	1	1	6	2	7	3	7	1	7	7	7	7
57	4	4	3	3	4	1	1	3	6	6	4	3
58	3	2	2	1	4	2	3	1	4	4	5	3
59	1	1	1	1	7	2	7	1	7	7	7	4
60	6	6	4	7	4	5	5	5	5	5	4	4
61	7	7	7	1	7	5	7	7	7	7	7	7
62	4	4	2	2	4	4	7	2	4	4	6	4
63	2	3	5	3	5	5	6	3	5	5	3	3
64	4	4	4	4	4	4	4	4	4	4	4	4
65	2	2	2	1	2	2	3	4	3	3	4	2
66	7	6	6	7	6	6	7	7	7	7	6	7
67	4	5	6	3	5	6	6	6	6	6	5	4
68	6	6	2	6	3	2	7	7	7	7	3	4
69	4	4	6	2	4	5	4	2	4	6	7	6
70	7	6	5	7	5	5	5	5	5	5	5	5
71	5	5	7	1	7	3	6	4	7	6	5	5
72	3	3	5	3	5	2	6	4	7	5	6	4
73	5	6	5	5	6	6	5	3	6	5	4	5

Table H2

Control Group

Question Subject	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	7	1	7	4	7	1	7	7	7	7
2	6	6	5	6	7	6	6	5	6	6	5	5
3	5	6	2	4	5	6	4	4	4	6	4	5
4	3	2	3	3	3	2	3	3	6	4	3	2
5	6	6	7	6	5	6	6	6	6	5	4	4

6	6	6	3	1	1	4	5	6	3	1	3	1
7	1	1	7	1	7	7	7	7	7	7	7	7
8	4	5	7	4	7	4	7	5	7	7	6	4
9	6	6	6	7	6	6	6	6	7	7	5	6
10	5	5	4	5	3	5	4	7	4	6	6	4
11	7	7	7	1	7	7	7	4	7	7	7	1
12	7	7	7	6	3	7	5	6	7	5	3	4
13	4	4	6	3	6	3	7	4	7	6	3	5
14	6	5	5	4	5	6	6	4	6	5	5	4
15	7	7	6	4	5	5	5	6	7	7	3	4
16	4	4	4	4	3	4	4	4	1	2	1	2
17	7	5	7	7	5	5	4	7	7	7	3	4
18	5	6	4	4	3	4	4	5	3	3	2	
19	5	5	6	5	5	6	5	5	6	6	4	5
20	5	6	5	6	6	6	6	5	6	5	7	6
21	4	5	3	6	3	6	4	4	5	4	5	3
22	7	6	5	5	5	6	5	5	7	5	6	4
23	6	6	5	6	3	5	6	6	6	6	4	4
24	5	5	4	4	4	4	3	4	3	4	4	3
25	4	4	7	4	6	6	4	6	6	4	4	
26	4	4	7	4	5	7	6	4	6	7	5	3
27	3	3	5	2	4	4	5	4	5	5	3	3
28	4	3	6	3	4	5	5	5	5	5	4	4
29	4	4	3	3	2	5	3	5	4	5	3	2
30	4	4	5	5	3	6	6	4	6	5	3	3
31	5	6	7	2	6	6	5	4	5	6	5	4
32	5	5	4	5	2	4	5	4	5	4	3	4
33	5	6	6	4	5	2	5	4	5	6	4	4
34	6	6	5	7	4	6	6	6	6	5	5	4
35	3	3	6	3	4	6	6	3	6	6	6	3
36	2	2	2	2	4	7	6	2	7	7	4	4
37	6	6	3	5	3	5	5	4	4	3	6	3
38	7	7	7	5	5	5	7	6	7	6	3	3
39	7	7	7	6	7	7	7	7	7	7	7	7
40	4	4	5	4	4	3	4	5	4	4	4	4
41	5	5	5	5	5	5	6	4	6	5	4	4
42	2	2	4	3	4	3	6	5	7	2	6	3
43	4	4	4	4	4	4	4	4	4	4	4	4
44	5	5	5	3	6	5	4	5	6	6	4	4
45	7	7	5	3	3	5	4	2		4	1	4
46	3	5	6	3	6	3	6	3	6	5	4	4
47	2	2	7	1	7	3	7	3	7	7	7	4
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