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The effects of cognitive style, method of instruction, and visual ability on learning  
chemical kinetics

by

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A dissertation submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Education (Curriculum and Instructional Technology)

Major Professors: Lynn W. Glass and Thomas J. Greenbowe

Iowa State University

Ames, Iowa

1997

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## **DEDICATION**

This dissertation is dedicated to my parents, James and Barbara Lynch. Without their encouragement and support I would not have been able to complete this work. I have gotten my strength and determination from them. Everything I have done in my life, including this dissertation, has been a result of their love and understanding.

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**ABSTRACT**

The relationships between cognitive style, method of instruction, and visual skill on learning chemical kinetics were investigated. Participants enrolled in a general chemistry course were classified on each of three factors: cognitive style (field dependent, field neutral, or field independent), method of instruction (computer lesson, teaching assistant, or neither), and visual skill (high visual skill, moderate visual skill, or low visual skill). Participants who were classified as field independent scored significantly higher than those classified as field dependent on the kinetics portions of the hour and final exams. Also, participants who worked with the computer lesson scored significantly higher than those who did not work with either the computer lesson or the teaching assistant on the kinetics portions of the hour and final exams. In addition, participants who were classified with high visual skill scored significantly higher than those classified with low visual skill on the kinetics portions of the hour and final exams. No significant interaction effects were found for cognitive style and method of instruction. However, a trend was discovered in that participants who were classified as field dependent or field independent and worked with the computer based lesson seemed to score higher than those classified as field dependent or field independent and worked with the teaching assistant. Also, those classified as field neutral and worked with the teaching assistant seemed to score higher than those who were classified as field neutral and worked with the computer lesson. Finally, no significant difference was found for cognitive style and the

percentage of time spent in the simulated environment component of the computer lesson. However, a trend was found in that participants classified as field independent seemed to spend a greater percentage of time in the simulated environment than participants classified as field dependent.

## INTRODUCTION

It is the responsibility of educators to prepare students to lead productive and personally fulfilling lives. Thus, no matter what the subject, educators should always try to develop ways to teach that subject better. This has become especially true in the sciences.

Ayers (1987) in an analysis of six science education journals compared the number and type of articles published in 1985 vs. 1970. Ayers reported that the number of articles published concerning science education increased from 447 to 551, a growth of 23.3%. The number of articles published dealing specifically with research in teaching increased 31.3% from 64 to 84. Also articles dealing with applications or methods of teaching science increased 37.8% from 188 to 259. Almost half (47.0%) of the articles published in these six journals were devoted applications and methods.

Reports have been published, such as A Nation at Risk (National Commission on Excellence in Education, 1983) and Science and Engineering Education for the 1980's and Beyond (National Science Foundation and U. S. Department of Education, 1980), that state that most Americans are not scientifically literate. Scientific organizations, such as the National Science Teachers Association (NSTA) and the American Association for the Advancement of Science (AAAS), have attempted to take the lead by making recommendations for new science curricula and then in turn developing new science curricula and national standards (NSTA, 1992; AAAS, 1989). In the

AAAS report, Science For All Americans, the authors stated, “We use technology to try to change the world to suit us better.” (AAAS, 1989).

From this statement we have a foundation for research in trying to develop new science curricula. Educators can, and should, use technology to change the way we teach science so that students will be more able to lead productive and fulfilling lives. In other words, science educators need to prepare students to be scientifically literate. In this document, the operational definition of scientific literacy is functional scientific literacy, as defined by Shamos (1995). Shamos (1995) defines “functional scientific literacy” as possessing a command of a science lexicon and be able to converse, read and write coherently, using science terms in a meaningful context.

Chemistry is one specific area in science that has proved difficult for students (Greenbowe, 1994). Students themselves feel that chemistry is a difficult subject (Solomon, 1983; Carter & Brickhouse, 1989). Within chemistry the topic of chemical kinetics has been shown to be difficult for a great number of first year college level chemistry students. From personal conversations with numerous chemistry professors at Iowa State University and their conversations with other chemical professors, all agree that this is a rather difficult topic. Data collected over two and a half years in several pilot studies (Lynch & Greenbowe, 1994) further supports this claim.

In chemical kinetics students may either hear or read phrases such as “the ability of the reactants to meet”, “rates of reaction”, “collision theory”, and “kinetic energy”. These are all ideas that imply motion. The dynamic nature of chemical kinetics is not well suited to a static presentation through the use

of diagrams as found in typical chemistry textbooks (e.g. McQuarrie & Rock, 1987; Brown, LeMay, & Bursten, 1994; and Brady & Holum, 1993). Figure 1 shows a representation of effective and ineffective collisions in a chemical reaction.

Also, chemical kinetics is concerned with interactions at the molecular or atomic level. Since one can not actually see motions and collisions of particles at the molecular level, one must be able to create one's own representation to gain some understanding of this topic. According to Halford (1993), one of the properties of understanding is representation. He states that "To understand a concept entails having an internal, cognitive representation or mental model that reflects the structure of that concept" (p. 7). Halford believes that representations may consist of images. Carter, LaRussa and

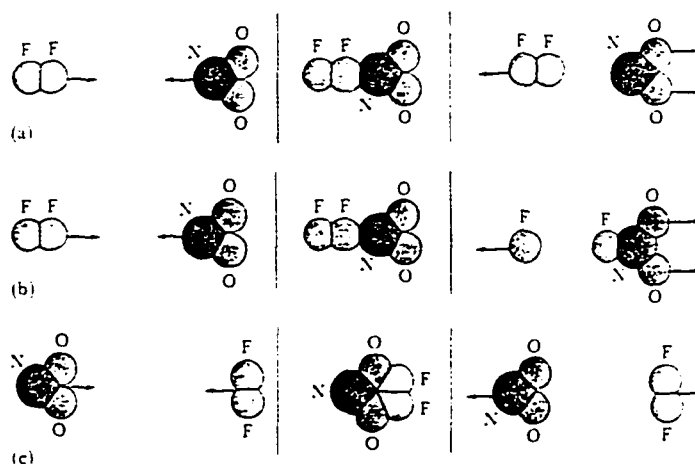
**Figure 13-5** Nonreactive and reactive collisions of the molecules  $\text{NO}_2$  and  $\text{F}_2$  in the reaction  $\text{NO}_2(\text{g}) + \text{F}_2(\text{g}) \rightarrow \text{FNO}_2(\text{g}) + \text{F}(\text{g})$ .

(a) Nonreactive collision.

Molecules bounce off one another without reacting because the kinetic energy of the colliding particles is less than the activation energy. (b) Reactive collision.

Molecules collide with a kinetic energy greater than  $E_a$  and react. (c) Nonreactive collision.

Molecules collide with a kinetic energy greater than  $E_a$  but do not react because they do not have the correct orientation for reaction.



**Figure 1. Effective and ineffective collisions in a chemical reaction.** (Figure 13-5, p. 418, in General Chemistry - Second Edition by McQuarrie and Rock, 1987).

Bodner (1985) reported that encouraging students to represent all chemistry problems pictorially adds to their development of problem solving skills.

Often students taking introductory college chemistry courses have not had sufficient opportunity for visualizing motions and collisions of molecules. A textbook does not adequately provide students with the appropriate experiences. However, through the use of computer animations students are able to “see” collisions and motions of particles at the molecular level.

Another topic in chemical kinetics is devoted to how certain factors affect the rate of reaction. There are five factors which alter the rate of chemical reactions: (1) the temperature of the reaction system; (2) the concentrations of the reactants; (3) the chemical nature of the reactants; (4) the ability of the reactants to come in contact with one another; and (5) the availability of catalysts. Students enrolled in the laboratory component of a chemistry course usually have the opportunity to perform a laboratory activity involving some of these five factors (Heideman and Staff of the Chemistry Department at ISU, 1994).

This laboratory activity is time consuming, usually lasting three hours. It involves manipulating the variables of concentration and of the availability of a catalyst. A series of experiments are performed in which students are asked to observe a reaction for 10 minutes, noting the volume of gas that is created. Students then must dispose of the chemicals and clean their glassware to prepare for the next experiment. These repeated experiments can be simplified by eliminating the need to dispose of chemicals and to clean the glassware by using “microworlds” or “simulated experiments”.

A computer-based simulated experiment is a computer program in which students essentially perform the same experiment as students in a traditional laboratory. Simulated experiments can utilize any or all of the following: still images, animations, digitized video sequences, and laserdisc images. Students are provided with the opportunity to manipulate variables and the computer program will respond to those changes. In a simulated experiment students are able to freely manipulate variables and/or adjust reaction conditions within the experiment. The computer may be used to perform the same "simulated experiment" many times over. Furthermore, the time required to perform the experiments would be less than a traditional experiment because it is not necessary to measure chemicals or clean glassware. Additionally, when doing a simulated experiment or exploring a microworld, there is no need to be concerned with the cost of the treatment and disposal of chemicals.

One example of a simulated experiment was created by Lynch and Greenbowe (1992). This experiment was an animated version of a method of initial rates kinetics experiment that students performed at Iowa State University. Students were given the same laboratory procedure as those in the traditional laboratory with some minor changes. Students were given the appropriate volumes of various solution to mix and were asked to enter these volumes when prompted. As the last solution was being added to the others, students were to click on the start button of the timer on the screen and were to stop the timer when the solution in the test beaker was the same color as that in the beaker which contained the standard. After collecting the data, the

students could calculate the average initial rate of reaction. Students could also adjust the temperature of the solutions or add differing amounts of the solutions to see if there was any effect on the time and, thus, the rate of reaction.

If we are to use technology, such as the simulated experiment, in order to actively engage students in the learning process, our instruction must be redesigned. When designing instruction, Dick and Carey (1990) state that the focus should be on the learner. As such, those who design instruction should understand that students have different cognitive styles. Schwen, Bedner, and Hodson (1979) define cognitive style as a person's typical or habitual mode of problem solving, thinking, perceiving, and remembering. One such cognitive style is field independence/dependence. Field independent students are able to separate portions of information from a perceptual field or from a block of information. Field dependent students see the perceptual field or block of information as a single entity, and have difficulty extracting pertinent information.

This cognitive style of field independence/field dependence is related to achievement in a number of academic areas such as mathematics, science, and engineering (Witkin, Moore, Goodenough, & Cox, 1977). Post (1987) found that there was a relationship between a student's cognitive style and achievement on a computer assisted instruction lesson in an electrical engineering course. Post (1987) stated that field independent students will benefit from computer assisted instruction. Davis (1991) summarized the results of studies relating academic achievement to field

dependence/independence. He reported that across virtually every curriculum area that field independent students perform better than field dependent students. Witkin, Moore, Goodenough, and Cox (1977) stated that field independence contributes greatly to achievement in chemistry. Since chemistry involves the ability to be analytical by locating and extracting data from problem-solving tasks, tables, and graphs, one would expect field independence to influence achievement in chemistry (Chandran, Treagust, & Tobin, 1987).

Krajcik, Simmons, and Lunetta (1988) stated that one should investigate whether there are relationships between computer graphics and learner variables. MacGregor, Shapiro, and Niemiec (1988) stated that additional research is needed to evaluate the effectiveness of computer assisted instruction for students with different learning profiles. These last two statements provide the impetus for this research.

This study investigated the relationship between the cognitive style of field independence/field dependence and the effects of computer assisted instruction on chemistry achievement. By using the current available technology, creation of a multimedia lesson involving computer simulations would allow students to explore the numerous components and connections on the specific topic of chemical kinetics. A combination of constructivist ideas and objectivist ideas provides the theory base for this research and the basis for the instructional design strategies of the computer program. Students should be active in their learning and be given the opportunity to construct their own knowledge.

Since many computer based instructional programs involve images, it follows that one's ability to obtain information from these images would affect one's achievement on the topic of the program. The cognitive style of field dependence/field independence describes one's ability to disembed information from a field. With animations and simulations as part of the instructional program used in this research, one's cognitive style should also affect whether one is able to obtain the information from the computer program or construct knowledge using the computer environment.

Also, the ability to visualize and gather information from pictures and representations appears to be very important for chemistry achievement. One's cognitive style of field independence or field dependence should also have an effect on chemistry achievement. Since most computer assisted instruction is based on visual images, research on this cognitive style and how it affects computer assisted instruction is an area of interest for research. Gardner (1984) states that committed instructors attempt to find solutions to problems in the teaching of chemistry. Very little research has been reported dealing with the topic of chemical kinetics. Also, no research has dealt with the relationship between cognitive styles and chemistry achievement in a computer assisted learning environment.

Another premise is that computer assisted instruction can help students learn chemistry. Although Clark (1983) argued that the computer has no effect on student achievement, others such as Kulik, Kulik, and Bangert-Drowns (1985) and Niemiec and Walberg (1985) have shown that the computer can be effective in raising student achievement. Specifically in

chemistry, Smith, Jones, and Waugh (1986) and Jackson, Moellenberg, and Brabson (1987) have shown that the computer can increase achievement. Therefore, using the computer as the method of instruction should be at least as effective, if not better, than traditional instruction for learning chemical kinetics.

This research looked at the relationship between the cognitive style of field dependence/field independence and achievement on the topic of chemical kinetics. Results of this research could influence how chemistry instructors provide instruction on chemical kinetics.

## LITERATURE REVIEW

### **Learning Theory and Instructional Design**

Educators must be aware of how students learn so that they may effectively utilize the available technology in order to teach better. Thompson, Simonson, and Hargrave in Educational Technology: A Review of the Research (1992) state that cognitive theory gives researchers guidelines for conducting research concerned with learning. In addition, they give guidelines to educators interested in designing instruction. They list six guidelines for educators or scientists to follow when designing instruction.

First, Bruner (1966) stated that “The single most characteristic thing about human beings is that they learn. Learning is so deeply ingrained in man that it is almost involuntary...” (p. 113). In other words he said that humans have a “will to learn”. Bruner (1977) stated that learning needs something to get it started, something to keep it going, and something to keep it from being random. Bruner called these activation, maintenance, and direction.

Second the learner must be actively involved in the learning process. This statement draws from the theories of Piaget (Pulaski, 1971), constructivism (Bodner, 1986), behaviorism (Thompson, Simonson, & Hargrave, 1992), and cognitivism (Thornburg, 1984). Constructivists believe that knowledge is constructed by the learner through the process of equilibration (Kitchener, 1986). Suppose two schemes, created by previous experience, are activated by the same stimulus. There is cognitive conflict if

they lead to contrary interpretations. Without destroying the original pair, this conflict can be resolved by the formation of more differentiated or all-embracing schemes. This process is called equilibration (Lunzer, 1986).

According to constructivist philosophy, knowledge is constructed by the learner and as such the learner must take an active role in learning.

Bredderman (1982) showed that students who were involved in active learning outperformed those who were not involved in active learning, especially in the process skills area. Renner (1973) discovered that science achievement is increased when one is actively, compared to passively, involved in one's own learning.

Next, the material to be learned must be organized in some optimal way. Telling students in advance about the way in which the material to be learned is organized is likely to improve their comprehension, recall, and application of the material (Gage & Berliner, 1988). Ausubel (1968) used the term advance organizer to describe this preliminary information. A meta-analysis by Luiken, Ames, and Ackerson (1980) found that advance organizers have a small but facilitative effect on learning and retention in all subject areas.

Fourth, sequencing of instructional materials is important. Sequencing here means the time and order in which topics are presented. The limited capabilities of learners to process information must be considered when sequencing instruction. Thornburg (1984) stated that to affect instruction and learning, a course of study needs to be sequenced. Thornburg continues to say that the better sequenced the instruction is, the greater the likelihood that teaching and learning behaviors will build on each other.

One method of sequencing has been proposed by Reigeluth, Merrill, Wilson, and Spiller (1980). They describe a zooming-in technique using the elaboration theory of instruction. First one starts with a general view of the subject matter. Then the subject matter is divided into parts with elaboration of each part. Each part is divided into subparts, again with elaboration of each subpart. The process continues until one's knowledge reaches the desired level of complexity and detail.

Sequencing also means the type of control the learner has concerning how one will progress through the lesson. Hooper and Hannafin (1988) suggested that the learner should be allowed to determine the lesson sequence when the content is familiar or poses little cognitive difficulty to the learner. However, guidance should be provided when learner control is selected. Research by Ross and Rakow (1981) showed that mathematics students with low entry-level ability perform better under program control than learner control. Those with high entry-level ability perform equally well under both conditions. Work by Clark (1982) supported this finding. In a review of selected aptitude-treatment interaction studies Clark found that low-ability students had greater achievement from more structured instruction. However, high-ability students had greater achievement from less structured methods. A literature review by Steinberg (1989) further supported these findings. This research implies that sequencing is important for educational program designers to consider. Low-ability learners and learners with low entry-level skills should let the program control the instruction. Once learners

become more comfortable and more familiar with the topic, then they perform better when they have more control over the program.

Fifth, new information must be connected in a meaningful way to information previously learned. Ausubel (1977) defined potential meaningfulness as the capacity to relate new learning to what the learner already knows. Hunter (1982) suggested creating an anticipatory set, which is similar to an advance organizer, in order to capture the students' attention. This is done in order to produce a greater desire in the students to relate the new material to their own cognitive structure. Ausubel (1977) believed that the more meaningful learned material is, the better the learned material is associated with prior knowledge. Luiten, Ames, and Ackerson (1980) stated that the use of an advance organizer to begin a lesson can make learned material more familiar and meaningful, thus easier to retrieve. In reviewing expert/novice research in various curricular areas, Bransford, Sherwood, Vye, and Rieser (1986) found that effective problem solving depended strongly on the nature and organization of the individual's knowledge.

Finally, discovery learning is important. It is based on the assumption that students learn more by discovering the objectives of the lesson covered in the instruction. Bruner (1977) stated that effective learning occurs when students gain a general understanding of the subject. They see the subject as a related whole. Students gain this understanding by building concepts, coding information, forming generalizations, and seeing relationships. A study by Haukoos and Penick (1983) found that although there was no difference in science-content achievement for nondiscovery and discovery groups, yet there

was a significant difference in learning process skills. Also a meta-analysis by Shymansky, Kyle, and Alport (1983) showed that students exposed to new science curricula, which integrated discovery learning as part of the class routine, outperformed students who were exposed to traditional curricula, which did not integrate discovery learning as part of the class routine.

### **Learning Theory and Computer-assisted Instruction**

Computer-assisted instruction allows one to create a computer lesson which incorporates all of the six guidelines mentioned. Computer-assisted instruction can be made so that the individual can explore different areas of interest. This may provide enough motivation for the student to get them started and to keep them involved in their learning. Computer-assisted instruction also has the capability to create an individualized learning environment which could support discovery learning. By allowing students to work with the computer, instructors would be able to allow students to explore without worrying about dangerous situations arising due to the unsupervised use of certain chemicals.

Computer-assisted instruction can be made to provide advance organizers to guide students and provide them with the potential meaningfulness necessary to make connections to previous knowledge. Also, computer-assisted instruction can be made with variable learner control. Appropriate sequencing can be built into the instruction to give learners more structure with unfamiliar material or allow those familiar with the material the ability for more self-directed learning.

## **Constructivism and Objectivism**

Constructivism and objectivism are opposing theories of thinking and learning. Jonassen (1991) stated that these two theories are polar extremes on a continuum with externally mediated reality (objectivism) on one end and internally mediated reality (constructivism) on the other end. According to Bodner (1986) the basic philosophy of constructivism can be summarized as “Knowledge is constructed in the mind of the learner.” Yarusso (1992) stated that the basic philosophy of objectivism is that there is “an external reality that is, ultimately, accessible to the human mind” and “the process of knowing, i.e. cognition, is primarily concerned with developing symbolic representations of the external world and then internalizing the symbols”.

For the constructivist, the real world exists and we interact with it. Thinking is grounded in perception of physical and social experiences which can only be comprehended by the mind (Jonassen, 1991). Constructivists describe learning as happening through interacting with one’s environment or culture (Rieber, 1992). Perkins (1991) stated that learners do not just respond to stimuli but engage, grapple, and seek to make sense of things. The learner builds an internal representation of knowledge, or a personal interpretation of reality. Thus, each person has a unique construct of reality (Yarusso, 1992). In other words, there is no ultimate, shared reality (Duffy & Jonassen, 1991).

Constructivists believe knowledge, attitudes, and skills are based on the learner’s interpretation of the external world. Bednar, et al. (1991) stated that learning is a constructive process in which the learner builds an internal

representation of knowledge. Merrill (1991) added that knowledge is constructed from experience. In Jonassen's view (1991) the mind produces mental models that explain to the knower what they have perceived. Merrill (1991) stated that mental models are constructed by the learner as a result of experience and that a mental model is modified as a result of every new experience. Merrill added a student needs a variety of experiences to construct an adequate mental model.

Constructivists also believe that meaning is negotiated from multiple perspectives (Merrill, 1991). Also, some constructivists believe in the "social negotiation of meaning" (Cole, 1992). Sanger and Greenbowe (1996) stated that the key component to constructivism is the negotiation of the meaning of knowledge with others so that a mutually-shared meaning is developed. Duffy and Jonassen (1991) believe that two people can construct an understanding which allows them to come to certain agreements. However, this does not suggest that their understandings are identical. Cunningham (in Bednar *et al.*, 1991) stated that the role of education is "to promote collaboration with others to show the multiple perspectives that can be brought to bear on a particular problem and to arrive at self chosen positions to which they can commit themselves...". Yager (1991) stated that constructivist teachers of science promote group learning, where two or three students discuss how to approach a given problem with little or no interference from the teacher. Bodner (1986) added that progress in science comes from the fact that conflicts between theories are resolved by groups of scientists not individuals. He also

states that there is an importance of two-directional flow of information between students and teachers.

The constructivist believes knowledge is good if and when it works and if and when it allows one to achieve one's goals (Bodner, 1986). Assessment of knowledge can therefore be difficult. Constructivists are primarily concerned with the learner's ability to apply and manipulate knowledge within an authentic task environment and less interested in the learner's ability to acquire knowledge and supply "right" answers (Lebow, 1993). Yarusso (1992) stated that constructivist evaluation considers answers to be right or wrong only to the extent that the answers demonstrate that the student is able to effectively interact in the content area and can defend judgments made within that context. Merrill (1991) added that testing should be integrated with the task and not a separate activity.

For the objectivist, there is an external world totally independent of the mind. Objectivists believe that the world is real. In other words, the world has structure and its structure can be modeled for the learner (Jonassen, 1991). Jonassen stated that the purpose of the mind is to mirror reality and its structure. In a perfect world, we would all have the same interpretation of what is true and false, and right and wrong. Objectivists believe knowledge is void of human emotion and that knowledge consists of universally accepted facts (Yarusso, 1992).

Rieber (1992) saw learning as a progression through a series of stages along a continuum from novice to expert (using Ausubel's vocabulary) or low-level learning to high-level learning (using Gagné's vocabulary). In

describing objectivism, Jonassen (1991) said that learners are told about the world and are expected to duplicate its content and structure in their thinking.

For objectivists the goal of instruction is to reduce the subjective errors that enter everyday life because of imperfect or incomplete knowledge (Yarusso, 1992). Jonassen (1991) stated that the role of education is to help students learn about the real world and the role of the teacher or the instruction is to interpret events for the learner. In objectivist thinking, knowledge can be assessed as either right or wrong and one can demonstrate mastery of knowledge against a determined specified level.

The theoretical base used in this research project will not be just constructivism or just objectivism but a combination of both. Jonassen (1991) stated that most theorists take positions that understanding and learning fall somewhere in the middle of the objectivism-constructivism continuum. Winn (1991) stated he is not yet convinced that all knowledge can be constructed by students. He adds that the students have to have some knowledge from which to start construction. Bodner (1986) also stated that social knowledge, such as the symbols for the elements, can be taught by direct instruction.

Well-known researchers in instructional design such as Reigeluth (1989) and Merrill (Merrill, Li, & Jones, 1990) believe that we should focus on combining elements from these two theories of knowledge in our instructional models. Rieber (1992) added that we can limit the boundaries of a computer microworld (an environment where discovery learning can take place in a computer setting), limit the range of learning outcomes, and make the achievement of predetermined learning objectives possible and probable.

Thus, one can create an environment of guided-discovery or learner-centered instruction that is goal-oriented.

### **Mental Models**

The tasks that one is asked to perform depend heavily on the conceptualizations one brings to the task. Also, the conceptualizations one brings to a topic affect the learning of that topic. Through interacting with the environment, people form internal mental models of the things with which they are interacting (Norman, 1983). Halford (1993) wrote that “the type of mental models that we have about an event profoundly influences the expectations we have about the world, the way we go about solving problems, and the way we acquire new knowledge” (p. 3). In applying this to learning scientific concepts Mayer (1993) stated that in learning how a scientific system works, one obtains a mental model of the system which includes the main components and the cause-and-effect relationships between a change in one component and changes in other components.

Halford (1993) described several “essential” properties of understanding. In order to understand a concept one must have an “internal, cognitive representation or mental model that reflects the structure of that concept” (p. 7). He added that “the representation defines the workspace for problem solving and decision making with respect to that concept” (p. 7). The second property of understanding is generality. Representations which are the basis for understanding “must have a certain degree of generality, in the sense that they must be transferable from one situation to another” (p. 8). The property of

generativity refers to making predictions and inferences from representations that “go beyond the information given” (Bruner, 1957, p. 67; as quoted in Halford, 1993). He continues by saying that mental models assist learning because “once a mental model of a situation is constructed it can be used to predict new aspects of the situation, reducing the effort required” (p. 8). Halford stated that the development of skills is guided by understanding. The final property of understanding is the organization of information. Here Halford stated “understanding should lead to organization of knowledge, so that relations between representations are recognized and kept consistent” (p. 9).

Norman (1983) made three observations about mental models. He said that they are unstable (details about the system are forgotten especially if they have not been used for some time). Next, mental models can be unscientific (“superstitious” behavior patterns are maintained even when they are not needed because they save mental effort and involve little physical effort). Lastly, they can be parsimonious (extra physical operations are done instead of mental planning that would allow one to avoid those actions).

Norman (1983) stated that conceptual models are different than mental models in that conceptual models “are devised as tools for the understanding and teaching of physical systems” whereas mental models “are what people really have in their heads and what guides their use of things” (p. 12). A simpler explanation of the difference between mental models and conceptual models came from Shih and Alessi (1993-1994). They stated that a mental model is a person’s understanding of the environment whereas a conceptual

model is instruction that provides an appropriate representation of the states and relationships. For Shih and Alessi a mental model can represent different states of the problem and the causal relationships among states.

Mental models differ from analogies. Mental models are representations that are active while solving problems and provide the workspace for inference and mental operations (Halford, 1993). Mental models can be used to make inferences about the environment based on premises (Byrne, 1992). Mental models are representations that can be mapped to a segment of the environment (Halford, 1993). In other words, mental models are mappings from a cognitive structure to the environment (Halford, 1993). Analogies differ in that they are mappings from one cognitive structure to another. They are mappings from a base representation to a target representation (Halford, 1993). Therefore, mental models can be used in analogies.

Norman (1983) believed that there are three functional factors which apply to mental models. These factors are belief system, observability, and predictive power. First a mental model reflects one's beliefs about a physical system gained through observation, instruction, or inference. Next, there should be some "correspondence between the parameters and states of the mental model that are accessible to the person and the aspects and states of the mental system that the person can observe" (p. 12). Finally, the purpose of the mental model is to allow one to understand and anticipate the behavior of a physical system.

Gentner and Gentner (1983) noted that analogies can have genuine effects on one's conception of a domain. They supported this by saying that analogies are often used in teaching and that working scientists report they use analogy in theory development. Gentner and Gentner continued their discussion by stating "...people's understanding of their own mental processes is not always correct. It could be that, despite these introspections, the underlying thought processes proceed independently of analogy and that analogies merely provide a convenient terminology for the results of the process." (p. 100).

Gentner and Gentner (1983) investigated how the mental models students held about electricity (analogies they used) affected inferences. Students either used a flowing water analogy or moving crowd analogy to describe their thoughts about electricity. Gentner and Gentner hypothesized that students who use the flowing water mental model should tend to do better on battery questions because serial and parallel reservoirs combine in the same way as serial and parallel type batteries. They should do less well on resistor type questions because one would view a resistor as two impediments instead of one, therefore two resistors lead to less current, no matter the configuration. Gentner and Gentner also hypothesized that for students who use the moving crowd mental model, battery questions should be more difficult because it is hard to find an analogy for batteries with appropriate serial-parallel behavior. However, resistor questions should be easier since resistors can be seen as gates. Therefore, students who use the moving crowd model should correctly respond that parallel resistors give more current than a

single resistor and for serial resistors, less current. Gentner and Gentner's results supported their hypotheses. These researchers found that subjects with the fluid model did better with batteries and subjects with the moving crowd model did better with resistors. Thus, they concluded that the results support a conceptual role for analogical mental models. They also state that based on one's ideas (models) about electricity, individuals infer significant physical relationships about electricity.

An example of an analogy in the area of chemical kinetics is that a multistep chemical reaction mechanism is like a toll road with toll plazas (Brown, LeMay, & Bursten, 1994). In multistep reaction mechanisms the overall rate of the reaction can not exceed the slowest elementary step. Similarly the rate at which cars get to the end of the toll road is dependent on the toll plaza with the least lanes open. A conceptual model of a multistep chemical reaction mechanism can be simultaneous animations of toll roads each with two toll plazas. One animation can show cars on a five lane road reaching a toll plaza with all five lanes open then continuing on to a second toll plaza with only two lanes open. At the same time the second animation can show cars on a five lane road reaching a toll plaza with all five lanes open then continuing on to a second toll plaza with four lanes open. At the end of each road would be some measurement of the rate at which cars are reaching the ends of the roads.

Norman (1983) stated that one's mental models are likely to be deficient, perhaps including unnecessary, contradictory, and erroneous concepts. Furthermore he states, "As designers, it is our duty to develop systems and

instructional materials that aid users to develop more coherent, useable mental models. As teachers, it is our duty to develop conceptual models that will aid the learner to develop adequate and appropriate mental models.” (p. 14).

Larkin (1983) believed that it should be possible to improve one’s success in problem solving by training students to represent problems using physical representation schemas. Larkin states that novices use a naive problem representation. She said that these naive problem representations involve objects that exist in the real world, such as blocks, pulleys, and springs. Larkin added that experts, in addition to this naive representation, are able to construct physical representations. Physical representations contain fictitious, imagined entities such as forces and momenta. She stated that there are physics textbooks which tend not to construct or use physical representations. Additionally, Larkin said that physics textbooks even have confusing representations or ones which are not relevant to the problems. Finally, Larkin stated that the differences in problem solving performance between novices and experts can be attributed to the use of different problem representations.

Mayer (1993) supported Larkin concerning textbook diagrams. In an analysis of six (6) sixth-grade science textbooks, Mayer found that the majority (85%) of the illustrations were either decorating the page or depicting a single element mentioned in the text. He discussed that there are four types of illustrations: decorative, representational, organizational, and explanative. Decorative illustrations are pictures not relevant to the text. Representational

illustrations show just one element mentioned in the text. Organizational illustrations show relations among elements in the text. Finally, explanative illustrations show how a system works. Mayer (1993) added that explanative illustrations help students acquire knowledge that allows inferences and problem solving. He also states “Illustrations that instruct foster acquisition of knowledge in the learner are of particular value in helping a learner build a mental model of how something works.” (p. 258).

Mayer (1993) discussed a cognitive model of learning from text and illustrations. He identified four cognitive processes which are relevant to this kind of learning: selecting organizing, integrating, and encoding. Selecting is paying attention to relevant pieces of information. Organizing is the process of building internal connections among pieces of information that are attended to. Integrating is the process of building external connections between incoming information and knowledge already in long-term memory. Finally, encoding is the process of placing the knowledge constructed in short-term memory into long-term memory. Mayer believed it is the first three processes that are relevant to a model of meaningful learning, which he defines as “the acquisition of knowledge that is systematically coherent and related logically to existing knowledge” (p. 264).

Mayer (1993) described the outcomes of meaningful learning. First there is retention of conceptual information such as the recall of major elements and relations. Next is retention of nonconceptual information such as the recall of isolated facts. The last outcome is problem solving transfer, such as answering open-ended questions that require inferences. In other

words, problem solving transfer is the ability to combine concepts or principles and then apply them to a novel problem solving task. For an example of questions showing problem solving transfer, see Appendix 1 which contains traditional and conceptual questions on stoichiometry. For Mayer, meaningful learning would involve good performance on tests of retention of conceptual information and problem solving transfer, not retention of nonconceptual information.

In a review of twenty studies involving thirty-one tests investigating the use of conceptual models as an instructional technique for improving students' understanding of scientific explanations, Mayer (1989) summarized that conceptual models improve conceptual retention. He found that in ten tests the model group outperformed the control group with an median improvement of 57%. He also summarized that conceptual models will reduce verbatim retention since models help students reorganize material to fit in with their conceptual model and this reorganization means that the students would tend to lose the original presentation format of the material. In five tests of verbatim retention, the control group outperformed the model group with a median reduction for the model group of 14%. Finally, Mayer reported that models improve problem-solving transfer. In sixteen comparisons, the model group outperformed the control group with a median improvement of 64%. These results do indicate that the use of conceptual models can lead to changes in the way students think about the material and improve students' understanding of scientific explanations.

Van Heuvelen (1991) in a review of instructional strategies to teach physics problem solving stated that physicists (experts) depend on qualitative analysis and representations to understand and help construct a mathematical representation of the process, as opposed to some students (novices) who use formula-centered problem-solving methods. He believed that diagrams can (1) “summarize the prominent features of a process while removing noisy details that distract from understanding”; (2) “be strung together to reason qualitatively about more complex processes”; (3) be used to construct a detailed mathematical representation of the process, using special rules and heuristics (p. 891). He added that the diagrammatic representation becomes even more important for developing understanding and for constructing the mathematical representation for more complex processes.

Van Heuvelen (1981) cited eighteen studies and summarizes that the present form of physics instruction is mismatched to the characteristics of students. He stated that after instruction many students still have the same preconceptions and misconceptions as when they started the course. He believes that students’ knowledge consists of a small number of facts and equations randomly stored in their mind. Also, Van Heuvelen believes that students still use a formula-centered approach to problem solving.

Consequently, Van Heuvelen stated many goals of instruction. First, he believes that one of the goals of instruction should be to understand basic physical quantities and concepts and learn to represent these quantities and concepts using qualitative representations and to use the representations to reason qualitatively about physical processes. Next, another goal is to help

students develop quantitative understanding and problem solving expertise by using multiple representations of the process. A third goal of instruction is to form a knowledge hierarchy so that they are more likely to see the world in terms of physical concepts. Another goal is to make students active participants during lectures in constructing concepts, confronting preconceptions that are misconceptions, reasoning qualitatively about physical processes, and learning to use concepts to solve problems. For Van Heuvelen the last goal of instruction is to use concepts and skills repeatedly in a variety of contexts and over a period of time so that the concepts will become a permanent part of students' knowledge.

Nurrenbern and Pickering (1987) found that being able to solve quantitative problems does not equate to understanding the underlying concepts of that problem. Their study involved asking traditional (quantitative) questions and conceptual (qualitative) questions. The quantitative questions could be solved using algorithmic strategies but these strategies could not be used to solve the conceptual questions. Nurrenbern and Pickering found that even though the students were proficient at solving traditional gas law problems, their answers on the conceptual questions did not reflect an accurate view of the behavior of gases. Another finding from the study was students could recite that gases have an indefinite volume but could not apply this concept to answering the conceptual question that gases occupy the entire volume of the container. Appendix 2 contains examples of the questions used by Nurrenbern and Pickering.

Nakleh and Mitchell (1993) also found that students could solve algorithmic problems but not solve conceptual problems. They found that more than 50% of students enrolled in an introductory chemistry course for declared chemistry majors could not solve a conceptual problem. However they found that 85% of the students could solve a similar algorithmic question. Further analysis revealed that 41.7% of the students could solve the algorithmic question but could not solve the conceptual question. These students were able to solve typical algorithmic problems but do not understand the underlying chemistry concepts. Furthermore, these students were unable to apply those concepts when solving conceptual questions.

Data collected in a pilot study investigating student understanding of kinetics concepts at Iowa State University (Lynch and Greenbowe, 1994) on the performance of students solving quantitative and qualitative problems shows that some students were not able to transfer their numerical (quantitative) knowledge to the more conceptual (qualitative) questions. In this pilot study, 93% of the students were able to solve the quantitative question which asks to determine a rate law. The numerical data for this question was displayed in the form of a table. However, only 56% of the students could solve the conceptual question which also asked to determine a rate law. For the conceptual question, the data was given through the use of pictures signifying three reaction conditions. Chi-square analysis ( $\chi^2 = 37.95$ ,  $p < 0.0001$ ) showed there was a significant difference in the number of students who obtained the correct answer on the quantitative question than on the conceptual question.

Appendix 3 contains both questions (quantitative question-question 1; conceptual question-question 5) and numerical data. Further research on transfer of numerical knowledge to conceptual questions is discussed in the following section.

### **Transfer of Learning and Understanding**

The ability to transfer learned information to a new situation provides one form of evidence that understanding is present (Royer, 1986). Andre (1986) added that students must be able to apply the strategies and knowledge they have acquired to problems that they may need to solve in the future. However, the primary goal of education is not to provide students with knowledge that is applicable to the everyday problems of living. The goal of problem solving transfer is to use prior knowledge to facilitate the learning of subsequent classroom knowledge (Ausubel, Novak, & Hanesian, 1978).

Research on the differences between experts and novices when solving problems gives some insight on the transfer of knowledge and problem solving. When investigating problem solving behaviors of experts and novices in physics, Chi, et al. (1981) found that experts possess a great deal of procedural knowledge with explicit conditions for applicability whereas novices possess sufficient declarative knowledge about the physical surface features of a problem but not abstract solution methods. Camacho and Good (1989) in researching problem solving behaviors of experts and novices when solving chemical equilibrium problems also found that successful subjects made comments beyond the context of the problems and used or mentioned relevant

information not stated in the problems whereas unsuccessful subjects did not perform any of these transfer-related behaviors. Greenbowe (1983), in the area of stoichiometry, found similar results to Camacho and Good. He found that experts bring extraneous information to the problem that novices do not. This information aids experts in correctly solving the problems.

In conclusion, in order to determine if understanding of chemical kinetics is present, students should show transfer of learning. This study will use a transfer problem in order to gain a measure of students' understanding of chemical kinetics. Specifically, performance on a quantitative question concerning rates of reaction will be compared to performance on a qualitative (conceptual) question concerning rates of reaction.

### **Problem Solving**

Resnick (1987) stated one of the important goals of education is the acquisition of higher order thinking skills associated with problem solving. In a review of the field of chemical education research, Herron (1990) listed many factors which influence student performance in problem solving. Student beliefs, problem complexity, memory-demand, and working memory are just a few of the factors that seem to play a role in student performance on chemistry content problems.

In addition to those factors listed by Herron, conceptual understanding is important. Herron (1990) stated, "Clearly, how well concepts are understood is an important factor in problem-solving success and it seems reasonable that how concepts are organized - what concepts are connected - will also be

important.” (p. 35). Kempa and Nichols (1983) found that good problem solvers possess more concepts of higher levels of abstractness than some of poor problem solvers. They also found that although good and poor problem solvers generally possessed the knowledge of the same concepts, the links between concepts are stronger and the number of links between concepts is greater for good problem solvers compared to poor problem solvers. Gorodetsky and Hoz (1980) found that unsuccessful problem solvers were unproductively using the relevant concepts necessary to solve problems. They state that this may be because the unsuccessful problem solvers comes from “partial or unclear perception of the concepts used”. Camacho and Good (1989) analyzed the problem solving behaviors of successful and unsuccessful problem solvers dealing with chemical equilibrium problems. These researchers found that unsuccessful problem solvers tended “to show or use many chemical misconceptions of equilibrium and related concepts and principles”, whereas successful problem solvers tended “to show adequate chemical conceptualizations of the concepts and principles involved”.

However, research has shown that numerical problems can be solved without understanding the underlying concepts (Yarroch, 1985; Herron & Greenbowe, 1986; Nurrenbern & Pickering, 1987; Sawrey, 1990; and Pendley, Bretz, & Novak, 1994). In the Herron and Greenbowe study on stoichiometry (1986), some students used cues in the problem statement and recalled algorithms based on these cues. Sawrey (1990), in replicating the Nurrenbern and Pickering (1987) research using the same quantitative and qualitative questions on gas laws and stoichiometry but a more heterogeneous college

student population, made essentially the same conclusion as Nurrenbern and Pickering - students could not solve conceptual questions even if they could solve numerical problems having the same underlying concepts. Appendices 1 and 2 contain examples of questions used in the Nurrenbern & Pickering (1987) and Sawrey (1990) studies.

Herron (1990) in his review of chemical education research stated that representation is also a key component in successful problem solving. Herron and Greenbowe (1986) found that successful problem solvers made connections between symbolic representations, such as formulas and equations, the microscopic species symbolized and macroscopic events. The less successful problem solvers tried to use problem cues to recall algorithms. Larkin (1983) discussed that many differences in the problem solving performance of experts and novices are due to different problem representations. Novices tend to use "naive problem representations" which are comprised of surface features or things that exist in the real world (such as pulleys and springs) while experts do not. Nahkleh (1990) interviewed high school students concerning their understanding of acid-base concepts. She found that students could not describe what was occurring at the molecular level during a titration of a strong acid with a strong base although they could solve numerical problems dealing with strong acid-strong base titrations. Yaroch (1985) found that while students could correctly balance chemical equations, differences occurred in the diagrams (circles were used to represent atoms and molecules) used by students to represent the chemical equations. Correct representation involved consistency with the number of particles, coefficients,

and subscripts in the chemical equation. Incorrect representation involved students staying consistent with only the number of particles. Appendix 4 contains examples of correct and incorrect student representations of the chemical equations from the Yarroch study.

Item analysis data collected from a chemistry exam administered to students at Iowa State University during the Fall 1994 semester revealed that many students could not draw a molecular picture after two molecules of ammonia have formed given a specific number of starting nitrogen and hydrogen molecules as well as the balanced chemical equation. Appendix 5 contains the problem and correct and incorrect student molecular diagrams from the Iowa State University exam. This trend also holds true for buffer and kinetics problems. Item analysis data from another chemistry exam administered to students at Iowa State University during the Fall 1994 semester also revealed that students had difficulty with problems involving conceptual questions. Appendix 6 contains sample exam questions and samples of student work from this exam.

Therefore, this study will include both quantitative and qualitative (conceptual) questions to assess understanding of chemical kinetics. Student performance on these two types of questions be compared. This comparison will determine whether students have an understanding of the concepts within the topic of chemical kinetics.

## **Learning Styles and Cognitive Styles**

When learning style research was in its infancy the term “cognitive style” was used instead of “learning style”. Messick (1976) defined “cognitive style” as “stable attitudes, preferences, or habitual strategies determining a person’s typical modes of perceiving, remembering, thinking, and problem solving” (p. 5). Schwen, Bedner, and Hodson (1979) had a slightly simpler definition. They defined cognitive style as a person’s typical or habitual mode of problem solving, thinking , perceiving, and remembering. The definition proposed by Schwen, Bedner, and Hodson will be the one used throughout this research.

Kirby (1979) stated that the term “learning style” came into use when researchers began searching for ways to combine course presentation and materials to match the needs of each learner. The widely accepted definition of learning style came from Keefe (1979). Keefe defined learning style as the “characteristic cognitive, affective, and physiological behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment” (p. 4). This definition of learning style will be used throughout this research.

Using these two definitions, learning style is a broader term which includes cognitive style. Cognitive styles are the ways students solve problems, think, perceive, and remember. Learning styles are behaviors which act as indicators of the ways that students solve problems, think, perceive, and remember. Saracho (1989) clarified this distinction by stating that cognitive styles usually denote techniques of responding and performing in diverse

situations, whereas learning styles are behaviors which actually can be observed.

One such cognitive style is that of field dependence/field independence. Messick (1976) defined this cognitive style as a global versus analytical way of approaching the environment. He stated that field independence denotes a tendency to experience items as discrete from their backgrounds and a facility to overcome the influence of an embedding context, as opposed to field dependence which entails a tendency to experience items globally in an undifferentiated manner.

Saracho and Spodek (1981) listed behaviors of both field dependent and field independent individuals. Some behaviors exhibited by those who are field dependent are they rely on the perceptual field; they experience their environment in a relatively global manner by conforming to the effects of the prevailing context; they are dependent on authority; and they search for facial cues in those around them as a source of information. Garger and Guild (1984) stated that field dependent students use a spectator approach for concept attainment. Saracho and Spodek (1981) stated that some behaviors for those who are field independent are they perceive objects as separate from the field; can abstract an item from the surrounding field and solve problems that are presented and reorganized in different contexts; and they experience an independence from authority which leads them to depend on their own standards and values. Garger and Guild (1984) stated that field independent students use a hypothesis-testing approach to attain concepts.

Learning style research should be important to educators. This type of research can be used to aid in creating more effective learning environments for students. By understanding the different cognitive styles in students, educators may be able to create learning environments in which students can flourish. To be able to do this educators must be able to identify behaviors or learning styles in students.

### **Field Dependence/Independence**

Polya (1973) talked of four phases to problem solving, one of which is understanding the problem. To understand the problem one must be able to determine what is required of one to do. Furthermore, one should be able to point out the principal parts of the problem: the unknown, the data, and the condition. Thus it is important for students to identify the necessary information needed for them to accomplish what is required of them. The ability to identify the relevant information needed to solve a problem or the ability to free oneself from the effects of the context in which the problem is placed is called field independence. Those who have difficulty doing this are called field dependent.

Field dependence/independence research began with studies on perception of the upright (Witkin & Goodenough, 1981). In order to gain a fuller understanding of how one determines the upright, information processing modes, field factors, and local sensory factors were investigated. The direction of the perceived upright can usually be determined by two sets of experiences working together. First, one uses vision to determine the field

which has the character of a framework where the main axes correspond to the true vertical and horizontal directions in space. Second, one uses other senses to determine the direction of gravity and thus the vertical direction of space. Since the two coincide, the upright can be determined using either one or the other method. The two methods were separated experimentally using three tests. Both the body-adjustment test (BAT) and the rod-and-frame test (RFT) were ways to tilt the visual framework without altering the gravitational pull on one's body. The rotating-room test (RRT) alters the direction of force acting on one's body without changing the visual framework. For accurate performance on the body-adjustment test and the rod-and-frame test one must use cues from the body or rod to adjust to the gravitational vertical but for the rotating-room test relying on the body would lead to inaccurate results. One had to separate body and rod from room and frame. Those who high performance on these tests were classified as field independent whereas those who performed poorly were classified as field dependent (Witkin & Goodenough, 1981).

It was considered that the tests also involved separation of an item (body or rod) from an organized field (room or frame). The Group Embedded Figured Test (GEFT) was developed to facilitate the identification of field dependent and field independent subjects. This test required one to disembed a figure from an organized field without involving perception of the upright. Ones who were not able to find the simple figures within a complex designs were classified as field dependent. Those who could not perform this task also could not keep body and rod separate from room and frame in the orientation

tests. Those who performed well on the orientation tests, ones who were field independent, could easily find the simple figure within the complex design (Witkin & Goodenough, 1981). A sample of a test item from the Group Embedded Figure Test can be found in Appendix 7.

Field independence/field dependence appears to be a component of one's general intelligence. Horn (1989) identified several factors of intelligence, which themselves are comprised of subtest measures or abilities. One factor is knowledge or crystallized intelligence,  $G_c$ . A large variety of measures of knowledge indicate this broad factor which is highly indicative of intelligence. Included in this factor are:

general information - Measures knowledge about many areas of scholarship including the physical sciences.

verbal knowledge - Measures understanding of the meaning of words.

problem definition/representation - Measures the ability to define and solve problems. Part of which includes indicating which information is required to solve the problem and which information is not.

syllogistic reasoning - Measures the ability to determine whether conclusions logically follow from particular premises and arguments.

story problem representation - Measures the ability to determine what operations are necessary for solving a problem. Given a verbal problem where mathematical calculations are needed one must choose the correct series of calculations that can lead to a correct solution.

A second factor is broad reasoning or fluid intelligence,  $G_f$ . The reasoning represented by  $G_f$  involves many mental operations such as identifying relations, formulating concepts, recognizing concepts, identifying conjunctions, and recognizing disjunctions. The reasoning test that measures fluid intelligence would not depend heavily on knowledge that is available to some and not others. Some subtest indicators of fluid intelligence are inductive reasoning, measured using letter series, number series, and/or figure series; matrices reasoning with visual patterns; interpreting verbal reasoning pertaining to visual patterns; classification (identifying an element which does not belong with the others); conjunctive reasoning, as measured with set recognition (which items do and do not belong together); and analogies reasoning (different from that in crystallized intelligence when words of the analogies are equally familiar or equally unfamiliar so that the relationship of

the words, not knowledge, introduces variance in individual differences in solving the problem).

Fluid intelligence will be measured instead of crystallized intelligence, when reasoning, not knowledge, is required for the following crystallized intelligence tests:

story problem representation (general reasoning) - require reasoning with everyday information and concepts

syllogistic reasoning - the terms must be equally familiar or equally unfamiliar and the reasoning of the problem must be difficult

assessing everyday arguments and evidence - the main source of the difficulty in the problem must be because of reasoning

problem definition/representation - the information of the problems must use basic English not requiring a large vocabulary

effectiveness in using problem-solving strategies - the strategies must not be unfamiliar.

The third factor Horn described is called broad visual intelligence. This involves tasks which require fluent visual scanning, Gestalt closure, mind's

eye rotation of figures, and the ability to see reversals. The following abilities are indicative of broad visual intelligence:

visual manipulation, as based on paper folding - involves manipulations that “simulate the folding of paper, punching a hole in that paper, unfolding the paper, and identifying where the holes will appear” (Horn, 1981, p. 80)

analytic perception, as measured in Gottschaldt figures (also known as hidden figures) - involves identifying “whether or not a figure can be traced within a collection of many more lines that the lines of the figure” (Horn, 1981, p. 80). Gottschaldt figures have also been used to measure the cognitive style of field dependence/independence (Witkin & Goodenough, 1981).

Gestalt closure - involves filling the gaps to complete a view that is obscure

design memory - involves visualizing steps in drawing a figure or visualizing how lines must be put together to create a figure

visual constancy - involves visualizing how a figure looks as it is rotated in space

It is difficult to determine in what specific factor of intelligence field independence/field dependence fits. According to Horn's descriptions of factors of intelligence, field independence/field dependence fits into parts of the three factors (crystallized intelligence, fluid intelligence, and broad visual intelligence). All of these factors of intelligence involve either the ability to process or manipulate visual information or the ability to disembed information required to solve problems. Field independence is the ability to accomplish such tasks.

### **Field Dependence/Independence and Academic Achievement in Chemistry**

Research with respect to general learning abilities has found that information recall in field dependents is hindered if the important cues are irrelevant or if the relevant cues are not prominent. In contrast, field independents are able to identify the important visual cues whether or not they are prominent (Witkin, Moore, Goodenough, & Cox, 1977). Moore (1985) found that field independents and neutrals both scored significantly higher than field dependents on a visual location task. It would follow that field independence/dependence should influence one's ability to learn chemistry.

Witkin, Moore, Goodenough, and Cox (1977) found that field independence contributes greatly to achievement in chemistry. Research by Lawson (1983) discovered that disembedding ability or field independence was an important predictor of science achievement. Niaz (1987) found that there was a significant correlation between field independence and proportional reasoning tasks.

Chandran, Treagust, and Tobin (1989) in a study investigating the role of formal reasoning ability, prior knowledge, memory capacity, and field independence/dependence on achievement in chemistry found that field independence/dependence was not a factor in chemistry achievement. This finding is suspect. The measures used in their study consisted mainly of stoichiometry questions. The types of questions the researchers used do not appear to require disembedding ability. Also, there are many other topics within chemistry, not just stoichiometry. Examples of other topics which appear to require disembedding ability are chemical equilibria, acids and bases, electrochemistry, and kinetics. Chandran, Treagust, and Tobin listed as one of their limitations that the instrument used to measure field independence/dependence may not have been valid. Furthermore they stated that the characteristics of the chemistry achievement tasks should be contemplated.

Herron (1990) stated that, "The ability to visualize the situation described in a problem probably aids problem solving by providing a representation that guides solution." (p. 39). Herron and Greenbowe's (1986) research supported this statement. Successful problem solvers frequently referred to the macroscopic conditions of the problem or described what atoms and molecules must be doing. Less successful problem solvers did not. They conclude that visualizations seem to provide useful information about what is sensible to do.

### **Spatial Ability and Academic Achievement in Chemistry**

Research by Bodner and McMillen (1986) showed that there is a statistically significant correlation between spatial ability and performance on chemistry problems that require highly spatial manipulations. The Pearson correlations obtained from correlating chemistry problems and spatial ability subscores ranged from 0.29-0.35. Furthermore, Bodner and McMillen found a significant correlation of 0.30 between performance on the spatial tests and on a comprehensive final exam in General Chemistry. Carter, LaRussa, and Bodner (1985), in a replication of the Bodner and McMillen (1986) study, found that spatial ability is correlated with success on chemistry exams with college chemistry students at a large Midwestern university. Specifically, Pearson correlations between the spatial ability tests and the comprehensive final exam in chemistry ranged from 0.17-0.25.

### **Student Profiles and Field Independence/Dependence**

At Iowa State University there are three different introductory Chemistry courses. These courses are designed for students with particular majors. Students who take these courses enter with various types of backgrounds. Some students have strong and some have weak mathematical backgrounds. Some possess poor problem solving skills, while others have very good problem solving skills. Research (Frank, 1986; Niaz, 1987) on career choice and field independence-dependence has shown that field-independent students tend to choose fields in areas such as mathematics, the sciences, and

engineering. Field-dependent students tend toward fields in areas such as the social sciences, humanities, and the “helping” professions.

Thus, in college general chemistry courses for physical science majors and engineering majors, one would expect to find more field independent students than field dependent students. In courses for students with other science majors (i.e. agronomy), one would also expect to also find more field independent students than field dependent students. However, now one would find a greater percentage of field dependent students than in the physical science majors general chemistry course.

In a pilot study for this research a truncated version of the Group Embedded Figures Test (GEFT) was administered to general chemistry students at Iowa State University in the fall of 1994. This truncated version included 12 questions instead of 18 questions. Analysis of the data showed that the students in this general chemistry course differed greatly from what one would expect based on the previous description. Since this assessment was given during a review session, attendance was low. Only 79 of 140 students (56%) took the shortened GEFT. Of the 79 students (41 male and 38 female) who took the exam, 65 were classified as field independent, 10 as field neutral, and 4 as field dependent. Broken down by gender, 33 males and 32 females were classified as field independent; 6 males and 4 females as field neutral; and 2 males and 2 females as field dependent. Classification was determined using the guidelines proposed by Renna and Zenhausern (1976). The data suggest that very high percentage of field independent students were enrolled in this course. One explanation can be obtained by analysis of the majors of the

students enrolled. A greater number of physical sciences majors were enrolled this semester when compared to previous semesters. Thus one would expect that there would be a larger percentage of field independent students. Another explanation can be because the truncated version of the test was used. Since six of the questions were not used, the ability to differentiate between the groups (field independent, field neutral, and field dependent) was diminished. This could have resulted in students being incorrectly identified. Perhaps by administering the complete version of the test to the students, there would have been fewer students classified as field independent and more classified as field neutral or field dependent.

For this research study, the complete version of the Group Embedded Figures Test will be used. This should lead to a truer classification of the field dependence/field independence of the students. Therefore one should expect to find less field independent students and more field neutral and field dependent students in the sample.

### **The Computer as a Method of Instruction**

In studying the use of the computer as a method of instruction there is great debate. A meta-analysis by Clark (1985) found that there is basically no significant difference when comparing media (computers vs. other media) with respect to student achievement. Clark (1983) argued that it is not the medium that causes the change in learning but the curriculum reform that accompanied the change. Clark (1983) added that "media are mere vehicles that deliver instruction but do not influence student achievement any more

than the truck that delivers our groceries causes changes in our nutrition.” (p. 445). According to Clark, one should not compare computer instruction to traditional instruction or compare the computer to another medium as the only method of instruction. However, there are others who disagree with Clark.

Kulik, Kulik, and Bangert-Drowns (1985) stated that as a result of their own meta-analysis study (Kulik, Bangert-Drowns, and Williams, 1983) that most computer based educational programs have had positive effects on student learning. Kulik and Kulik (1991) performed another meta-analysis with more recent studies and found the same result as their earlier meta-analysis. Niemiec and Walberg (1985) also came up with a similar conclusion in that computer-assisted instruction is effective in raising student achievement scores. Kozma (1994) argued that Clark’s metaphor of the delivery truck is not applicable today since there are many educators who believe that teachers do not “deliver” instruction but that students construct their own knowledge. He states that

to understand the role of media in learning we must ground a theory of media in the cognitive and social processes by which knowledge is constructed, we must define media in ways that are compatible and complementary with these processes, we must conduct research on the mechanisms by which characteristics of media might interact with and influence these processes, and we must design our intervention in ways that embed media in these processes. (p. 8)

However for specific areas within a subject or for a specific topic a difference between media may be found. Two research studies have shown that computer-based simulated experiments are more effective than

traditional laboratory experiments for increasing learning (Smith, Jones, and Waugh, 1986; Jackman, Moellenberg and Brabson, 1987). Each of these two studies investigated different topics within general chemistry. Smith, Jones, and Waugh (1986) studied the topics of equilibrium and kinetics whereas Jackman, Moellenberg and Brabson (1987) looked at the topic of spectrophotometry.

Krajcik, Simmons, and Lunetta (1988) discussed research strategies for the study of students' science concepts and science problem solving using computer software. They state as one of their implications for research that one should investigate whether there are relationships that exist between computer graphics and learner variables. Hahn (1983-1984) found that field dependent students benefited from a computer-assisted instructional teaching method in learning about a computerized information retrieval system. Hahn believed this was a result of the added structure of the learning environment from which field-dependent students benefit. MacGregor, Shapiro, and Niemiec (1988) found that field-dependent students perform better in a computer-assisted instruction environment than in a traditional instruction environment. They added however that the research is inconclusive concerning the relationship between cognitive style and the effects of computer-assisted instruction on achievement. MacGregor, Shapiro, and Niemiec (1988) also stated that, "Additional research is needed to evaluate the effectiveness of computer-assisted learning environments for students with different learning profiles." (p. 455).

A study by Lynch and Greenbowe (1993) investigated the effectiveness of a computer based simulated experiment compared to a traditional laboratory experiment. The computer-based simulated experiment was an animated version of a traditional laboratory experiment dealing with chemical kinetics. This experiment attempted to show the relationship between the concentration of reactants and the rate of reaction. In addition, students were asked to determine the rate law equation for the reaction from their experimental data. In this study five laboratory sections of approximately twenty students each were randomly assigned to work with either the computer-based simulated experiment or the equivalent traditional experiment in the laboratory. Three lab sections ( $\underline{n} = 51$ ) worked with the simulated experiment while two sections ( $\underline{n} = 33$ ) worked with the traditional experiment.

Results from this study showed that there was no significant difference between student scores on the immediate laboratory postquiz for those who performed the traditional experiment versus those who performed the simulated experiment ( $p = 0.2496$ ). Therefore, it did not matter whether the students completed the simulated experiment or the traditional experiment. From the data one can determine that neither group did especially well on the laboratory postquiz which was scored on a 10-point scale (traditional experiment,  $\underline{M} = 4.5$ ,  $\underline{n} = 33$ ; simulated experiment,  $\underline{M} = 3.8$ ,  $\underline{n} = 51$ ). Table 1 contains the data analysis.

Data shown in Table 2 reveals no significant differences in student scores on the kinetics portion of the hour exam between the traditional experiment group, the simulated experiment group, and those students not

**Table 1. ANOVA Table for the Lab Quiz Scores (out of 10 possible points)**

Source	df	Sum of Squares	Mean Square	F value	p Value
laboratory type	1	10.008	10.008	1.345	0.2496
residual	82	610.381	7.444		

Incidence Table (Number of Participants, Average Score)

Laboratory Type	Count	Average Score	Standard Deviation
simulation	51	3.824	2.504
traditional	33	4.530	3.046

**Table 2. ANOVA Table for the Exam 3 - Kinetics Scores (out of 30 possible points)**

Source	df	Sum of Squares	Mean Square	F value	p Value
laboratory type	2	32.630	16.315	0.721	0.4880
residual	158	3576.488	22.636		

Incidence Table (Number of Participants, Average Score)

Laboratory Type	Count	Average Score	Standard Deviation
simulation	47	22.511	5.324
traditional	46	23.022	4.041
none	68	21.941	4.791

enrolled in the laboratory course ( $p = 0.4880$ ). Students not enrolled in the laboratory course served as the control group. The laboratory experiment, either traditional or simulated, did not help students achieve better scores on the kinetics portion of the hour exam compared with those students who did not perform the experiment.

On the chemical kinetics portion of the final exam, a significant difference between students who performed the traditional experiment and those who were not enrolled in the laboratory course was detected ( $p = 0.0023$ ). A significant difference was also seen between students who perform a simulated experiment and those not enrolled in the laboratory course ( $p = 0.0021$ ). There was no significant difference between students who performed a simulated experiment and those who performed a traditional experiment ( $p = 0.9989$ ). Therefore, students who performed the experiment, either computer or traditional, did better on the chemical kinetics portion of the final exam when compared to students who did not do the experiment. Table 3 contains the ANOVA analysis.

These results indicate that a simulated experiment can be as effective as a traditional experiment. Students who performed a simulated experiment did as well as students who performed a traditional experiment on all the measures, which included an immediate postquiz after the experiment and chemical kinetics questions on both the hour exam and final exam. Students who do either the computer experiment or the traditional experiment tended to score higher on chemical kinetics measures than those students who do not do the experiment.

**Table 3. ANOVA Table for the Final Exam - Kinetics Scores (out of 24 possible points)**

Source	df	Sum of Squares	Mean Square	F value	p Value
laboratory type	2	1587.431	793.715	9.424	0.0001
residual	208	17518.541	84.224		

**Incidence Table (Number of Participants, Average Score)**

Laboratory Type	Count	Average Score	Standard Deviation
simulation	53	16.528	8.266
traditional	54	16.444	8.248
none	104	11.000	10.029

**Scheffé Table for the Final Exam - Kinetics Scores**

Comparison	Mean Difference	p value
simulation vs. traditional	0.084	0.9989
simulation vs. none	5.528	0.0021
traditional vs. none	5.444	0.0023

The results on the hour and final exam may be explained by looking at the number of questions on the hour and final exams. On the hour exam, there were eleven questions whereas there were only six on the final exam. Perhaps with more questions on the final exam the differences between those who did the experiment and those who did not would decrease or perhaps it might increase. Students who performed either the traditional or simulated experiment spent more time working on chemical kinetics. As a result of

time-on-task research, Karweit (1984) stated that the more time one spends working on a task, the better one will be at later performing the task.

### **Computer Simulations**

Computer simulations are based upon mathematical models or equations. The software is programmed to accept several inputs of variables and then display models or simulations as real world events. In chemical kinetics time, temperature, concentration, pressure, and catalysts are variables.

Computer simulations are different from animations. In the computer simulations the students are able to make choices concerning variables and the computer responds to those choices. Animations usually display a visual representation of a dynamic event.

Rieber and Parmley (1992) stated that in using the computer for the instruction of chemistry, "simulations seem to offer the most potential of exploiting both the display and the interactive strengths of the computer". Gress (1982) added by receiving immediate feedback on their decisions while in the structured environment students can learn specific problem solving strategies through simulations. Reigeluth and Schwartz (1989) said that simulations can enhance the transfer of learning by providing an environment that approximates the real world setting. Studies by Rieber (1990a, 1990b) have shown that structured simulations have been successful as practice activities in teaching physical science.

## **Chemical Kinetics**

The area of chemical kinetics is an area that has received little attention by chemical education researchers. Only one study by Smith, Jones, and Waugh (1986) investigated an aspect of chemical kinetics. In this study the researchers used an interactive computer-assisted videodisc to provide tutorial lessons on the topics of chemical kinetics and equilibrium. Smith, Jones, and Waugh found that students who viewed the videodisc scored significantly higher on an immediate postquiz than students who did not view the videodisc. Presently, there has been no misconception research done in this area. From personal data collection and analysis (1990-1994) as a teaching assistant at Iowa State University and discussions with professors from Iowa State University (Greenbowe, 1994 - personal communication and exam item analysis data), many students have great difficulty with this topic. In addition, at Iowa State University, Lynch and Greenbowe have observed a consistently poor performance by students on chemical kinetics questions on the final examination. Appendix 11 shows item analysis data from General Chemistry 177 (a course for physical sciences majors and chemical engineering majors) and General Chemistry 164 (a course for soft science majors and prehealth professionals).

A study by Lynch and Greenbowe (1994) identified examples of difficulty that students have in chemical kinetics. One such example is the inability of students to determine a rate law from chemical experimental data. Some students are able to perform the mathematics of calculating the correct order of the reactant (i.e., determine the order of the reactant to be zero order), but

then make an incorrect written statement about that order (i.e. write down the order of the reactant as first order). Others try and use only data from one of the experiments to determine the order of reactants. In order to solve the problem the “method of initial rates” must be used. This method requires one to use data from two or more related kinetics experiments. Appendix 8-Student A work contains a correct solution method for answering a method of initial rates problem. Appendix 8-Student B work shows how a student calculates the correct order, but not put the correct number in the rate law expression. Appendix 8-Student C work shows how the student used only one set of data to incorrectly determine the rate law.

Another example of student difficulty is in determining the units of the rate constant in a specific rate law expression. Units of the rate constant are dependent on the overall order of the reaction and thus can be different in different instances. Therefore, students either do not include any units (similar to equilibrium constants,  $K_{eq}$ , discussed earlier in the semester) or use the same units that one uses for rates (M/s). Other students simply calculate the incorrect units. Appendix 9-Student D work contains a correct solution method for determining the units of the rate constant. Appendix 9-Student E work shows how a student calculates a rate constant, but does not include any units for the rate constant. Appendix 9-Student F work shows how a student who calculates the incorrect units for the rate constant.

A third example of student difficulty is in using initial concentrations to determine the time for the reaction to take to reach another concentration. Some students simply use the wrong formula for determining the

concentration at a specific time after identifying the correct order for the reaction (i.e., student identifies the reaction as first order, but then uses the equation for a second order reaction). Others use the rate instead of the rate constant. Appendix 10-Student G work contains a correct solution method for determining the time for a reaction to reach another concentration. Appendix 10-Student H work shows how a student uses the wrong formula for calculating the time. Appendix 10-Student I work shows how a student uses the rate of reaction instead of the rate constant when calculating the time.

Finally, at Iowa State University we have discovered a consistently poor performance by students on chemical kinetics questions on examinations. Appendix 11 shows sample questions and item analysis data. The item analysis data illustrates the performance of students enrolled in different general chemistry courses which were taught by different professors during different semesters.

### **Prerequisite Skills and Knowledge**

The area of expert and novice research provides researchers with the foundation that there are prerequisite skills and knowledge one must have in order to be successful in solving both quantitative and qualitative problems. Successful problem solvers possess a complete set of knowledge on the topic of the problem while unsuccessful problem solvers do not (i.e. Chi, et al., 1981; Camacho and Good, 1989; Larkin, et al., 1980). However, research in other areas also adds to this foundation.

Andre and Ding (1991) found that students' performance on a basic electricity problem was influenced by their knowledge of relevant declarative facts. In this study undergraduate students were asked to perform a series of battery, bulb, and buzzer circuit problems. The students were asked to think-aloud while doing these tasks in which they were given electrical components and asked to make the bulb or buzzer work. Andre and Ding stated that two pieces of declarative knowledge were important for solving some of the more difficult circuit problems. They assert that for successful task performance one needed to know where the terminals are on a bulb and where the terminals are on a battery.

Sumfleth (1988) concluded from her research on students' achievement on problems in the areas of structure-property relations and setting-up of formulas that knowledge of terms is a necessary prerequisite for successful problem solving. In this study students, aged 16+ years, in a high school chemistry class in Germany were given an explanation test, an achievement test, and a connectivity test. For the explanation test students were asked to give an explanation for a number of terms which included *solution* and *compound*. For the achievement test students were given two sets of three problems each which consisted of structure property relations and the setting up of formula. Examples of the questions given in the achievement test are "Describe the structure of the water molecule."; "Which properties follow from this?"; and "Ten liters of a gas, whose molecules consist exclusively of oxygen atoms, weigh 21.4 g at standard conditions. Calculate the molecular formula of the gas." For the connectivity test the students were given a list of chemical

terms, which included *molecules*, *substances*, and *molecular formula*. and were asked to formulate statements concerning chemistry using the terms. In a correlational analysis between the explanation test and the achievement test, Sumfleth found there was no correlation between the two tests. Sumfleth concluded that although students possessed a reasonable basic knowledge of chemical terms they were unable to make correlations between them and to apply their knowledge.

Shavelson and others (1988) found that the ability to transform a problem from its original symbolic form (i.e. words) into an alternative representation (i.e. mathematical, iconic) in order to arrive at a solution affected the accuracy of students' solutions to gas law questions. In this study 20 high school students were asked to think-aloud while solving 20 gas laws problems. An example of one of the gas law problems used was "200 liters of gas, under a pressure of 1 atm, were compressed until the pressure was 4 atm. What will the new volume of the gas be, assuming that there is no change in temperature?". The transcripts of the protocols were analyzed to determine the kinds of symbolic representations the students used to solve the problems. Shavelson and others concluded from their results that students who generated a correct representation of the problem (either the correct formula or the correct description of the relationship between the variables) will correctly solve the problem.

Lynch and Greenbowe (1994) found that the students enrolled in a general chemistry course at Iowa State University had difficulty translating a verbal representation into a mathematical equation. Students were asked to

write a sentence comparing the relative rates of reaction between two reactions (i.e. the reaction in Flask I will react at a rate two times as fast as the reaction in Flask II) and then choose the correct mathematical relationship that represents the explanation [i.e.  $\text{rate (reaction in Flask I)} = 2 \times \text{rate (reaction in Flask II)}$ ]. On an exam, two questions asked for this type of response. The percentages of students who chose the correct mathematical equation were 64% and 52%. Appendix 3 contains the specific kinetics questions and the item analyses. Lynch and Greenbowe concluded that success in chemical kinetics is partially dependent on certain algebra skills, such as ratios and equation manipulation.

College students even have difficulty with simple, low-level mathematics skills. Menis (1987) found that students had difficulty transferring mathematical concepts to chemistry. Students were able to solve mathematical problems concerning proportions, percentages, and changing variables but had lower success in solving chemical problems involving the use of these same mathematics concepts. An example of a mathematical question involving the concept of ratios is, "There are 600 students and 30 teachers in a school. What is the ratio of students to teachers in this school?" An example of a similar question in chemistry involving the ratio concept is, "Analysis of a compound showed that it is made up of 9.2 moles of carbon, 27.6 moles of hydrogen, and 4.6 moles of oxygen. What is the empirical formula of this compound?" Students who have difficulty solving ratio problems, such as the student and teacher problem, also have difficulty solving chemistry problems involving ratios.

Gabel and Sherwood (1984) stated that students must possess other mathematical skills, such as working with scientific notation and performing multistep problems, if they are to have success in solving chemistry problems. In this study, 332 high school students were given a 14 item multiple choice mathematics test with questions similar to those that would be found on a mole concept test. This analog mathematics test used oranges or granules of sugar as the analog instead of using moles of atoms. An example of one of the questions used by Gabel and Sherwood is, "A bag contains 12 oranges, weighs 4 pounds, and has a volume of 7 pints. How much would 48 oranges weigh?" From this research, Gabel and Sherwood (1984) found that chemistry problems involving division were difficult for many high school students.

Further evidence of the need for basic mathematical skills and prerequisite knowledge is the presence of a review of mathematical concepts in some chemistry textbooks. In the textbooks used in some of the general chemistry courses at Iowa State University, Chemistry: The Study of Matter and Its Changes (Brady and Holum, 1993) and Chemistry: The Central Science (Brown, LeMay, and Bursten, 1994), a review of basic mathematics skills is found in the appendix of these textbooks. This review includes working with exponential numbers; powers and roots; logarithms; and graphing, which includes the calculation of slope. Both books also include fairly detailed instructions for using calculators to perform the previously listed calculations. Using the calculator for graphing is not included as a topic. In addition, the Brady and Holum textbook gives an explanation of using one's calculator to do simple calculations such as multiplication. There are also a number of self-

help books which offer reviews of mathematics for chemistry. Basic Mathematics for Beginning Chemistry (1990), Basic Mathematics for Chemists (1994), and Math Survival Guide - Tips for Science Students (1994) are examples of these self-help books. Examples of student work collected at Iowa State University showing algebra and mathematical mistakes can be seen in Appendix 12.

Algebra skills are important in solving many types of chemistry problems, including chemical kinetics problems. Therefore, instructional designers must be aware of this fact when developing chemistry instruction. In this study the computer program used by the students contains examples and problems with step-by-step mathematical solutions with very detailed explanations for the reasons for each step. Students who do not use the computer program and receive instruction from a teaching assistant generally get similar step-by-step mathematical solutions and explanations when discussing chemical kinetics problems.

## **Summary**

Cognitive theory provides us with the guidelines for conducting research dealing with learning. Drawing from Piaget, constructivism, behaviorism, and cognitivism the statement can be made that learners must be actively involved with their own learning. Constructivists believe that knowledge is constructed by the learner. Learners should take an active role in their own learning. Research by Bredderman (1982) and Renner (1973) supported this.

Jonassen (1991) stated that the theory of constructivism is on one end of a continuum with the theory of objectivism on the other. He states that constructivists believe in an internally mediated reality while objectivists believe in an externally mediated reality. Constructivists believe knowledge and skills are based on the learner's interpretation of the world and learning occurs by interacting with the real world. Objectivists believe that there is an external world independent of the mind and that world can be modeled for the learner. For the objectivist knowledge is void of human emotion and consists of universally accepted facts (Yarusso, 1992).

Norman (1983) believed that through interacting with the environment people form internal mental models of the things with which they are interacting. Halford (1993) stated that in order to understand a concept that one must have a mental model that reflects the structure of that concept. Norman (1983) said that mental models are unstable (details can be forgotten over time) and can be unscientific (affected by superstition).

Conceptual models differ from mental models in that conceptual models are tools for understanding and teaching, whereas mental models are what learners have in their heads. Mental models provide a means for prediction of results when factors are varied. Having a conceptual model of a concept is important. Mayer (1989) summarized that conceptual models will improve conceptual retention and reduce verbatim retention.

Herron (1990) stated that conceptual understanding and representation are each important factors in problem solving success. Research by Gorodetsky and Hoz (1991) and Camacho and Good (1989) has supported this

statement. Conceptual understanding can not be determined by just the ability to solve numerical problems. A number of studies have shown that solving numerical problems does not mean that one understands the underlying concept (Yarroch, 1985; Herron and Greenbowe, 1986; Nurrenbern and Pickering, 1987; Sawrey, 1990; and Pendley, Bretz, and Novak, 1994).

Polya (1973) stated that one of the phases of problem solving is to understand the problem and know what is required to do. The ability to identify the relevant information needed to solve a problem or the ability to not be distracted by the context of the problem is called field independence. The lack of this ability is called field dependence. This cognitive style of field independence-field dependence is therefore important.

Cognitive styles are a person's typical or habitual mode of problem solving, thinking, perceiving, and remembering (Schwen, Bedner, and Hodson, 1979). Cognitive styles are persistent and therefore stable over time (Saracho and Spodek, 1981). One of the elements included in cognitive style is intelligence (Saracho, 1989) and field independence-field dependence covers a number of different intelligences. These intelligences include knowledge or crystallized intelligence, broad reasoning or fluid intelligence, and broad visual intelligence.

Field independence-field dependence affects one's achievement in chemistry (Witkin, Moore, Goodenough, and Hoz, 1977). Also, disembedding ability is a predictor of science achievement (Lawson, 1983). A number of research studies have shown that field independence-field dependence is an important factor in the learning of chemistry (Herron, 1990; Herron and

Greenbowe, 1986; Niaz, 1987; Bodner and MacMillen, 1986; and Carter, LaRussa, and Bodner, 1985).

The use of the computer as a method of instruction has sparked great debate. Clark (1985) stated that there is no difference when comparing media with respect to student achievement and likens media to a “delivery truck”. Kozma (1994) argued that Clark’s metaphor of media delivering instruction is not applicable since many educators believe that instruction is not “delivered” to the students but constructed by the students. In addition, Kulik, Kulik, and Bangert-Drowns (1985) found that most computer based educational programs had a positive effect on student learning. Niemiec and Walberg (1985) also found that computer based instruction is effective in raising student achievement. Furthermore, research studies specific to chemistry have concluded that computer-based instruction can increase achievement (Smith, Jones, and Waugh, 1986; and Jackson, Moellenberg, and Brabson, 1987).

Chemical education researchers have paid little attention to the topic of chemical kinetics. Only Smith, Jones, and Waugh (1986) have investigated this topic. Their work involved the use of a videodisc to provide tutorial lessons on equilibrium and chemical kinetics.

Students at Iowa State University have performed poorly on chemical kinetics questions on a consistent basis. Lynch and Greenbowe (1994) have identified some examples of student difficulty with chemical kinetics problems. Also, mathematical difficulties have been observed as the reason students are not able to correctly solve chemical kinetics problems. Gabel and Sherwood (1984) have stated that students must possess mathematical skills,

such as working with scientific notation and performing multistep problems, in order to have success in solving chemistry problems.

## METHODOLOGY

### Overview

College students enrolled in a general chemistry course received instruction on the topic of chemical kinetics either by a teaching assistant or by a computer program that included text, graphs, animations, and simulations. In the lecture class prior to the instruction, participants were administered a multiple-choice pretest. Immediately following the instruction, participants were given a multiple-choice posttest. Additionally, data was collected from the kinetics portion of the hour exam. This exam was administered approximately 1 week after the instruction. The items on the kinetics portion of the hour exam were in multiple-choice format. Data was also collected from the kinetics portion of the final exam in which all questions on the comprehensive exam were multiple-choice. The final exam was given approximately 2 weeks after the instruction.

Achievement on all four of these measures was compared on the factors of cognitive style (field dependent, field neutral, and field independent), method of instruction (computer program, teaching assistant, and neither), and visual skill (high visual skill, moderate visual skill, and low visual skill). Also, achievement on quantitative questions vs. qualitative questions was compared. Further analysis comparing achievement on quantitative questions vs. qualitative questions was compared on the factors of cognitive style, method of instruction, and visual skill.

**Population**

The participants in this study came from the population of college students enrolled in the Chemistry 177 (General Chemistry) course at Iowa State University. Students who choose to take the Chemistry 177 course are typically physical and biological science majors, chemical engineering majors, and those students who plan to take 300-level and above chemistry courses. Chemistry 177 is the first course of a two semester sequence. The prerequisites for this course are one year of high school chemistry and at least one year of high school algebra.

**Method of Instruction**

One of the methods of instruction used in this study was a computer program that deals with three main topics within the area of chemical kinetics: reaction rates, rate laws, and the method of initial rates. Specifically, participants were able to explore the difference between kinetics and equilibrium; the definition and calculation of instantaneous rate, initial rate, and average rate; the factors that affect the rate of reaction; collision theory; the general and integrated rate laws; the order of reactant and overall reaction order; the rate law constant; and solving kinetics problems using the method of initial rates. Participants were able to explore these topics through reading textual information, viewing still images and animations, and experimenting in simulated environments. The student difficulty of determining a rate law from chemical data and was specifically addressed with the section on solving kinetics problems using the method of initial rates. The step-by-step process

was shown in much detail, including explanations of the mathematical steps for solving problems using the method of initial rates. The student difficulty of determining the units of the rate constant again was addressed in the section covering the rate constant. Again much explanation including the mathematical steps used for determining the units of the rate constant were shown. Practice problems on each of the topics were provided at the end of each main section.

Students were provided a with worksheet to go along with the computer program. The worksheet contained all of the sample problems within the computer program with space to write problem solutions. The worksheet also contained graphs in which students were able to put in their own points so that they may be able to calculate such things as instantaneous rates at any time, average rates, and initial rates. The worksheets were collected at the end of the session but were not used as data.

The computer program was designed using some of the instructional design techniques proposed by Dick and Carey (1990). Performance objectives were stated on the second screen of the program so that participants knew what was expected of them after completing the instruction. On the third screen participants were informed of the prerequisite skills that are required of them before they begin the instruction. These prerequisite skills are what a chemical reaction is, how to write a chemical reaction, mathematics of exponential numbers, the mathematics of common logarithms ( $\log x$ ) and natural logarithms ( $\ln x$ ), how to set up the axes on a graph, how to plot points on a graph, and how to determine the slope of a line on a graph.

Part of the computer program used in this study was designed using Authorware®™ (1992) by Macromedia. Authorware is an authoring tool which allows one to create a program using many types of images such as text, still graphics, animations, digitized video images, and sound. The computer program used in this study contains text as well as many kinds of visual images. The visual images consist of graphics and animations. Animations were created using Macromedia's Director®™ (1994).

Participant control over the visual images varied. For instance, participants were able to select two points on a graph of concentration vs. time and have the computer calculate the average rate between those two points. This activity utilized visual aids (graphs, lines, and diagrams) to show how the calculation of average rate should be carried out (see Figure 2 and Figure 3).

At another point in the program participants were able to view the changes in a reaction vessel after altering variables such as temperature, concentration, and the amount of energy change (see Figure 4). In this simulation color changes indicate the changes in concentrations of reactants and products in the reaction vessel. Also, graphs of concentration vs. time show the relationship between these two variables. Finally, numerical displays of time, various rates, and various concentrations allow participants to view textual data from the reaction system.

There were practice problems at the end of each main section. These problems were similar to those found in the textbook that the participants were using, Chemistry: The study of matter and its changes, 6th edition (Brown, LeMay, Bursten, 1994). The answers to each question were available to the

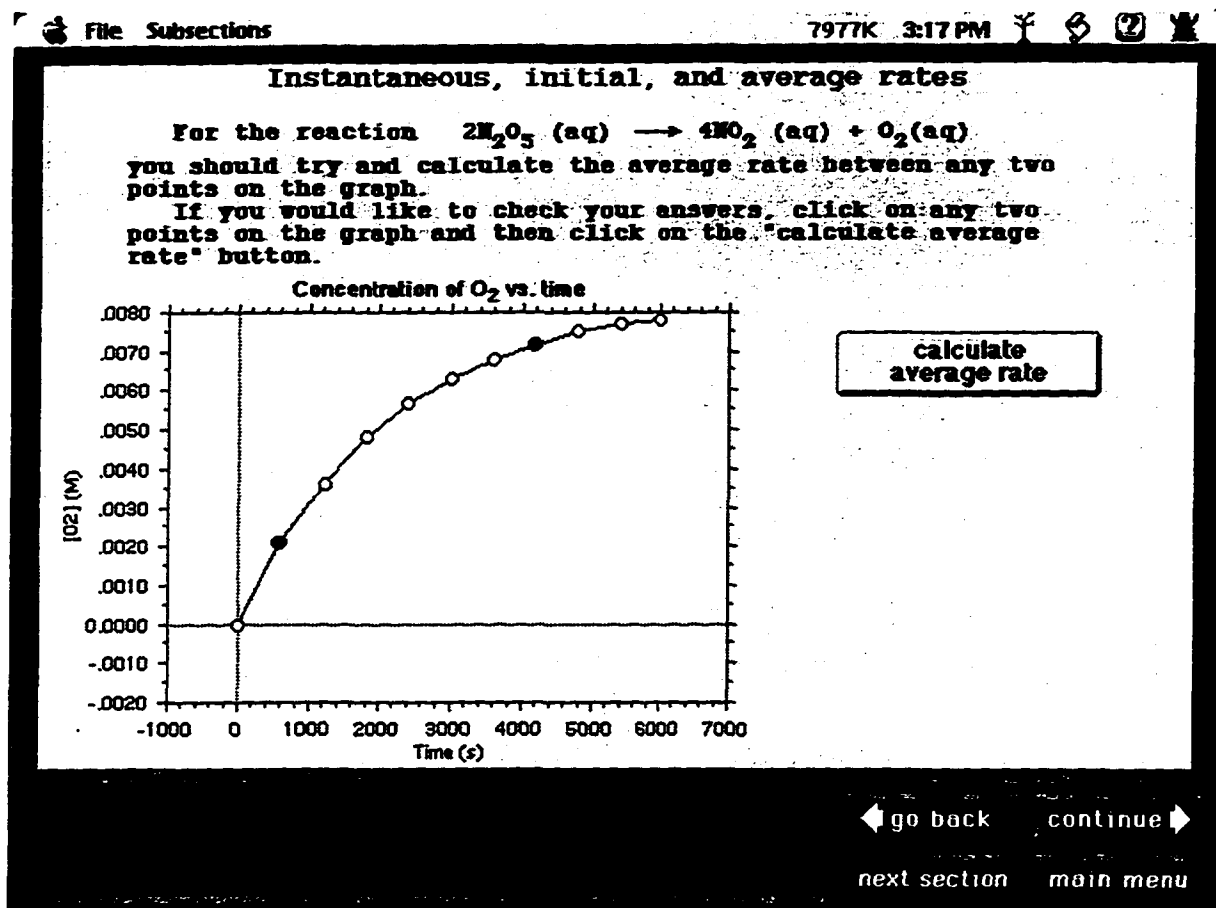


Figure 2. "Calculation of average rate" page from Chemical Kinetics (Lynch & Greenbowe, 1996).

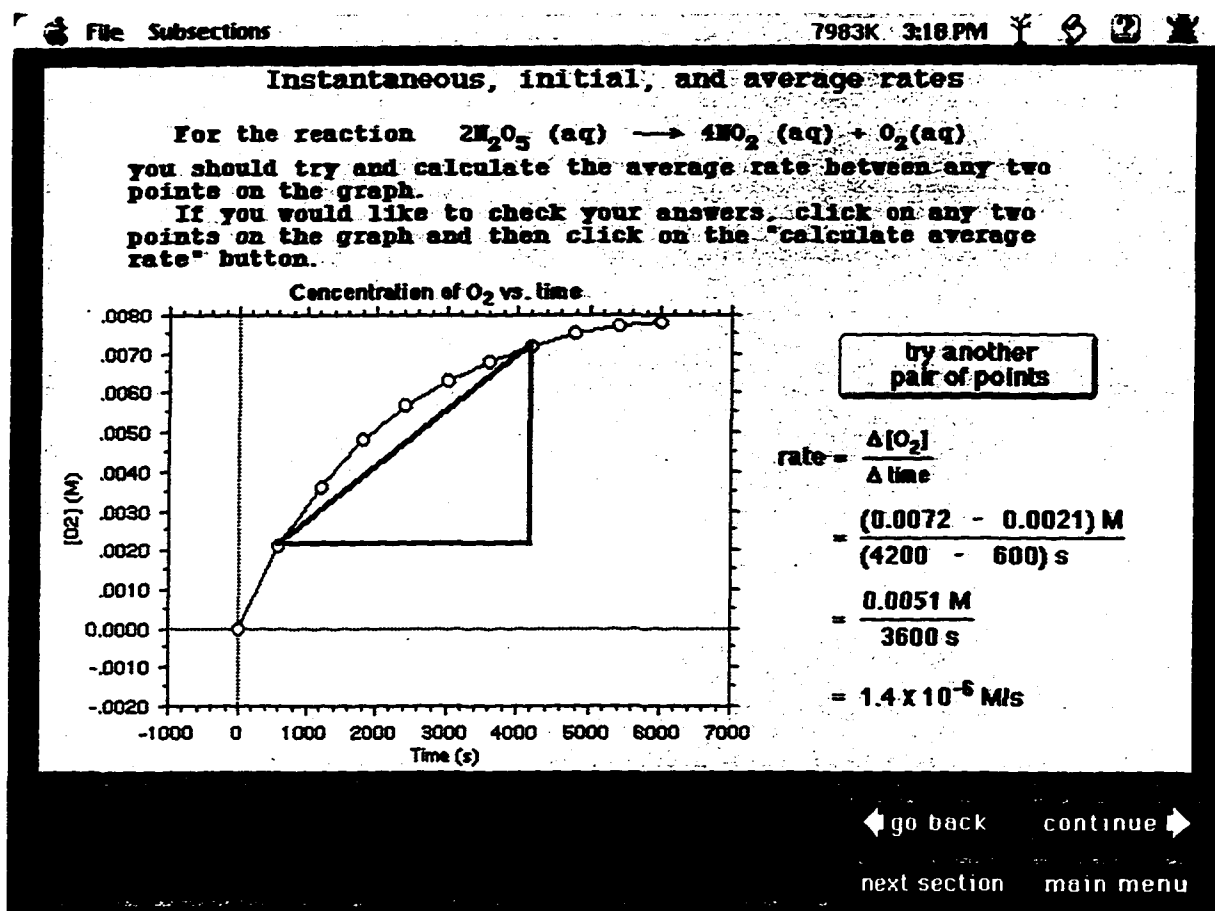
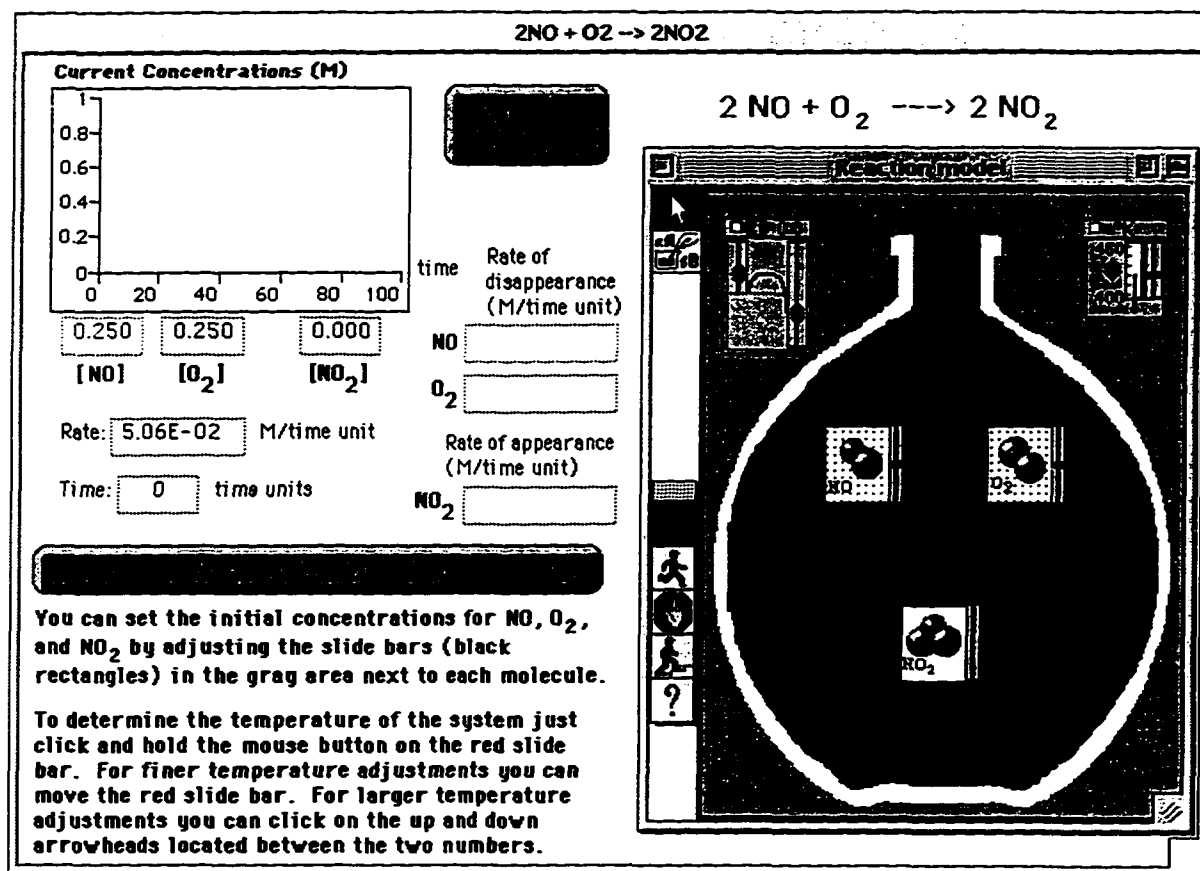


Figure 3. "Calculation of average rate" page showing calculation of the average rate from Chemical Kinetics (Lynch & Greenbowe, 1996).



**Figure 4.** The reaction system from Chemistry Explorer-Chemical Equilibrium (Logal Software, 1993) and from Chemical Kinetics (Lynch & Greenbowe, 1996).

participants by clicking on a "check answer" button on the problem screen. Detailed explanations were given for verbal questions. Step-by-step mathematical solutions were given for mathematical problems.

The simulation of this system and other chemical systems in the computer program were designed by Logal Software Inc. (1993). These simulations utilize mathematical models to simulate the behavior of a chemical system. The simulations are run using a modified version of Logal's Chemistry Explorer: Chemical Equilibrium computer program (1993). Students were able to manipulate a number of variables within the chemical system. Written instructions provided a guided discovery environment so students were able to discover for themselves the relationship of these variables to the chemical system.

The other method of instruction involved working with a teaching assistant. However, the teaching assistant was not the researcher. Since the method of instruction the students received was determined by recitation section and some of the sections ran concurrently, the researcher chose to supervise those sections receiving instruction by the computer. However, the teaching assistants were instructed to go over the same topics that the computer program covered: the difference between kinetics and equilibrium; the definition and calculation of instantaneous rate, initial rate, and average rate; the factors that affect the rate of reaction; collision theory; the general and integrated rate laws; the order of reactant and overall reaction order; the rate law constant; and solving kinetics problems using the method of initial rates. During this time the teaching assistant was to review the method for

solving problems covering the topics, providing any explanation and instruction necessary to help participants solve the homework problems. The teaching assistants were instructed to make sure they at least discuss the method of initial rates for solving chemical kinetics problems. It is estimated that the teaching assistants discussed the method of initial rates, the rate constant and its units, and the order of the reactant and overall reaction order.

After the instruction by the teaching assistant or the computer program, the participants received lecture instruction by the professor in charge of the course. Four 50-minute lectures were given by the professor on the topic of chemical kinetics. The topics discussed in these lectures were the same as those covered by the computer program (the difference between kinetics and equilibrium; the definition and calculation of instantaneous rate, initial rate, and average rate; the factors that affect the rate of reaction; collision theory; the general and integrated rate laws; the order of reactant and overall reaction order; the rate law constant; and solving kinetics problems using the method of initial rates). In addition the professor discussed activation energy, reaction mechanisms, and catalysis. The professor provided examples of problem solutions for solving quantitative problems concerning the various topics. However there were no examples of problem solutions for solving qualitative (conceptual) questions.

Homework problems were also assigned to provide the participants with additional practice. Again, only quantitative problems were assigned. No qualitative (conceptual) questions were assigned. Examples of the homework questions may be found in Appendix 13.

## **Instruments**

The cognitive styles of field independence and field dependence were assessed using the Group Embedded Figures Test (Oltman, Raskin, and Witkin, 1971). This is a group administered test which takes approximately 20 minutes to complete. The Group Embedded Figures Test has a reliability between 0.70 - 0.85 (Witkin, 1971). This test involves finding a simple shape within a complex pattern. A sample of an item from this test may be found in Appendix 7.

An additional test of visual skill was administered. The Purdue Spatial Visualization Test was used to assess visual skill. This test takes approximately 30 minutes to complete. The test is designed to determine how well one can visualize the rotation of three-dimensional objects. A sample of an item from this test may be found in Appendix 14.

Chemical Kinetics achievement was assessed using a pretest, a posttest, and scores on the kinetics questions on the following hour exam and final exam. The questions on the pretest and posttest were comprised of previously used Iowa State University test and quiz questions. The format of the questions was multiple-choice.

The questions covered the topics of rates of reaction, rate laws, order of the reactant, and method of initial rates. These topics would be the same as those taught by either the computer program or the teaching assistant. The quantitative questions that were chosen were similar to those found in any general chemistry textbook. The qualitative (conceptual) questions that were chosen were similar in terms of topics to the quantitative questions. Since

similar qualitative questions could not be found in any general chemistry textbook, they had to be created by this researcher. For the pretest, the types of questions and the topics they would cover would be similar to questions that would appear on the posttest, hour exam, and final exam.

The pretest consisted of 9 multiple-choice questions and participants were given approximately 15 minutes to complete the test. The purpose of the pretest was to determine the initial knowledge concerning chemical kinetics. On the pretest there were no algebra questions analogous to chemical kinetics questions. Appendix 15 contains the questions used on the pretest.

The posttest consisted of one question with four parts. Each part was multiple-choice in format. Students were given 10 minutes to complete the postquiz. Due to the amount of time allotted to administer the quiz (10 minutes), only one question concerning one topic could be asked. Therefore, a question on the method of initial rates was selected since questions on that topic would appear on the hour and final exams. Appendix 16 contains the questions used on the posttest.

On the hour exam there were seven multiple-choice questions concerning chemical kinetics. Students were given 60 minutes to complete the entire exam. The hour exam not only dealt with the chapter on chemical kinetics but also with the chapter on liquids and solids, and the chapter on properties of solutions. The questions not concerned with chemical kinetics were of the free-response type (short answer or quantitative problems). Appendix 17 contains the chemical kinetics questions used on the hour exam.

The final exam contained four multiple-choice covering chemical kinetics. Students were given two hours to complete the final exam. The final exam was cumulative over the entire semester. Topics also covered on the final exam included: measurements; atoms, molecules, and ions; stoichiometry; thermochemistry; electronic structure of atoms; periodic properties of the elements; chemical bonding; molecular geometry; gases; and chemical equilibrium. Appendix 18 contains the chemical kinetics questions used on final exam.

The validity of the pretest and posttest was determined by consultation with two General Chemistry professors and one Chemistry graduate student. All reviewers agreed that each of the questions were appropriate chemical kinetics questions. Furthermore, the reviewers each agreed that the questions corresponded to the specific topic the question was supposed to query.

Reliability was determined after the pretest and posttest were used. The Spearman-Brown reliability for the pretest was 0.34. The KR-20 reliability for the posttest was 0.38. An item analysis provided difficulty and discrimination indices for each question. The item analyses for each question on the pretest and posttest can be seen in Appendices 15 and 16, respectively.

Both the hour exam and final exam were created by the professor in charge of the course and this researcher. Validity for the chemical kinetics questions on the hour and final exams was established through using previously used Iowa State University test questions. By using questions that have been used by other professors, the questions can be said to be valid since all of these professors would agree that the questions measure the objectives or

content they are supposed to measure. The Spearman-Brown reliability for the kinetics portion of the hour exam was 0.48. The Spearman-Brown reliability for the kinetics portion of the final exam was 0.98. An item analysis provided difficulty and discrimination indices for each question after the hour and final exams were administered. The item analyses for each chemical kinetics question on the hour and final exams can be seen in Appendices 17 and 18, respectively.

### **Experimental Design**

The design of the experiment was a series of nonequivalent control group designs (Borg and Gall, 1989) on a number of factors. The factors (independent variables) are type of instruction (traditional/computer/neither) and learning style (field independent/field neutral/field dependent). The dependent variable was the participant's score on each of the following: pretest, posttest (quiz), delayed posttest (kinetics questions on the subsequent hour exam), and far delayed posttest (kinetics questions on the final exam). Figure 5 shows the design of the experiment.

Classes (recitation sections) were selected for either traditional or computer instruction. Those students who did not attend recitation class on the day of the treatment formed the control group. The room in which the participants viewed the computer program held 24 persons. When two recitation sections occurred during the same time period, one section was randomly assigned to view the computer program while the other remained with their assigned teaching assistant. All classes spent equal amounts of

<b>Factor - cognitive style</b>					
field independent	O <sub>1</sub>	X <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
field neutral	O <sub>1</sub>	X <sub>2</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
field dependent	O <sub>1</sub>		O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
<b>Factor - method of instruction</b>					
computer program	O <sub>1</sub>	X <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
teaching assistant	O <sub>1</sub>	X <sub>2</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
neither	O <sub>1</sub>		O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
<b>Factor - visual skill</b>					
high visual skill	O <sub>1</sub>	X <sub>1</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
moderate visual skill	O <sub>1</sub>	X <sub>2</sub>	O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>
low visual skill	O <sub>1</sub>		O <sub>2</sub>	O <sub>3</sub>	O <sub>4</sub>

O<sub>1</sub> = pretest

O<sub>2</sub> = posttest

O<sub>3</sub> = hour exam

O<sub>4</sub> = final exam

X<sub>1</sub> = computer program

X<sub>2</sub> = teaching assistant

**Figure 5. Research design.**

time with either the teaching assistant in a normal recitation class or in the computer lab with the teaching assistant and computer program. Those using the computer programs were tracked to determine which screens of the program they viewed and the amount of time spent on each. The treatment

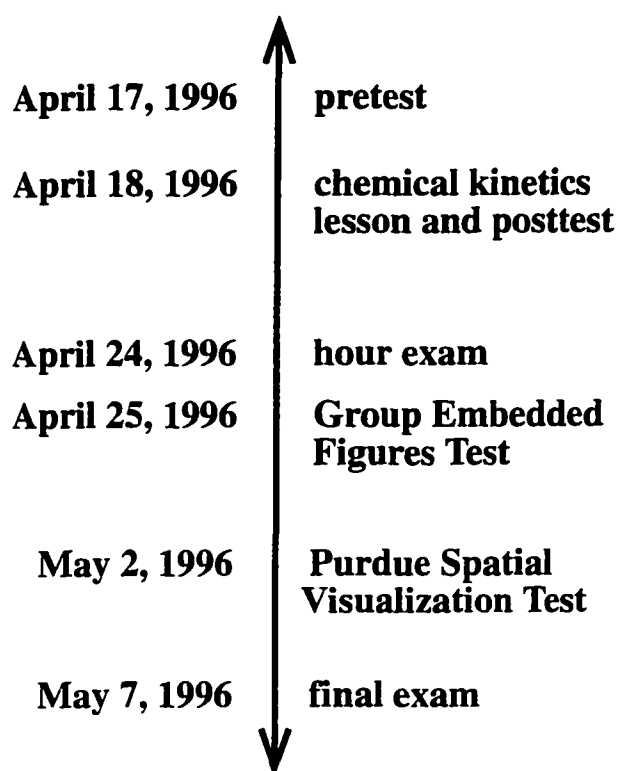
was administered during one recitation section. A scheduled recitation sections lasts for 50 minutes.

Each instrument was given on different days. The Group Embedded Figures Test was administered during the recitation after the hour exam which covered the topic of chemical kinetics. The Purdue Spatial Visualization Test was administered during the recitation after the last hour exam. The chemical kinetics pretest was administered at the end of the first lecture period concerning chemical kinetics. The chemical kinetics posttest was administered at the end of the recitation period on chemical kinetics after the treatment. An hour exam was given approximately one week following the treatment. A final exam was given approximately three weeks following the treatment. Figure 6 shows the time table showing when all of the measurements were administered.

During the recitation period in which the treatment was administered, a brief introduction on how the software program works was given. This introduction lasted approximately two minutes. Overall, the amount of time that students had available to work with the interactive software program was approximately 35 minutes.

### **Research Questions**

1. Will field independent participants score higher on Chemical Kinetics achievement tests (posttest, delayed posttest, far delayed posttest) than both field neutral and field dependent participants?



**Figure 6. Time table.**

2. Will participants who viewed a computer lesson score higher on Chemical Kinetics achievement measures (posttest, delayed posttest, far delayed posttest) than those who received instruction from a teaching assistant and those who received no instruction?
3. Will participants who are classified as having high visual skill score higher on Chemical Kinetics achievement measures (posttest, delayed posttest, far delayed posttest) than those classified as having moderate visual skill or low visual skill?

4. Will there be an interaction between method of instruction and cognitive style?
5. Will field independent participants spend more time exploring the simulated environment than field dependent participants?
6. Will more students answer quantitative chemical kinetics correctly than matching qualitative chemical kinetics questions?
7. Will more field independent students correctly answer matching quantitative vs. qualitative chemical kinetics questions than either field neutral or field dependent students?
8. Will more students who interacted with the computer correctly answer matching quantitative vs. qualitative chemical kinetics questions than either students who work with a teaching assistant or those who did not interact with the computer or work with a teaching assistant?
9. Will more high visual skill students correctly answer matching quantitative vs. qualitative chemical kinetics questions than either moderate or low visual skill students?

## RESULTS

### Classification of the Participants

There were 239 students enrolled in the Chemistry 177 (General Chemistry) course at Iowa State University during the 1996 Spring semester. Grouping of students was based on three factors: cognitive style, visual skill, and method of instruction. Examination of participant scores on the Group Embedded Figures Test revealed that out of 170 participants who took the test, 40 participants were classified as field dependent, 43 participants were classified as field neutral (field indiscriminate), and 87 participants were classified as field independent. The Purdue Spatial Visualization Test was scored with approximately one-third (33.3%) of the participants grouped into three categories (high visual skill, moderate visual skill, low visual skill). Of the 149 participants who took this visual test, 44 were classified with high visual skill, 49 with moderate visual skill, and 56 with low visual skill. Classification based on method of instruction showed that 118 participants viewed the computer lesson, 44 participants received instruction from a teaching assistant, and 77 participants received no instruction. Participants classified as receiving no instruction were those who did not attend recitation class on the day students either interacted with the computer or were taught the material by the teaching.

### **Chemical Kinetics Measures**

Four instruments were used to measure chemical kinetics achievement. They were a pretest, posttest or quiz, chemical kinetics questions on the hour exam, and chemical kinetics questions on the final exam. Out of 9 questions on the pretest, 145 students answered an average of 4.21 questions correctly with a standard deviation (SD) of 1.46. This corresponds to an average of 46.7% correct. For the 4-question posttest or quiz, 162 students answered an average of 1.78 questions correctly (SD = 1.56), or 44.5% correct. The 213 students who took the hour exam answered an average of 3.40 out of 7 questions correctly (SD = 1.54), or 48.6% correct. Finally, 218 students took the final exam and answered an average of 1.64 out of 4 questions correctly (SD = 0.92). This equals an average of 41.0% correct. The means and standard deviations for the chemical kinetics assessments are summarized in Table 4.

### **Student Performance on Similar Questions**

In order to track student achievement, performance on pretest questions was compared to similar questions on the posttest (quiz), chemical kinetics portion of the hour exam, and chemical kinetics portion of the final exam. For this analysis and any subsequent analyses, the level of significance was selected as  $p < 0.05$ .

On the pretest and the posttest (quiz) there was only one set of directly matching questions, question 2 on the pretest and question 1a on the quiz.

**Table 4. Descriptive statistics for the chemical kinetics measures**

Measure	Number of Questions	Number of Students	Mean	Standard Deviation	Average % Correct
Pretest	9	145	4.21	1.46	46.7
Posttest (quiz)	4	162	1.78	1.56	44.5
Hour exam	7	213	3.40	1.54	48.6
Final exam	4	218	1.64	0.92	41.0

Question 2 and 1a dealt with the method of initial rates. There was no statistical difference in the number of students who answered the question correctly on the pretest and posttest. Chi-square analysis on the number of correct and incorrect responses on these questions resulted in a chi-square value of 3.14 ( $p = 0.0763$ ). Observed and expected values for the correct and incorrect responses can be found in Table 5. Questions for the pretest can be found in Appendix 15, and questions for the posttest can be found in Appendix 16.

On the pretest and the chemical kinetics portion of the hour exam there were four sets of matching questions. Question 6 appeared on both the pretest and the chemical kinetics portion of the hour exam. This was a qualitative question using the method of initial rates. More students were able to answer this question correctly on the hour exam than on the pretest. Chi-square analysis resulted in a chi-square value of 9.20 ( $p = 0.0024$ ). Observed and expected values for the correct and incorrect responses can be found in Table 6. Questions for the chemical kinetics portion of the hour exam can be found in Appendix 17.

**Table 5. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and posttest (quiz)**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 2)	83 (90.54)	63(55.46)	146
posttest (question 1a)	108(100.46)	54(61.54)	162
Total	(191.00)	(117.00)	308

<sup>a</sup> the expected frequencies are listed in parentheses

**Table 6. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and chemical kinetics portion of the hour exam**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 6)	55 (69.03)	90 (75.97)	145
hour exam (question 6)	114 (99.97)	96(110.03)	210
Total	(169.00)	(186.00)	355

<sup>a</sup> the expected frequencies are listed in parentheses

Question 7 appeared on both the pretest and chemical kinetics portion of the hour exam. This was a qualitative question based on the method of initial rates. There was no statistical difference in the number of students who answered the question correctly on the pretest and the hour exam. Chi-square analysis on question 7 resulted in a chi-square value of 3.80 ( $p = 0.0528$ ). Table

7 shows the observed and expected values for the correct and incorrect responses for these questions.

Question 8 appeared on both the pretest and hour exam. This question probed students' qualitative understanding of rates of reaction. For this question, more students answered this question incorrectly on the hour exam than on the pretest. Chi-square analysis on these questions gave a chi-square value of 19.13 ( $p < 0.0001$ ). The observed and expected values for the correct and incorrect responses for these questions can be found in Table 8.

Question 9 was also on both the pretest and chemical kinetics portion of the hour exam. This question was quantitative in nature and based on rates of reaction. More students were able to correctly answer this question on the hour exam than on the pretest. Chi-square analysis resulted in a chi-square value of 169.25 ( $p < 0.0001$ ). The observed and expected values for the correct and incorrect responses for this question can be found in Table 9.

**Table 7. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and chemical kinetics portion of the hour exam**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 7)	38(30.63)	107(114.37)	145
hour exam (question 7)	37(44.37)	173(165.63)	210
Total	(75.00)	(280.00)	355

<sup>a</sup> the expected frequencies are listed in parentheses

**Table 8. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and chemical kinetics portion of the hour exam**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 8)	92(30.63)	53(114.37)	145
hour exam (question 8)	85(44.37)	128(165.63)	213
Total	(177.00)	(181.00)	358

<sup>a</sup> the expected frequencies are listed in parentheses

**Table 9. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and chemical kinetics portion of the hour exam**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 9)	9( 69.24)	136( 75.76)	145
hour exam (question 9)	161(100.76)	50(110.24)	211
Total	(170.00)	(186.00)	356

<sup>a</sup> the expected frequencies are listed in parentheses

Lastly, there were two instances of directly matching questions on the pretest and the chemical kinetics portion of the final exam. In both instances, the questions were quantitative in nature and probed the students' understanding of the method of initial rates. The questions used on the chemical kinetics portion of the final exam can be found in Appendix 18. The first instance was question 2 on the pretest and question 24 on the final exam.

There was no statistical difference in the number of students who answered these matching questions correctly on the pretest and the final exam. Chi-square analysis resulted in a chi-square value of 0.10 ( $p = 0.7475$ ). Observed and expected values for the correct and incorrect responses can be found in Table 10. The second instance of matching questions was question 2 on the pretest and question 41 on the final exam. More students answered the question correctly on the final exam than on the pretest. Chi-square analysis for these questions resulted in a chi-square value of 18.93 ( $p < 0.0001$ ). Table 11 shows the observed and expected values for the correct and incorrect responses for the questions.

### Cognitive Style

Using cognitive style as the grouping factor, the analysis of the average scores on the chemical kinetics measures produced mixed results.

**Table 10. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and chemical kinetics portion of the final exam**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 2)	82 (83.48)	63(61.52)	145
hour exam (question 24)	127(125.52)	91(92.48)	218
Total	(209.00)	(154.00)	363

<sup>a</sup> the expected frequencies are listed in parentheses

**Table 11. Observed and expected<sup>a</sup> number of students answering matching method of initial rates questions on the pretest and chemical kinetics portion of the final exam**

Type of question	Correct responses	Incorrect responses	Total
pretest (question 2)	82(61.91)	63 (83.09)	145
hour exam (question 41)	73(93.09)	145(124.91)	218
Total	(155.00)	(208.00)	363

<sup>a</sup> the expected frequencies are listed in parentheses

Differences between participants classified as field dependent, field neutral (field indiscriminate), or field independent, were investigated using two 2-factor analyses of variance (ANOVA) on the scores of the chemical kinetics pretest. The first analysis involved using the type of instruction by cognitive style and the second involved using the type of instruction by visual skill.

There was no significant difference ( $F = 0.001$ ,  $p = 0.9994$ ) in the pretest scores among participants classified as field dependent, field neutral, or field independent with method of instruction as the other factor. Out of 9 questions on the pretest, field dependent participants answered an average of 4.78 questions correctly ( $SD = 1.60$ ). Field neutral participants answered an average of 4.82 questions correctly ( $SD = 1.42$ ). Field independent participants answered an average of 4.76 questions correctly ( $SD = 1.60$ ). The ANOVA results for this analysis can be seen in Table 12.

**Table 12. ANOVA Table for the interaction between method of instruction and cognitive style on the pretest (9 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	2	3.87	1.94	0.77	0.4647
cognitive style	2	0.003	0.001	0.001	0.9994
method of instruction x cognitive style	4	0.29	0.07	0.03	0.9984
residual	111	213.69	1.93		

**Incidence Table**

Method of Instruction	Count	Average Correct	Standard Deviation
computer	87	4.10	1.41
teaching assistant	35	4.43	1.33
neither (none)	23	4.26	1.79

**Incidence Table**

Cognitive Style	Count	Average Correct	Standard Deviation
field dependent	27	4.78	1.60
field neutral	33	4.82	1.42
field independent	59	4.76	1.60

**Table 12. (continued)**

Incidence Table			
Group	Count	Average Correct	Standard Deviation
computer, FD	16	3.81	1.42
computer, FN	19	4.26	1.33
computer, FI	38	4.08	1.34
teaching assistant, FD	5	4.80	1.79
teaching assistant, FN	9	4.44	1.67
teaching assistant, FI	16	4.38	0.96
neither, FD	6	4.50	1.65
neither, FN	5	4.60	1.14
neither, FI	6	4.33	1.86

FD = field dependent

FN = field neutral (field indiscriminate)

FI = field independent

There were no significant differences for cognitive style between groups on the quiz scores ( $F = 0.75$ ,  $p = 0.4722$ ). Out of 4 questions, field dependent students answered 1.60 questions correctly ( $SD = 1.35$ ), field neutral students answered 1.75 questions correctly ( $SD = 1.74$ ), and field independent students answered 2.00 questions correctly ( $SD = 1.57$ ). These results are displayed in Table 13.

Table 14 reveals that there is a significant difference between the groups on their average scores on the kinetics portion of the hour exam ( $F = 3.47$ ,  $p = 0.0337$ ). A Scheffé post-hoc analysis revealed that field independent students scored significantly higher than field dependent students on the chemical kinetics portion of the hour exam ( $p = 0.0400$ ). No other significant differences were detected. Out of 7 questions on the hour exam, students classified as field

**Table 13. ANOVA Table for the interaction between method of instruction and cognitive style on the quiz (4 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	1	0.07	0.07	0.03	0.8711
cognitive style	2	3.65	1.82	0.73	0.4846
method of instruction x cognitive style	2	2.85	1.42	0.57	0.5676
residual	124	310.21	2.50		

**Incidence Table**

Method of Instruction	Count	Average Correct	Standard Deviation
computer	94	1.83	1.59
teaching assistant	36	1.89	1.53
neither (none)	0	---	---

**Incidence Table**

Cognitive Style	Count	Average Correct	Standard Deviation
field dependent	30	1.60	1.35
field neutral	32	1.75	1.74
field independent	68	2.00	1.57

**Table 13. (continued)**

Incidence Table			
Group	Count	Average Correct	Standard Deviation
computer, FD	22	1.50	1.44
computer, FN	21	1.91	1.84
computer, FI	51	1.94	1.56
teaching assistant, FD	8	1.88	1.13
teaching assistant, FN	11	1.46	1.57
teaching assistant, FI	17	2.18	1.67

FD = field dependent

FN = field neutral (field indiscriminate)

FI = field independent

dependent answered an average of 3.97 questions correctly (SD = 1.64).

Students classified as field neutral scored an average of 4.63 questions correctly (SD = 1.92) and students classified as field independent scored an average of 4.89 questions correctly (SD = 1.78).

For the kinetics portion of the final exam, a significant difference in scores was detected ( $F = 3.22$ ,  $p = 0.0229$ ). Out of four questions, field dependent students answered an average of 1.34 questions correctly (SD = 0.85), field neutral students answered an average of 1.78 questions correctly (SD = 0.94), and field independent students answered an average of 1.88 questions correctly (SD = 0.94). Table 15 shows the ANOVA results for this analysis. Post-hoc comparisons using the Scheffé method revealed that participants classified as field independent scored significantly higher than those classified as field dependent ( $p = 0.0114$ ).

**Table 14. ANOVA Table for the interaction between method of instruction and cognitive style on the hour exam (7 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	2	11.90	5.95	1.85	0.1609
cognitive style	2	22.32	3.47	2.85	0.0337
method of instruction x cognitive style	4	4.86	1.21	0.38	0.8246
residual	151	485.79	3.22		

**Incidence Table**

Method of Instruction	Count	Average Correct	Standard Deviation
computer	89	4.80	1.81
teaching assistant	36	4.64	1.84
neither (none)	35	4.09	1.76

**Incidence Table**

Cognitive Style	Count	Average Correct	Standard Deviation
field dependent	37	3.97	1.64
field neutral	43	4.62	1.93
field independent	80	4.89	1.78

**Table 14. (continued)**

Incidence Table			
Group	Count	Average Correct	Standard Deviation
computer, FD	21	4.38	1.69
computer, FN	21	4.61	1.99
computer, FI	47	5.06	1.77
teaching assistant, FD	8	3.62	1.41
teaching assistant, FN	11	5.00	2.10
teaching assistant, FI	17	4.88	1.76
neither, FD	8	3.25	1.58
neither, FN	11	4.27	1.74
neither, FI	16	4.37	1.82

Scheffé Table

Groups	Mean Difference	P-value
computer, teaching assistant	0.47	0.2372
computer, neither	0.72	0.0162
teaching assistant, neither	0.25	0.7155

Scheffé Table

Groups	Mean Difference	P-value
field neutral, field dependent	0.44	0.1062
field independent, field dependent	0.54	0.0114
field independent, field neutral	0.10	0.8419

FD = field dependent

FN = field neutral (field indiscriminate)

FI = field independent

**Table 15. ANOVA Table for the interaction between method of instruction and cognitive style on the final exam (4 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	2	5.86	2.93	3.52	0.0320
cognitive style	2	6.45	3.22	3.87	0.0229
method of instruction x cognitive style	4	1.67	0.42	0.50	0.7347
residual	155	129.08	0.83		

**Incidence Table**

Cognitive Style	Count	Average Correct	Standard Deviation
field dependent	38	1.34	0.85
field neutral	41	1.78	0.94
field independent	85	1.88	0.94

**Incidence Table**

Method of Instruction	Count	Average Correct	Standard Deviation
computer	115	1.81	0.89
teaching assistant	44	1.66	0.91
neither (none)	59	1.32	0.92

**Table 15. (continued)****Incidence Table**

Group	Count	Average Correct	Standard Deviation
computer, FD	21	1.52	0.75
computer, FN	21	1.86	0.91
computer, FI	50	2.02	0.96
teaching assistant, FD	8	1.38	1.19
teaching assistant, FN	11	2.00	0.89
teaching assistant, FI	17	1.71	0.85
neither, FD	9	0.89	0.60
neither, FN	9	1.33	1.00
neither, FI	18	1.67	0.97

**Scheffé Table**

Groups	Mean Difference	P-value
computer, teaching assistant	0.47	0.2372
computer, neither	0.72	0.0162
teaching assistant, neither	0.25	0.7155

**Scheffé Table**

Groups	Mean Difference	P-value
field neutral, field dependent	0.44	0.1062
field independent, field dependent	0.54	0.0114
field independent, field neutral	0.10	0.8419

FD = field dependent

FN = field neutral (field indiscriminate)

FI = field independent

### **Method of Instruction**

Method of instruction was the treatment so there were two 2-factor analyses of variance that included method of instruction as a factor. Table 12 shows that there were no significant differences between groups on their pretest scores ( $F = 0.77$ ,  $p = 0.4647$ ). Out of 9 questions on the pretest, participants who interacted with the computer program answered an average of 4.64 questions correctly ( $SD = 1.51$ ). Participants who worked with the teaching assistant answered an average of 4.94 questions correctly ( $SD = 1.50$ ). Those who did not interact with the computer program or work with the teaching assistant (classified as neither or none) answered an average of 5.13 questions correctly ( $SD = 1.75$ ). Table 16 also shows that there were no significant differences between groups on their pretest scores ( $F = 0.42$ ,  $p = 0.6569$ ). Students who interacted with the computer program answered an average of 4.64 questions correctly ( $SD = 1.48$ ). Participants who worked with the teaching assistant answered an average of 4.97 questions correctly ( $SD = 1.55$ ). Those who did not interact with the computer program or work with the teaching assistant (classified as neither or none) answered an average of 4.61 questions correctly ( $SD = 2.10$ ).

Additionally, ANOVA analyses showed that no significant differences between groups were found upon analysis of the quiz scores on the 4-question quiz ( $F = 0.03$ ,  $p = 0.8648$ ). Participants who received instruction by interacting with the computer answered 1.77 questions correctly ( $SD = 1.58$ ). Participants who worked with the teaching assistant answered 1.82 questions correctly ( $SD = 1.50$ ). Participants who did not interact with the computer or work with the

**Table 16. ANOVA Table for the interaction between method of instruction and visual skill on the pretest (9 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	2	2.00	1.00	0.42	0.6569
visual skill	2	15.11	7.56	3.20	0.0451
method of instruction x visual skill	4	24.72	6.18	2.61	0.0396
residual	103	243.61	2.37		

**Incidence Table**

Method of Instruction	Count	Average Correct	Standard Deviation
computer	70	4.64	1.47
teaching assistant	29	4.97	1.55
neither (none)	13	4.62	2.10

**Incidence Table**

Visual Skill	Count	Average Correct	Standard Deviation
high	32	4.75	1.34
moderate	37	4.89	1.54
low	43	4.56	1.75

**Table 16. (continued)****Incidence Table**

Group	Count	Average Correct	Standard Deviation
computer, high visual	17	4.35	1.12
computer, moderate visual	24	4.63	1.44
computer, low visual	29	4.83	1.69
teaching assistant, high visual	12	5.42	1.44
teaching assistant, moderate visual	10	5.00	1.41
teaching assistant, low visual	7	4.14	1.77
neither, high visual	3	4.33	1.53
neither, moderate visual	3	6.67	2.08
neither, low visual	7	3.86	1.95

**Scheffé Table**

Groups	Mean Difference	P-value
computer, teaching assistant	0.32	0.6381
computer, neither	0.03	0.9983
teaching assistant, neither	0.35	0.7929

teaching assistant did not attend class on the day of instruction. Therefore, those participants did not take a quiz. Thus, there are no scores available for this group. The ANOVA results for this analysis are displayed in Table 13. Table 17 shows that participants who received instruction by interacting with the computer answered 1.82 questions correctly (SD = 1.61). Participants who worked with the teaching assistant answered 1.94 questions correctly (SD = 1.49).

**Table 17. ANOVA Table for the interaction between method of instruction and visual skill on the quiz (4 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	1	0.49	0.49	0.19	0.6609
visual skill	2	0.46	0.23	0.09	0.9129
method of instruction x visual skill	2	3.63	1.82	0.72	0.4892
residual	119	300.48	2.52		

Incidence Table

Method of Instruction	Count	Average Correct	Standard Deviation
computer	89	1.82	1.61
teaching assistant	36	1.94	1.49
neither (none)	0	---	---

Incidence Table

Visual Skill	Count	Average Correct	Standard Deviation
high	39	1.82	1.55
moderate	42	1.98	1.69
low	44	1.77	1.49

**Table 17. (continued)**

Incidence Table			
Group	Count	Average Correct	Standard Deviation
computer, high visual	26	1.85	1.59
computer, moderate visual	29	2.03	1.78
computer, low visual	34	1.62	1.48
teaching assistant, high visual	13	1.77	1.54
teaching assistant, moderate visual	13	1.85	1.52
teaching assistant, low visual	10	2.30	1.49

A significant difference between the groups on their average scores on the kinetics portion of the hour exam was not detected ( $F = 1.85$ ,  $p = 0.1609$ ). Table 14 displays the ANOVA with method of instruction and cognitive style as factors. Out of 7 questions, students who interacted with the computer answered an average of 4.80 questions correctly ( $SD = 1.81$ ). Students who worked with the teaching assistant answered an average of 4.64 questions correctly ( $SD = 1.84$ ). Students who did not interact with the computer or work with a teaching assistant answered an average of 4.09 questions correctly ( $SD = 1.76$ ). Using method of instruction and visual skill as factors, a significant difference between the groups on their average scores on the kinetics portion of the hour exam was not detected ( $F = 1.89$ ,  $p = 0.1558$ ). Table 18 shows that out of 7 questions, students who interacted with the computer answered an average of 4.90 questions correctly ( $SD = 1.69$ ). Students who worked with the teaching assistant answered an average of 4.83 questions correctly ( $SD = 1.68$ ). Students

**Table 18. ANOVA Table for the interaction between method of instruction and visual skill on the hour exam (7 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	2	10.28	5.14	1.89	0.1558
visual skill	2	26.16	13.08	4.80	0.0097
method of instruction x visual skill	4	4.21	1.05	0.39	0.8185
residual	135	367.95	2.73		

Incidence Table

Method of Instruction	Count	Average Correct	Standard Deviation
computer	87	4.90	1.69
teaching assistant	36	4.83	1.68
neither (none)	21	4.10	1.79

Incidence Table

Visual Skill	Count	Average Correct	Standard Deviation
high	44	5.23	1.74
moderate	47	5.06	1.66
low	53	4.11	1.55

**Table 18. (continued)**

## Incidence Table

Group	Count	Average Correct	Standard Deviation
computer, high visual	26	5.50	1.58
computer, moderate visual	27	5.04	1.77
computer, low visual	34	4.32	1.55
teaching assistant, high visual	13	5.08	1.71
teaching assistant, moderate visual	13	5.31	1.44
teaching assistant, low visual	10	3.90	1.73
neither, high visual	5	4.20	2.49
neither, moderate visual	7	4.71	1.80
neither, low visual	9	3.56	1.33

## Scheffé Table

Groups	Mean Difference	P-value
high, moderate	0.22	0.7633
high, low	0.96	0.0046
moderate, low	0.74	0.0334

who did not interact with the computer or work with a teaching assistant answered an average of 4.10 questions correctly (SD = 1.79).

There was a significant difference between groups based on their scores on the kinetics portion of the final exam ( $F = 3.52$ ,  $p = 0.0320$ ) in one of the analyses. Table 15 shows the results of the analysis using method of instruction and cognitive style as factors. Students who interacted with the computer scored significantly higher on the chemical kinetics portion of the final exam than those who did not interact with the computer or work with the

teaching assistant. No other significant differences were detected. On the 4-question chemical kinetics portion of the final exam, students who interacted with the computer answered an average of 1.87 questions correctly ( $SD = 0.92$ ). Students who worked with the teaching assistant answered an average of 1.72 questions correctly ( $SD = 0.94$ ). Students who did not interact with the computer or work with the teaching assistant answered an average of 1.39 questions correctly ( $SD = 0.93$ ). Table 19 reveals no significant differences between groups when using method of instruction and visual skill as factors. Students who interacted with the computer answered an average of 1.82 questions correctly ( $SD = 0.90$ ). Students who worked with the teaching assistant answered an average of 1.69 questions correctly ( $SD = 0.89$ ). Students who did not interact with the computer or work with the teaching assistant answered an average of 1.52 questions correctly ( $SD = 0.99$ ).

### **Visual Skill**

Mixed results were found using visual skill as the grouping factor in the 2-factor analyses of variance on the chemical kinetics measures. A significant F-value was found ( $F = 3.20$ ,  $p = 0.0451$ ), however post-hoc analysis revealed no significant differences in pretest scores. The results of this analysis can be seen in Table 16. Out of 9 questions, students classified as having high visual skill answered an average of 4.75 questions correctly ( $SD = 1.34$ ). Students classified as having moderate visual skill answered an average of 4.89 questions correctly ( $SD = 1.54$ ). Finally, students classified as having low visual skill answered an average of 4.56 questions correctly ( $SD = 1.75$ ).

**Table 19. ANOVA Table for the interaction between method of instruction and visual skill on the final exam (4 questions)**

Source	df	Sum of Squares	Mean Square	F value	p Value
method of instruction	2	0.65	0.33	0.46	0.6347
visual skill	2	11.53	5.76	8.07	0.0005
method of instruction x visual skill	4	12.02	3.01	4.21	0.0030
residual	37	97.84	0.71		

**Incidence Table**

Method of Instruction	Count	Average Correct	Standard Deviation
computer	87	1.82	0.90
teaching assistant	36	1.69	0.89
neither (none)	23	1.52	0.99

**Incidence Table**

Visual Skill	Count	Average Correct	Standard Deviation
high	43	1.95	0.93
moderate	47	1.92	0.91
low	56	1.43	0.83

**Table 19. (continued)**

Incidence Table

Group	Count	Average Correct	Standard Deviation
computer, high visual	25	2.20	0.87
computer, moderate visual	28	1.75	0.97
computer, low visual	34	1.59	0.78
teaching assistant, high visual	13	1.54	0.97
teaching assistant, moderate visual	13	1.92	0.76
teaching assistant, low visual	10	1.60	0.97
neither, high visual	5	1.80	0.84
neither, moderate visual	6	2.67	0.52
neither, low visual	12	0.83	0.58

Scheffé Table

Groups	Mean Difference	P-value
high, moderate	0.04	0.9769
high, low	0.53	0.0107
moderate, low	0.49	0.0165

Table 17 reveals that there was no significant difference between groups on the scores of the 4-question quiz ( $F = 0.09$ ,  $p = 0.9129$ ). Students with high visual skill answered an average of 1.82 questions correctly ( $SD = 1.55$ ). Students with moderate visual skill answered an average of 1.98 questions correctly ( $SD = 1.69$ ). Lastly, students with low visual skill answered an average of 1.77 questions correctly ( $SD = 1.49$ ).

Analysis of the scores on the 7 questions of the kinetics portion of the hour exam revealed a significant difference between groups ( $F = 4.80$ ,  $p = 0.0097$ ), which can be seen in Table 18. Students with high visual skill answered an average of 5.22 questions correctly ( $SD = 1.74$ ). Students with moderate visual skill answered an average of 5.06 questions correctly ( $SD = 1.66$ ). Students with low visual skill answered an average of 4.11 questions correctly ( $SD = 1.55$ ). Analysis of the group means showed that those participants classified with high visual skill scored significantly higher on the kinetics portion of the hour exam compared to those classified with low visual skill. Furthermore, students who were classified with moderate visual skill scored significantly higher than students who were classified with low visual skill.

A significant difference between groups was again detected for scores on the kinetics portion of the final exam. This analysis can be seen in Table 19. Students with high visual skill answered an average of 1.95 questions correctly ( $SD = 0.93$ ). Students with moderate visual skill answered an average of 1.92 questions correctly ( $SD = 0.91$ ). Lastly, students with low visual skill answered an average of 1.43 questions correctly ( $SD = 0.83$ ). Post-hoc comparisons of the group means using the Scheffé method indicate that participants classified with high visual skill scored significantly higher on the kinetics portion of the final exam as compared to those classified with low visual skill ( $p = 0.0107$ ). Also, participants classified with moderate visual skill scored significantly higher on the kinetics portion of the final exam than those classified with low visual skill ( $p = 0.0165$ ).

## Regression Analysis

A hierarchical regression analysis was done to determine whether the pretest score, visual skill score, cognitive style score, and method of instruction were significant predictors of the scores the chemical kinetics portion of the hour exam and chemical kinetics portion of the final exam. In these analyses, the cognitive style and visual skill scores were maintained as continuous variables. For this hierarchical regression analyses, the pretest score was first put in followed by the visual skill score, cognitive style score, and the method of instruction. Method of instruction was a categorical variable but was dummy coded so that it could be used in the regression analysis. This recoding was done according to the method described by Ferguson and Takane (1989).

Hierarchical regression analysis using the quiz score as the dependent variable showed that none of the independent variables (pretest score, visual skill score, cognitive style score, and method of instruction) are good for predicting quiz scores. Their partial correlation coefficients are not significantly different from zero. The coefficient for the pretest was 0.08 ( $t = 0.86$ ,  $p = 0.3944$ ). The coefficient for the visual skill score was -0.02 ( $t = -0.40$ ,  $p = 0.6934$ ). The coefficient for the cognitive style score was 0.03 ( $t = 0.66$ ,  $p = 0.5109$ ). The coefficient for the dummy coded variable 1 for the method of instruction was -0.04 ( $t = -0.13$ ,  $p = 0.8949$ ). This variable assigned a value of 1 to those students who interacted with the computer. The coefficient for the dummy coded variable 2 for the method of instruction was 0.06 ( $t = 0.16$ ,  $p = 0.8743$ ). This variable assigned value of 1 to those students who worked with

the teaching assistant. Results of this analysis can be found in Table 20.

Analysis using the chemical kinetics portion of the hour exam score as the dependent variable showed that the visual skill score and method of instruction) are good for predicting hour exam scores. Their partial correlation coefficients of the pretest score were significantly different than zero. The partial correlation coefficients of the pretest score and cognitive style score were not significantly different from zero. Table 21 shows that the coefficient for the pretest was 0.14 ( $t = 1.46$ ,  $p = 0.1483$ ). The coefficient for the visual skill score was 0.12 ( $t = 2.24$ ,  $p = 0.0271$ ). The coefficient for the cognitive style score was 0.04 ( $t = 0.78$ ,  $p = 0.4363$ ). The coefficient for the dummy coded variable 1 (computer) for the method of instruction was 0.66 ( $t = 2.02$ ,  $p = 0.0459$ ). The coefficient for the dummy coded variable 2 (teaching assistant) for the method of instruction was 0.06 ( $t = -0.13$ ,  $p = 0.8949$ ). Results of this analysis can be found in Table 21.

Analysis using the chemical kinetics portion of the final exam score as

**Table 20. Hierarchical regression analysis using the quiz score as the dependent variable**

Variable	B	Standard Error B	Beta	t	Significance t
pretest	0.08	0.091	0.083	0.86	0.3944
visual skill	-0.02	0.049	-0.043	-0.40	0.6934
cognitive style	0.03	0.044	0.072	0.66	0.5109
method of instruction (1)	-0.04	0.301	-0.013	-0.13	0.8949
instruction (2)	0.06	0.390	0.015	0.16	0.8743
(constant)	1.62	0.887		1.83	0.0702

(1) = computer      (2) = teaching assistant

**Table 21. Hierarchical regression analysis using the chemical kinetics portion of the hour exam score as the dependent variable**

Variable	B	Standard Error B	Beta	t	Significance t
pretest	0.14	0.099	0.132	1.46	0.1483
visual skill	0.12	0.054	0.230	2.24	0.0271
cognitive style	0.04	0.048	0.080	0.78	0.4363
method of instruction (1)	0.66	0.327	0.184	2.02	0.0459
(2)	-0.08	0.431	-0.017	-0.18	0.8559
(constant)	1.62	0.887		1.83	0.0702

(1) = computer      (2) = teaching assistant

the dependent variable revealed that none of the partial correlation coefficients were significantly different than zero except for the dummy coded variable 1 (computer) for the method of instruction. Table 22 shows that the coefficient for the pretest was 0.05 ( $t = 1.02$ ,  $p = 0.3081$ ). The coefficient for the visual skill score was 0.05 ( $t = 1.72$ ,  $p = 0.0889$ ). The coefficient for the cognitive style score was 0.03 ( $t = 1.09$ ,  $p = 0.2768$ ). The coefficient for the dummy coded variable 1 for the method of instruction was 0.37 ( $t = 2.18$ ,  $p = 0.0313$ ). The coefficient for the dummy coded variable 2 (teaching assistant) for the method of instruction was -0.03 ( $t = -0.15$ ,  $p = 0.8798$ ). Results of this analysis can be found in Table 22.

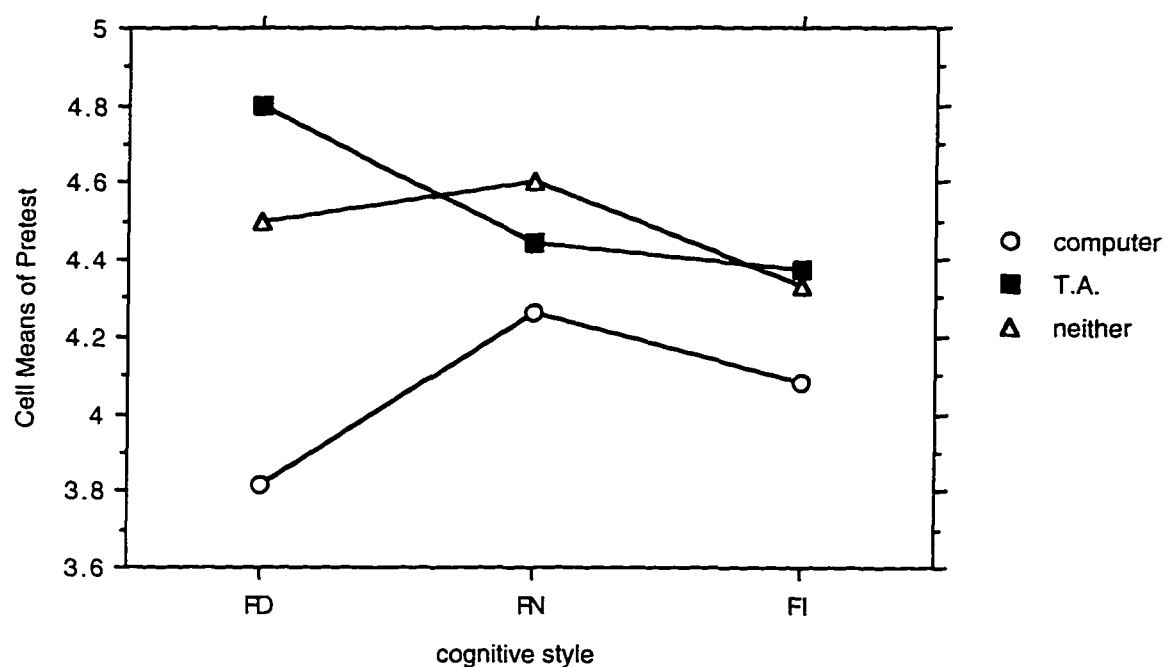
### **Analysis of the Interaction Between Method of Instruction and Cognitive Style**

A 2-factor ANOVA revealed there was no significant interaction effect between method of instruction and cognitive style on the average scores of the 9-question pretest ( $F = 0.29$ ,  $p = 0.9984$ ). A graph of the interaction can be seen

**Table 22. Hierarchical regression analysis using the chemical kinetics portion of the final exam score as the dependent variable**

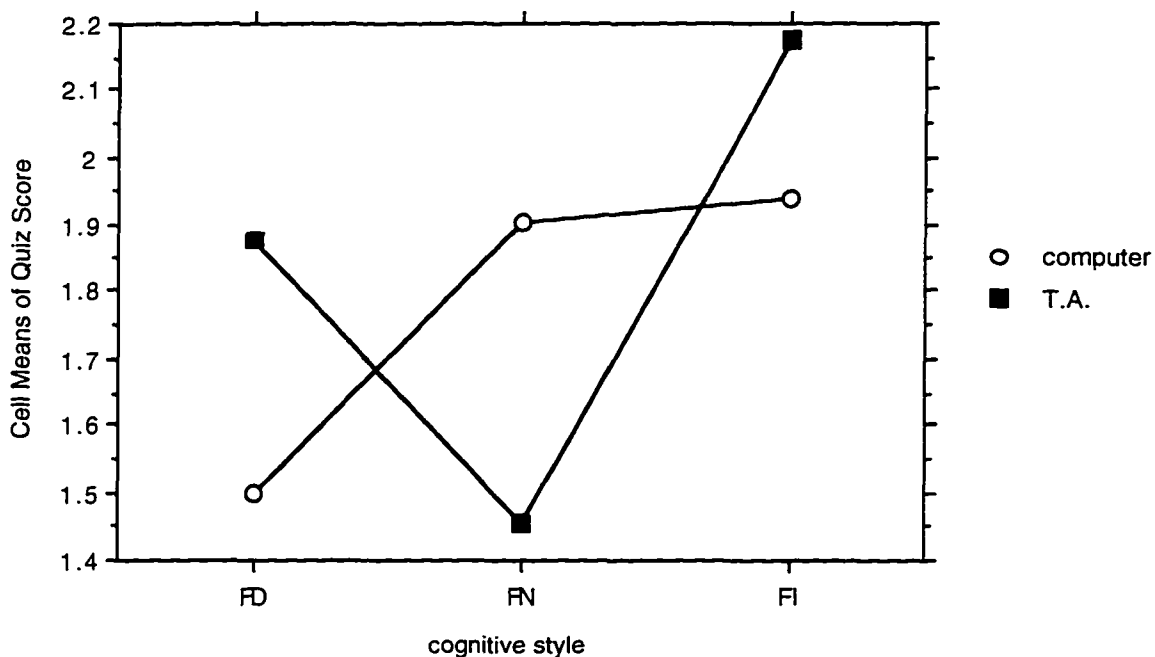
Variable	B	Standard Error B	Beta	t	Significance t
pretest	0.05	0.051	0.094	1.02	0.3081
visual skill	0.05	0.028	0.178	1.72	0.0889
cognitive style	0.03	0.025	0.113	1.09	0.2768
method of instruction (1)	0.37	0.169	0.201	2.18	0.0313
(2)	-0.03	0.223	-0.014	-0.15	0.8798
(constant)	0.38	0.460		0.84	0.4051

(1) = computer      (2) = teaching assistant

**Figure 7. Interaction between method of instruction and cognitive style on the pretest.**

in Figure 7. In addition, the results of the 2-factor ANOVA of the interaction and group means can be seen in Table 12.

For the average scores on the 4-question quiz, no significant interaction effect between method of instruction and cognitive style was found ( $F = 0.57$ ,  $p = 0.5676$ ). Remember that only students who interacted with the computer or received instruction from a teaching assistant are included in this analysis. Students classified as having neither form of instruction were students who did not attend class on the day of instruction and thus did not take the quiz. A graph of the interaction on the average scores of the quiz is shown in Figure 8. The results of the 2-factor ANOVA of the interaction and the average scores of the groups are summarized in Table 13.

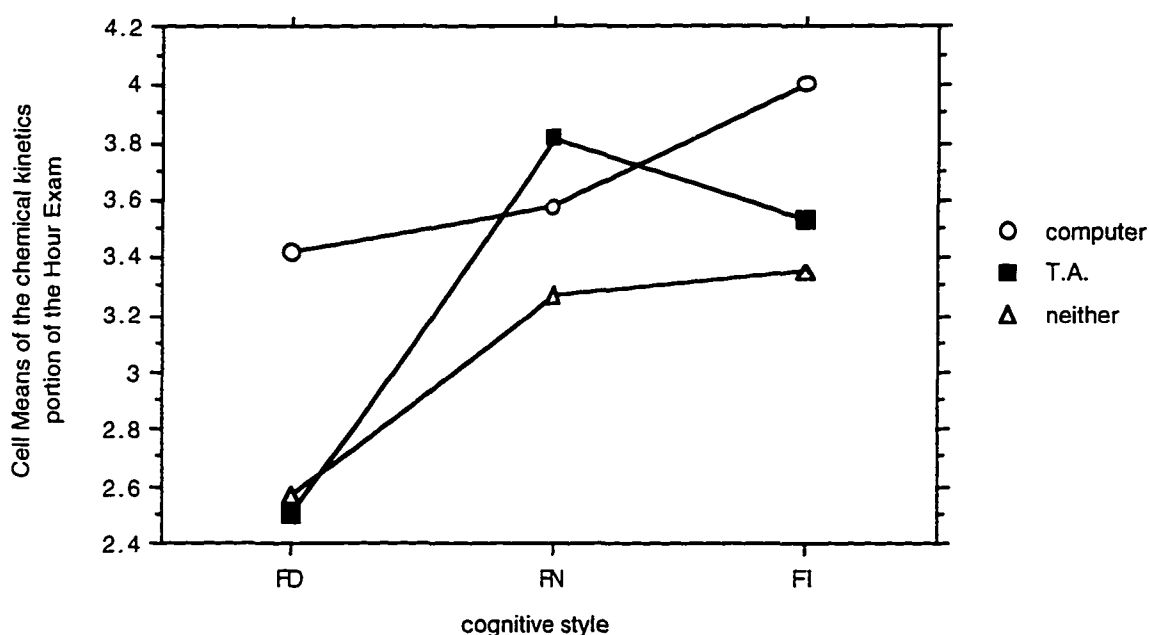


**Figure 8.** Interaction between method of instruction and cognitive style on the quiz.

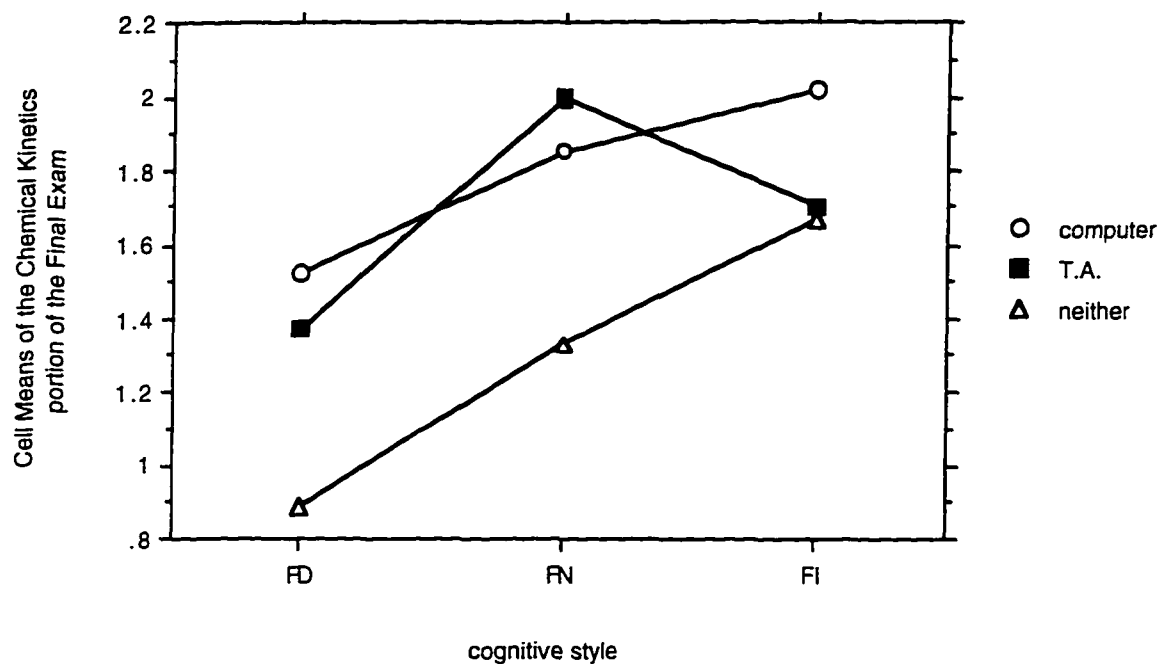
Again there was no interaction effect detected between method of instruction and cognitive style on the groups' average scores on the 7 questions of the chemical kinetics portion of the hour exam ( $F = 0.51$ ,  $p = 0.7313$ ). A graph of the interaction is displayed in Figure 9. The results from the 2-factor ANOVA on the interaction between method of instruction and cognitive style on the average scores of the groups are shown in Table 14.

Finally, there was no interaction effect detected between method of instruction and cognitive style on the average scores of the groups on the 4 questions of the chemical kinetics portion of the final exam ( $F = 0.56$ ,  $p = 0.7313$ ).

A graph of this interaction can be seen in Figure 10. The results from



**Figure 9.** Interaction between method of instruction and cognitive style on the hour exam.



**Figure 10. Interaction between method of instruction and cognitive style on the final exam.**

the 2-factor ANOVA of the interaction between method of instruction and cognitive style on the average scores of the groups are shown in Table 15.

### **Time in the Simulated Environment**

In order to determine if time on task influence the students, an analysis of the amount of time spent in the simulated environment was performed. No significant effect was detected for cognitive style and the amount of time spent in the simulated environment ( $F = 1.58, p = 0.2141$ ). Out of the total time used interacting with the computer program, field dependent students used an average of 6.83% of the total time exploring the simulated reaction system ( $SD = 7.75$ ). Field neutral students spent an average of 9.52% of the total time

exploring the simulated reaction system ( $SD = 7.83$ ). Lastly, field independent students spent an average of 13.46% of the total time exploring the simulated reaction system ( $SD = 14.76$ ). Analysis of the interaction and group means can be found in Table 28.

### Quantitative vs. Qualitative Questions

In an attempt to determine if a correlation exists between qualitative and quantitative chemistry problems, analyses were performed on matching questions. Matching quantitative-qualitative (conceptual) questions are questions based on the concept. Quantitative questions are numerical problems in which mathematical formulas can be used to answer the question. Qualitative questions are ones which probe conceptual

**Table 28. ANOVA Table for the percentage of time spent exploring the simulated reaction system using cognitive style as the grouping factor**

Source	df	Sum of Squares	Mean Square	F value	p Value
cognitive style	2	502.55	251.27	1.58	0.2141
residual	67	10671.86	159.28		

### Incidence Table

Cognitive Style	Count	Average Percentage	Standard Deviation
field dependent	13	6.83	7.75
field neutral	14	9.52	7.83
field independent	43	13.46	14.76

understanding, which generally deal with the particulate level. These questions may or may not be able to be answered using mathematical formulas. On the pretest, there were two sets of matching quantitative-qualitative (conceptual) questions. One set, which dealt with the method of initial rates, was question 2 (quantitative) and question 6 (qualitative). The other set, which dealt with rates of reaction, was question 8 (qualitative) and question 9 (quantitative). The questions used on the pretest can be found in Appendix 15. On the matching quantitative (question 2) and qualitative (question 6) method of initial rates questions, a significant difference in the number of students answering each type of question correctly was detected. A chi-square analysis showed that more students were able to answer the quantitative method of initial rates question correctly than the qualitative method of initial rates question ( $\chi^2 = 9.28$ ,  $p = 0.0023$ ). Table 29 shows the observed and expected frequencies for each question.

For the matching quantitative (question 9) and qualitative (question 8) rate of reaction questions, a significant difference in the number of students answering each type of question correctly was also found. Again, a chi-square analysis showed that more students were able to answer the quantitative rate of reaction question correctly than the qualitative rate of reaction question ( $\chi^2 = 103.33$ ,  $p < 0.0001$ ). Table 30 shows the observed and expected frequencies for each question.

There was only one set of matching quantitative-qualitative (conceptual) questions on the chemical kinetics portion of the hour exam. The questions

**Table 29. Observed and expected<sup>a</sup> number of students answering matching quantitative and qualitative method of initial rates questions on the pretest**

Type of question	Correct responses	Incorrect responses	Total
quantitative (question 9)	83(70)	63(76)	146
qualitative (question 8)	57(70)	89(76)	146
Total	(140)	(152)	292

<sup>a</sup> the expected frequencies are listed in parentheses

**Table 30. Observed and expected<sup>a</sup> number of students answering matching quantitative and qualitative rate of reaction questions on the pretest**

Type of question	Correct responses	Incorrect responses	Total
quantitative (question 9)	93(70)	53(76)	146
qualitative (question 8)	10(70)	136(76)	146
Total	(140)	(152)	292

<sup>a</sup> the expected frequencies are listed in parentheses

used on the chemical kinetics portion of the hour exam can be found in Appendix 16. For the matching quantitative (question 9) and qualitative (question 8) rate of reaction questions, a significant difference in the number of people answering each type of question correctly was also detected. A chi-square analysis showed that more students were able to answer the quantitative rate of reaction question correctly than the qualitative rate of

reaction question ( $\chi^2 = 57.65$ ,  $p < 0.0001$ ). Table 31 shows the observed and expected frequencies for each question.

### **Cognitive Style and Quantitative vs. Qualitative Questions**

Based on the factor of cognitive style, there was no significant difference between any of the three groups (field dependent, field neutral, field independent) on the number of students who correctly answered matching sets of questions. On the pretest for the two matching method of initial rate questions (question 2-quantitative; question 6-qualitative), the chi-square analysis resulted in a chi-square value of 0.23 ( $p = 0.8901$ ). For the two matching rate of reaction questions on the pretest (question 9-quantitative; question 8-qualitative), the chi square analysis resulted in a value of 2.21 ( $p = 0.3306$ ). Lastly, for the two matching rate of reaction questions on the chemical kinetics portion of the hour exam, the chi-square analysis resulted in a chi-

**Table 31. Observed and expected<sup>a</sup> number of students answering matching quantitative and qualitative rate of reaction questions on the chemical kinetics portion of the hour exam**

Type of question	Correct responses	Incorrect responses	Total
quantitative (question 9)	85(123.58)	128(89.42)	213
qualitative (question 8)	161(122.42)	50(88.58)	211
Total	(246.00)	(178.00)	424

<sup>a</sup> the expected frequencies are listed in parentheses

**Table 32. Observed and expected<sup>a</sup> number of students correctly answering matching quantitative and qualitative rate of reaction questions based on cognitive style**

Type of question	Field dependent	Field neutral	Field independent	Total
quantitative (pretest-question 2)	13(13.88)	22(21.13)	32(31.99)	67
qualitative (pretest-question 6)	10( 9.12)	13(13.87)	21(21.01)	44
Total	(23.00)	(35.00)	(53.00)	111
quantitative (pretest-question 9)	4( 2.23)	1( 1.86)	3( 3.91)	8
qualitative (pretest-question 8)	20(21.77)	19(18.14)	39(38.09)	78
Total	(24.00)	(20.00)	(42.00)	86
quantitative (hour exam-question 9)	23( 2.23)	33( 1.86)	66( 3.91)	122
qualitative (hour exam-question 8)	15(21.77)	19(18.14)	35(38.09)	69
Total	(38.00)	(52.00)	(101.00)	191

<sup>a</sup> the expected frequencies are listed in parentheses

square value of 0.28 ( $p = 0.8679$ ). Table 32 contains the observed and expected frequencies of the number of students answering each type of question correctly based on cognitive style.

### **Method of Instruction and Quantitative vs. Qualitative Questions**

Based on the factor of method of instruction, there was no significant difference between any of the three groups (computer, teaching assistant, neither) on the number of students who correctly answered a matching set of questions on either the pretest or the chemical kinetics portion of the hour exam. For the two matching method of initial rate questions (question 2-quantitative; question 6-qualitative) on the pretest, the chi-square analysis resulted in a chi-square value of 1.70 ( $p = 0.4270$ ). On the pretest for the two matching rate of reaction questions (question 9-quantitative; question 8-qualitative), the chi-square analysis resulted in a value of 0.33 ( $p = 0.8467$ ). Finally, for the one set of matching rate of reaction questions on the chemical kinetics portion of the hour exam, the chi-square analysis resulted in a chi-square value of 5.70 ( $p = 0.0578$ ). Table 33 contains the observed and expected frequencies of the number of students answering each type of question correctly based on method of instruction.

### **Visual Skill and Quantitative vs. Qualitative Questions**

Based on the factor of visual skill there was no significant difference between any of the three groups (high visual skill, moderate visual skill, low visual skill) on the number of students who correctly answered a set of

**Table 33. Observed and expected<sup>a</sup> number of students correctly answering matching quantitative and qualitative rate of reaction questions based on method of instruction**

Type of question	Computer	Teaching assistant	Neither	Total
quantitative (pretest-question 2)	47(45.49)	19(22.15)	16(14.36)	82
qualitative (pretest-question 6)	29(30.51)	18(14.85)	8( 9.64)	55
Total	(76.00)	(37.00)	(24.00)	137
quantitative (pretest-question 9)	6( 5.26)	2( 2.23)	1( 1.51)	9
qualitative (pretest-question 8)	53(53.74)	23(22.77)	16(15.49)	92
Total	(59.00)	(25.00)	(17.00)	101
quantitative (hour exam-question 9)	85(89.01)	32(35.34)	44(36.65)	161
qualitative (hour exam-question 8)	51(46.99)	22(18.66)	12(19.35)	85
Total	(136.00)	(54.00)	(56.00)	246

<sup>a</sup> the expected frequencies are listed in parentheses

matching questions. On the pretest, for the one set of matching method of initial rate questions (question 2- quantitative; question 6-qualitative), the chi-square analysis resulted in a chi-square value of 0.08 ( $p = 0.9626$ ). On the pretest for the two matching rate of reaction questions (question 9-quantitative; question 8-qualitative), the chi-square analysis resulted in a chi-square value of 0.61 ( $p = 0.7377$ ). Lastly, for the two matching rate of reaction questions on the chemical kinetics portion of the hour exam, the chi-square analysis resulted in a chi-square value of 1.20 ( $p = 0.5493$ ). Table 34 contains the observed and expected frequencies of the number of students answering each type of question correctly based on visual skill.

**Table 34. Observed and expected<sup>a</sup> number of students correctly answering matching quantitative and qualitative rate of reaction questions based on visual skill**

Type of question	High visual skill	Moderate visual skill	Low visual skill	Total
quantitative (pretest-question 2)	19(19.33)	23(22.35)	19(19.33)	61
qualitative (pretest-question 6)	13(12.67)	14(14.65)	13(12.67)	40
Total	(32.00)	(37.00)	(32.00)	101
quantitative (pretest-question 9)	3( 2.1)	2( 2.36)	2( 2.54)	7
qualitative (pretest-question 8)	21(21.90)	25(24.64)	27(26.46)	73
Total	(24.00)	(27.00)	(29.00)	80
quantitative (hour exam-question 9)	38(37.83)	33(35.97)	40(37.21)	111
qualitative (hour exam-question 8)	23(23.17)	25(22.03)	20(22.79)	68
Total	(61.00)	(58.00)	(60.00)	191

<sup>a</sup> the expected frequencies are listed in parentheses

## CONCLUSIONS

### Chemical Kinetics Measures

The average scores on the four instruments used to measure chemical kinetics achievement (pretest, posttest [quiz], chemical kinetics portion of the hour exam, chemical kinetics portion of the final exam) were quite low. On the pretest, students had an average score of 46.7% correct. This result is to be expected. Students knowledge of the subject before instruction should be expected to be low. After instruction, one would expect to find some improvement. This was not observed. On the posttest, which was administered immediately following instruction (either interacting with the computer or working with a teaching assistant), the average score of the students was now 44.5% correct. On the kinetics portion of the hour exam the average score was 48.6%. The average score on the chemical kinetics portion of the final exam was 41.0%. The chemical kinetics questions on the final exam were more difficult than the questions on the pretest.

These scores are similar to scores observed on previous tests during previous semesters at Iowa State University. Average scores on chemical kinetics questions generally are in the range of 40-60%. The average scores on the instruments used to assess knowledge of chemical kinetics in this research study fall into that range.

Looking at the item analysis of the questions on the quiz, one finds that students had some difficulty in determining the rate at a given set of concentrations, calculating the rate constant, and determining the initial rate.

Correct answers on questions 2, 3, and 4 on the quiz were dependent on a correct response to question 1. Only 67% of the students answered question 1 correctly. We would expect that the percentage of students correctly answering the remaining questions would probably decrease.

Performance seemed to have improved somewhat on the chemical kinetics portion of the hour exam. Students answered the quantitative questions better than the qualitative (conceptual) questions. Previous research on quantitative and qualitative questions (Yarroch, 1985; Herron and Greenbowe, 1986; Nurrenbern and Pickering, 1987; Sawrey, 1990; and Pendley, Bretz, and Novak, 1994), supports the results found in this study. One explanation for this trend is that students usually see quantitative questions presented as examples in lecture. Students are usually assigned quantitative questions as homework. This is the main type of question with which the students practice. Time-on-task research (Karweit, 1984) states that the longer one spends working on a task, the better one will be at performing that task. When no conceptual problems are presented in lecture or are assigned as homework, one should expect students to do poorly on conceptual questions.

Performance on the chemical kinetics portion of the final exam was lower than on any of the other measures. With cumulative final exams, students have to remember material covered throughout the entire semester. Generally, chemical kinetics is one of the last topics covered in General Chemistry 177 at Iowa State University. Students probably choose to review the material from the beginning of the semester more than the material discussed

at the end, since the students probably feel that the material discussed at the end of the semester is more fresh in their memories. This might account for the lack of success on chemical kinetics problems on the final exam.

### **Student Performance on Similar Questions**

In order to determine whether the students learned and retained the material, performance on similar questions was analyzed. One should expect more students would be able to answer the same type of question correctly after instruction than before. Generally, this was the case. Improvement seemed to have occurred more on the quantitative questions (pretest question 2-quiz question 1a; and pretest question 6-hour exam question 6) than the qualitative questions (pretest question 9-hour exam question 9). When there was no improvement, this seemed to have occurred more on the qualitative questions (pretest question 7-hour exam question 7; and pretest question 8-hour exam question 8) than the quantitative questions (pretest question 2-final exam question 41; and pretest question 2-final exam question 24).

Again, students in this study were given only quantitative questions for homework. Therefore, improvement should occur more with quantitative than qualitative questions because time-on-task research indicates that the more time spent on practicing a task, the better one is later performing the task (Karweit, 1984). However, there was no improvement observed on some quantitative questions. These instances occurred on the final exam.

## **Cognitive Style**

This research, which looked at the effect of cognitive style on chemistry achievement on questions dealing with chemical kinetics, served to confirm previous research in general chemistry, add to the research concerning conceptual understanding, and add to the research concerning multimedia. This research attempted to confirm previous research by Lawson (1983) and Witkin, Moore, Goodenough, and Cox (1977) which showed that field independence contributes to a higher achievement in chemistry. This research also attempts to add to the knowledge base concerning the interaction of student attributes on achievement in chemical kinetics. One of these student attributes is the cognitive style of field dependence-field independence.

Statistically, there was no difference in scores on the pretest based on cognitive style. Students classified as field independent, field neutral, or field dependent scored equally well on the chemical kinetics pretest. This indicates that when grouped by cognitive style, students entered the topic of chemical kinetics with the same amount of content knowledge.

While there was no statistical difference on the average scores of the students on the quiz, tendencies were detected. Field independent students tended to score higher than field neutral or field dependent students. Also, field neutral students tended to score higher than field dependent students.

For the kinetics portion of the hour exam, a significant difference in average scores was detected based upon cognitive style. Field independent students scored higher on the chemical kinetics portion of the hour exam than those that were field dependent. No other significant differences were

detected. Several weak trends were observed. Field independent students tended to score higher than field neutral students and field neutral students tended to score higher than field dependent students on the chemical kinetics portion of the hour exam.

For the kinetics portion of the final exam, when cognitive style is a factor a significant difference in average scores was detected. Field independent students scored significantly higher than field dependent students. No other significant differences were detected. Again, consistent weak trends emerged. Field independent students tended to score higher than field neutral students on the chemical kinetics portion of the final exam. Field neutral students tended to score higher than field dependent students.

The analysis of the average scores on the chemical kinetics measures supports research by Lawson (1983) and Witkin, Moore, Goodenough, and Cox (1977). Field independence is a factor that contributes to success in chemistry achievement.

### **Problems with the Quiz**

One would expect that there would be no differences in the scores of participants on the pretest. With no prior knowledge of the topic it seems logical that differences due to cognitive style would not be found. Due to time constraints, only 10 minutes were allotted to administer the quiz in the recitation class. As such only one problem on the method of initial rates was used on the quiz. No questions concerning the rates of reaction were on the quiz. This quiz did not test for several chemical kinetics topics, only knowledge

and skills concerning the topic of method of initial rates. This could have been the cause for the lack of significant differences to be found for the average scores on the quiz based on cognitive style. With additional questions concerning the rates of reaction, a significant difference might have been found. Also, with the quiz given immediately after instruction, perhaps the participants may not have had sufficient time to internalize the information presented. More time during the treatment, including time for questions and answers, might have produced significant differences between groups.

Furthermore, the question on the quiz used just a small data table. With additional information on the table, such as more entries, as was the case on the final exam, students who were field independent may have scored significantly higher than the field dependent students. The visual field may not have had enough information displayed to cause field dependent students to have to disembed information. Remember that field independence is the ability to identify the relevant information necessary to solve a problem or the ability to free oneself from the effects of the context in which the problem is placed.

### **Method of Instruction**

Investigating the method of instruction used to provide information dealing with chemical kinetics attempted to confirm research by others, as summarized in a meta-analysis by Kulik, Kulik, and Bangert-Drowns (1985), which found that most computer based educational programs had a positive effect on student learning. Also, this research attempted to confirm research

by Niemiec and Walberg (1985) who found that computer based instruction is effective in raising student achievement. In addition, this research attempted to confirm the results of previous research by Smith, Jones, and Waugh (1986) and Jackson, Moellenberg, and Brabson (1987) on the use of computers for chemistry instruction to improve student performance.

There were no statistical differences found in the average scores of the students on the pretest using method of instruction as the grouping factor. Students who interacted with the computer, students who worked with the teaching assistant, or students who did not get additional instruction from either interacting with the computer or working with the teaching assistant scored equally well on the pretest. Again this result allows one to assume that the students, when randomly grouped by method of instruction, are no different in terms of the amount of knowledge concerning chemical kinetics they possess before instruction began.

Also, there was no difference in scores on the immediate posttest. Participants who received instruction from the teaching assistant tended to score higher on the quiz than participants who interacted with the computer. No statements can be made concerning students classified as neither since they did not have any quiz scores. These were the students who did not attend recitation class on the day the instruction was given.

On the chemical kinetics portion of the hour exam a significant difference was not found. Participants who interacted with the computer scored tended to score higher than participants who did not interact with the computer or work with a teaching assistant. Also, participants who interacted

with the computer tended to score higher than those who worked with the teaching assistant. In addition, participants who worked with the teaching assistant tended to score higher than those who did not interact with the computer or work with a teaching assistant.

For the chemical kinetics portion of the final exam, a significant difference was found on the average scores between the three groups. Students who worked with the computer scored significantly higher than students who did not interact with the computer or work with a teaching assistant. Students who worked with the computer tended to score higher than those who worked with the teaching assistant. In addition, those who worked with the teaching assistant tended to score higher than those who did not interact with the computer or work with a teaching assistant.

Analysis of the average scores of students using method of instruction as the grouping factor again yielded results which support the literature. Participants who worked with the computer program scored significantly higher than those who did not work with either the computer or a teaching assistant. The data also suggest that students who worked with a teaching assistant scored higher than those who did not work with either the computer or teaching assistant. These two findings support the notion that students who receive instruction spent more time studying the material than those who did not come to class on the day the instruction was given.

The data also suggest that participants who worked with the computer scored higher than those who worked with a teaching assistant. These findings are supported by research which states that computer-assisted

instruction has positive affects on student learning (Kulik, Bangert-Drowns, and Williams, 1983; Niemiec and Walberg, 1985; Kulik and Kulik, 1991). The information was presented using many different formats. Some information was written and students could just read the text. Some information was presented in terms of graphs and animations. Finally, some information could be gained through interacting with the simulated environment. The ideal situation would be to create an instructional environment where students could build their own concepts and ideas and be given the opportunity to hypothesize. By providing a variety of methods for obtaining information, students could choose the method with which they felt most comfortable. This would allow students to learn the material better by allowing them to choose a method of instruction that best matches their learning style.

Finding no differences between groups on the immediate posttest was an unexpected result. The data seemed to suggest that those participants who worked with the teaching assistant scored higher than those who worked with the computer program. One must look at the manner in which the recitation class is run in order to explain this finding. The purpose of the recitation class is to discuss homework problems that the students were assigned or to answer student questions. Typically students ask specifically what is the material that will be covered on the quiz. The teaching assistant receives the quiz prior to the recitation class and therefore can structure the recitation class so that questions and homework problems that are specifically related to questions posed on the quiz can be answered and discussed. The instruction these students received was from their normal recitation teaching assistant and not

the investigator. The investigator was present in the computer lab at the time the other recitation classes were being held. The teaching assistants were asked to not specifically discuss only the material that was to be covered on the quiz, but other topics, such as rates of reaction, as well. However the investigator could not completely control the actions of the teaching assistants and they might have ignored the instructions of the investigator. This may contribute to an explanation as to how the students who worked with the teaching assistant tended to score higher on the posttest than students who worked with the computer program.

### **Visual Skill (Spatial Ability)**

Investigating the effect of visual skill (spatial ability) attempts to add to the knowledge base concerning learner attributes and achievement in chemistry. Krajcik, Simmons, and Lunetta (1988), in the discussion of their own research, state that the relationships between computer graphics and learner variables should be investigated. Furthermore, MacGregor, Shapiro, and Niemiec (1988) state that additional research is needed to evaluate the effectiveness of computer assisted instruction for students with different learning styles. These statements provided the idea for designing a study to investigate another learner variable, visual skill (spatial ability).

Students classified as high visual skill, moderate visual skill, and low visual skill scored equally well on the pretest. No significant difference in average pretest scores was detected. This allows one to assume that when grouped by visual skill, the participating students were no different in terms of

the amount of knowledge concerning chemical kinetics prior to formal instruction.

A significant difference was found between the spatial ability of the groups on their average scores on the chemical kinetics portion of the hour exam. Students classified with high visual skill scored significantly higher than students classified with low visual skill. Also, students with moderate visual skill scored significantly higher than low visual skill students. No other significant differences were discovered. Significant differences were also found in the average scores on the chemical kinetics portion of the final exam. High visual skill students scored significantly higher than low visual skill students. In addition, moderate visual skill students scored significantly higher than low visual skill students. Students classified with high visual skill tended to score higher than students classified with moderate visual skill on all measures of chemical kinetics knowledge and skills.

An effect was found for visual skill on learning chemical kinetics. For the scores on the kinetics portions of the hour and final exams, those participants classified with high visual skill or moderate visual skill scored significantly higher than those classified with low visual skill. The data also suggest that those classified with high visual skill scored higher than those classified with moderate visual skill. Although significant statistical differences were detected, any educational differences attributed to spatial ability must be viewed with caution due to such small differences. However, these findings are supported by the research which states that visual skill is an important factor in learning chemistry (Niaz, 1987; Herron and

Greenbowe, 1986; Bodner and McMillen, 1986; and Carter, LaRussa, and Bodner, 1985).

No significant differences were found between groups classified as having high, moderate, or low visual skill on the average posttest scores. The data suggest that students classified as having moderate visual skill seemed to score highest, followed by students classified as having high visual skill, and then students classified as having low visual skill. The quiz had questions concerning one topic, the method of initial rates. This question was not visual in nature. Data was given in the form of a table with four entries and students needed to perform some mathematical procedures in order to calculate an answer. The numbers were in a simple form. There were no exponents in the data. Therefore, visual skill did not appear to be an important factor in solving the questions on the posttest. There were only quantitative questions on the chemical kinetics portion of the final exam. On the final exam though, the data tables had more entries (5) and numbers with exponents. Visual skill may have become a factor in obtaining the necessary information from the tables with greater number of entries and exponents.

### **Regression Analysis**

A hierarchical regression analysis was done to further support the findings of the analyses of variance. The instruments used to measure cognitive style and visual skill provided data that was continuous in nature. In order to preserve the continuous nature of the variables, a regression analysis was performed.

The results of the regression analyses did support the analyses of variances. None of the variables (pretest, visual skill score, cognitive style score, and method of instruction) were able to be used to predict the quiz score. For the hour exam, the visual skill score and interacting with the computer as the method of instruction were able to be used to predict scores on the chemical kinetics portion of the hour exam. Finally, for the hour exam, interacting with the computer as the method of instruction was the only variable that was able to be used to predict scores on the chemical kinetics portion of the final exam.

### **Interaction Between Method of Instruction and Cognitive Style**

MacGregor, Shapiro, and Niemiec (1988) looked at the interaction of method of instruction and cognitive style on math achievement. This research attempted to look at the effect of method of instruction and cognitive style on chemistry achievement, specifically the topic of chemical kinetics. This portion of the study attempted to confirm the MacGregor, Shapiro, and Niemiec research which found that the learning environment affects students with different cognitive styles.

No significant interaction effects were found on the pretest. Again this is a finding that one would expect. With no significant differences on either of the two factors independently, one would not expect to find an interaction between the two factors. This allows one to assume that the students scored equally well on the pretest no matter which group they belonged to.

No significant interaction effects were found on the posttest. Again with no significant differences present, one would not expect to find an interaction between any two factors. The difficulties with the quiz when each factor was investigated separately seemed to have affected these results also. A general trend was observed. Students who were field dependent or field independent and worked with a teaching assistant tended to score higher on the quiz than those who were field dependent or field independent and worked with the computer. Also for those who worked with the computer, it seems as though field independent students tended to score higher than field neutral students and field neutral students tended to score higher than field dependent students.

No significant differences were found between groups based on cognitive style on the average scores on the chemical kinetics portion of the hour exam. The same general was observed. Students who were field dependent or field independent and interacted with the computer tended to score higher than those who were field dependent or field independent and worked with a teaching assistant. Also, for students who interacted with the computer and students who did not interact with the computer or work with a teaching assistant, it appears that field independent students tended to score higher than field neutral students and field neutral students tended to score higher than field dependent students.

No significant differences were found for the interaction of method of instruction and cognitive style on the average scores on the chemical kinetics portion of the final exam. The same pattern of results for the chemical

kinetics portion of the hour exam was found for the chemical kinetics portion of the final exam. The trend was that students who were field dependent or field independent and interacted with the computer tended to score higher than those who were field dependent or field independent and worked with a teaching assistant. Also, for students interacted with the computer and students who did not interact with the computer or work with a teaching assistant, it appears that field independent students tended to score higher than field neutral students and field neutral students tended to score higher than field dependent students.

No significant interaction effects between method of instruction and cognitive style on any of the chemical kinetics achievement measures were found. However the data did reveal some trends. Participants who did not interact with the computer program or work with a teaching assistant seemed to score lower than those who did not interact with the computer program or work with a teaching assistant. This can also be explained by the amount of time participants spent studying the material.

For the chemical kinetics portions of the hour and final exams the data suggest that those who were field independent or field dependent and interacted with the computer scored higher than those who were field independent or field dependent and worked with a teaching assistant. Also, those who were field neutral and worked with a teaching assistant seemed to score higher than those who were field neutral and interacted with the computer. These findings are similar to the findings of research by MacGregor, Niemiec, and Shapiro (1988). Their study found that participants

who were classified as field dependent and worked in a computer-augmented environment exhibited greater math achievement than those who worked in a traditional learning environment. In addition they found that those who were field neutral (field indiscriminate) exhibited greater math achievement in a traditional learning environment than in the computer-augmented environment. In their study they did not have any field independent students and therefore could state no conclusions concerning that type of student. However, Post (1987) found that field independent students benefited from computer based instruction when learning about logic circuits.

The data for the quiz scores revealed a trend which was the opposite of the one for scores on the chemical kinetics portions of the hour and final exams. Here the data suggest that those participants who were classified as field dependent or field independent and worked with the computer scored lower than those participants classified as field dependent or field independent and worked with the teaching assistant. These results can be explained using the same reasoning as that for the factor of method of instruction. Teaching assistants were asked not to structure their recitation classes to specifically cover the material on the quiz but on the entire topic of chemical kinetics. The actions of the teaching assistants could not be completely controlled and they might have taught specifically for the quiz, ignoring the instructions of the investigator. These teaching assistants may have discussed only method of initial rates problems which could have resulted in the higher scores for this group.

### **Time in the Simulated Environment**

This portion of the research attempted to confirm one of the characteristics attributed to field independent students. The characteristic is how students prefer to learn. Garger and Guild (1984) state that field independent students prefer to learn using the hypothesis testing approach and that field independent students prefer to learn using the spectator approach.

No significant differences for cognitive style were found between groups for the amount of time spent in the simulated environment. The data seemed to suggest that participants who interacted with the computer program and were field independent spent a greater percentage of their time exploring the simulated environment than those who were field neutral or field dependent. Also, those who were field neutral seemed to spend a greater percentage of their time in the simulated environment than those who were field dependent. Significance might not have been obtained due to the number of students who took the Group Embedded Figures Test and interacted with the computer. There were only 13 field independent students, 14 field neutral students, and 43 field independent students who interacted with the computer. With larger numbers of field dependent and field neutral students, the differences in the average percentage of time spent in the simulated environment may have been significant.

However, these findings do reflect the characteristics of field dependent and field independent persons that Garger and Guild (1984) list. They stated that field independent students use a hypothesis testing approach to attain

concepts whereas field dependent students use a spectator approach. The simulated environment provided the students the opportunity to explore and test hypotheses. In the simulated environment students could manipulate variables such as temperature and concentration in order to determine their effects on the rates of reactions if any. Students could also use the simulated environment to determine the order of each reactant and the rate law. By changing the concentration of just one of the reactants and seeing how the rate of formation of the product changes, students could determine the order of that reactant and by performing the same steps for the other reactant students could determine that reactants order. With that information students could then write the rate law for that reaction.

### **Quantitative vs. Qualitative Questions**

Previous research by Yarroch (1985), Herron and Greenbowe (1986), Nurrenbern and Pickering (1987), Sawrey (1990), and Pendley, Bretz, and Novak (1994) have shown that solving a numerical problem does not mean that one understands the concept underlying the problem. Students are able to solve numerical problems concerning a concept but are not able to solve qualitative or conceptual questions concerning the same topic. This research incorporated matching quantitative and qualitative problems in the chemical kinetics measures to challenge the findings reported in the literature. The chemical kinetics program used in this study included specific instruction on numerical procedures and concepts. The emphasis of the computer instruction was on quantitative problems. It was hoped that by learning from

a visual medium that students would increase their conceptual understanding of chemical kinetics.

There were three instances of matching quantitative and qualitative questions on the chemical kinetics measures. On the pretest there were two instances, one which dealt with the method of initial rates and one which dealt with rates of reaction. On the chemical kinetics portion of the hour exam there was one instance which dealt with rates of reaction. In all three instances there was a difference in the number of correct responses on the quantitative vs. qualitative questions. In each case students answered more quantitative questions correctly than qualitative questions. These findings confirm previous research by Yarroch (1985), Herron and Greenbowe (1986), Nurrenbern and Pickering (1987), Sawrey (1990), and Pendley, Bretz, and Novak (1994).

### **Cognitive Style, Method of Instruction, and Visual Skill and Quantitative vs. Qualitative Questions**

Since there was a difference in performance on quantitative vs. qualitative questions perhaps one of the learner attributes (cognitive style or visual skill) influences one's ability to solve quantitative vs. qualitative questions. Perhaps students who used the computer, which contained visual images of molecules and the opportunity to hypothesize and build concepts, would do better on qualitative questions than students who worked with the teaching assistant or students who did not interact with the computer or work with the teaching assistant. Research has been not been found in this area of

the interaction of learner differences and one's ability to answer qualitative questions.

No significant differences were found between any of the groups based on either cognitive style (field dependent, field neutral, field independent), method of instruction (computer, teaching assistant, neither), and visual skill (high, moderate, low visual skill). Furthermore, within each group, no one class answered qualitative questions better than any other class. In other words, field dependent students, field neutral students and field independent students answered qualitative questions equally as well. Still in every case, students were able to answer more quantitative questions correctly than qualitative questions. These findings support previous research by Yarroch (1985), Herron and Greenbowe (1986), Nurrenbern and Pickering (1987), Sawrey (1990), and Pendley, Bretz, and Novak (1994).

### **Implications of the Study**

This study confirms previous research (Witkin, Moore, Goodenough, and Cox, 1977; Lawson, 1983) which stated that persons who are classified as being field independent do better in chemistry than those classified as being field dependent. Identifying students who are field dependent or field neutral may be a necessary task for an instructor. As a result of this identification, instructors can design instruction which best suits students with differing cognitive styles.

This study seemed to confirm previous research which stated that students learn better with computer-assisted instruction than without (Kulik,

Bangert-Drowns, and Williams, 1983; Niemiec and Walberg, 1985; Kulik and Kulik, 1991). Although, there were no significant effects for method of instruction but a trend was present. An interactive computer software program may be a better method of instruction than a teaching assistant in recitation.

According to Clark (1983) the media itself should not influence learning but it may be that certain aspects of the computer program that influence all types of learners. The computer-based instruction used in this study was comprised of text, graphics, animations, and simulations. Students may have been able to learn more because they were exposed to a greater variety of learning situations and were therefore able to learn from the type of information with which they feel most comfortable. Therefore, instructors could create computer-based instruction to teach or review a topic which contains a variety of learning situations so that individuals can choose the type of instructional situation with which they best learn.

This study also confirmed research which stated that visual skill is an important factor in learning chemistry (Niaz, 1987; Herron and Greenbowe, 1986; Bodner and McMillen, 1986; and Carter, LaRussa, and Bodner, 1985). Students with high visual skill scored higher than those with low visual skill. Again it may be important for instructors to determine the visual skill of their students prior to instruction. This information could help instructors design lessons to best fit students with different visual skills. This information could also provide instructors with the ability to identify students who may have trouble with the course.

This research indicates that those who are field dependent or field independent seem to do better with computer-assisted instruction. Their preference is for differing reasons though. Again, according to Clark (1983) it may not be the computer itself that influences learning but the ability of the computer to provide individualized instruction or give the students a variety of ways for them to learn. Such may be the case with the interactive computer program used in this study.

Field dependent students use the structure of the instructional materials in their cognitive processing (Thompson, 1988). They also utilize a passive approach to attain concepts (Thompson, 1988). In this study, field dependent participants were able to use the structure of the computer program to help organize the information presented. Textual information may be easier for field dependent students to learn the concepts of rates and rate laws. Field independent students prefer to use an active approach to learning that provides opportunities for them to test hypotheses (Thompson, 1988). Participants in this experiment were able to explore and test hypotheses in the simulated environments of the computer lesson. Thus, knowing the cognitive style of an individual may help a chemistry instructor to tailor the instruction to best suit the needs of an individual.

Finally, this research also seemed to confirm previous research in the literature which has produced a list of characteristics of field dependent and field independent students (Thompson, 1988; Saracho and Spodek, 1981). All of these researchers have stated that field dependent students prefer a passive or spectator approach to learning. Also, all of these researchers present evidence

which confirms that field independent students prefer an active or hypothesis testing approach to learning.

The results of this present study showed that field dependent participants seemed to spend the least percentage of time in the computer simulated environment as compared to field neutral or field independent participants. The results of this study also revealed that field independent participants seemed to spend the greatest percentage of time in the computer simulated environment compared to field neutral or field dependent participants. These results were not statistically significant. Participants worked with the computer program for approximately 35 minutes. Working with the computer program for a longer length of time may produce different results. Also, the computer program could also provide both visual and textual information for each topic.

### **Limitations of the Study**

The number of questions on the measures of chemical kinetics were few (4, 7 or 9). This number of questions may not be enough to sufficiently assess knowledge on chemical kinetics or any other topic. In addition, the quiz asked questions concerning only one topic, the method of initial rates. With the topic of rates of reaction added, the quiz would be a better instrument to assess chemical kinetics knowledge.

The amount of time given for the instruction was only 40 minutes. This amount of instructional time was small. More time was probably needed for instruction. Students may not have had sufficient time to learn the material

from either the interactive computer program or the teaching assistant. However, working within the constraints of the class schedule, only one recitation period could be used in order to prevent confounding and minimize the effects of what the students could do after the recitation class in order to better learn the material on chemical kinetics. For technical subjects such as chemistry, students may need additional time to work problems, to read or re-read instructional material, and to process the information. It may be too much to expect gains in content knowledge on the basis of 40 minutes of exposure to the material.

The type of students in this research were from a population of students who have selected physical sciences or chemical engineering as their majors. Therefore these students come from a very small subsection of the population. These students tend to be more field independent and therefore did not allow for the subjects in the study to provide for a more even distribution of field independent, field neutral, and field dependent subjects.

The overall level of statistical significance of this study is not 0.05, though the level of significance for each analysis was 0.05. However, as each analysis was run the overall statistical significance became greater than 0.05. The number of students who took all three tests and all of the chemical kinetics assessments was small. A multiple analysis of variance using all three variables of cognitive style, method of instruction, and visual skill could not be done since the number of persons in each cell was too few. Therefore it became necessary to do individual analyses of variances on the data since the individual persons taking each assessment were different each time the

assessment was administered. Because of the overall statistical significance being greater than 0.05, these results must be looked at with some care.

Regression analysis could not be performed on the data, since only two of the three variables (cognitive style, method of instruction, and visual skill) were continuous variables. Regression analysis could have provided information concerning the predictive abilities of the variables. In addition, regression analysis could have provided further information concerning the relationship and interaction of the variables.

A final limitation is due to researcher bias. This researcher alone administered the measure of cognitive style. Also this researcher was also responsible for the administration of the computer lesson on chemical kinetics. Finally, this researcher also analyzed all of the data. Expectations and anticipation of statistically significant and positive results may have influenced analysis and interpretation of the data.

### **Suggestions for Future Research**

The participants in this study came from a population of students taking general chemistry. This was a required course in the program of study for science and preprofessional majors. They possess strong science and mathematics backgrounds. These participants come from a very small subset of the college student population. Further research should be done with participants enrolled in general chemistry courses but with different science and mathematics backgrounds. Also, further research with participants with

similar science and mathematics backgrounds but from different curricular areas such as physics or mathematics is needed.

Research should also be done with a larger number of participants or with a more equitable distribution of field dependent, field neutral (field indiscriminate), and field independent persons. An interaction between method of instruction and cognitive style was not present in this study. However, the numbers of participants in each group (i.e. field dependent students who worked with the computer) were not equal and sometimes very small. Therefore, additional research which investigates the interaction of method of instruction and cognitive style is needed.

Furthermore, additional research is necessary which allows participants a greater amount of time to interact with the computer-based instruction. Perhaps, this should occur in multiple sessions with the computer. One short length of time with the computer may not be sufficient to determine the effectiveness of using the computer with participants of different cognitive styles.

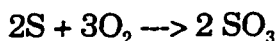
Additional research should be done using a cognitive style other than field dependence-field independence. Messick (1970) has defined eight other cognitive styles besides field dependence/field independence. Research which investigates the interaction between method of instruction and cognitive style should contribute to the knowledge to create learning environments which best suit the learning style of individual students. This would allow the students to best learn what instructors want them to learn.

However, this not the goal of all educators. For example, constructivists want students to construct their own knowledge through collaboration and negotiation with others. Yager (1991) stated that constructivist teachers of science promote group learning. Future research could therefore be done on group learning with interactive computer programs. This future study could investigate the effects of different individual cognitive styles on the learning of the group. Quantitative research though may be difficult to perform. Constructivists are primarily concerned with the learner's ability to apply and manipulate knowledge within an authentic task environment and less interested in the learner's ability to acquire knowledge and supply "right" answers (Lebow, 1993). Instruments which assess knowledge would be inherently objectivist. Yarusso (1992) stated that constructivist evaluation considers answers to be right or wrong only to the extent that the answers demonstrate that the student is able to effectively interact in the content area and can defend judgments made within that context. This future research seems to lend itself to a study that would be qualitative in nature.

## APPENDIX 1. TRADITIONAL AND CONCEPTUAL QUESTIONS ON STOICHIOMETRY

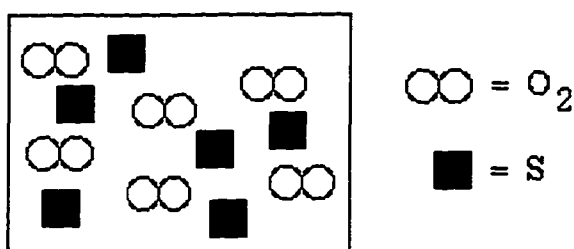
Traditional question on stoichiometry:

Calculate the maximum weight of  $\text{SO}_3$  that could be produced from 1.9 mol of oxygen and excess sulfur.

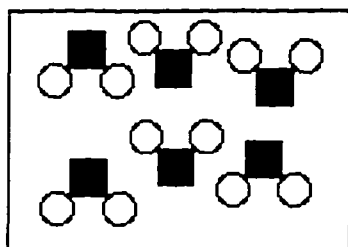


Conceptual question on stoichiometry:

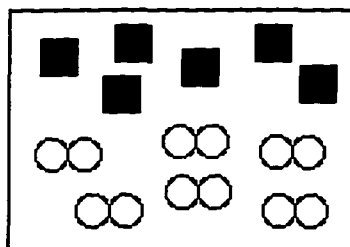
The equation for the reaction is  $2\text{S} + 3\text{O}_2 \rightarrow 2\text{SO}_3$ . Consider a mixture of S and  $\text{O}_2$  in a closed container as illustrated below:



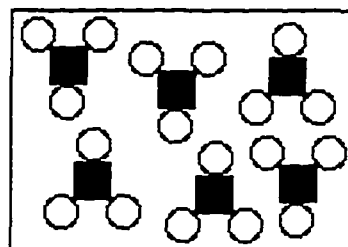
Which of the following represents the product mixture?



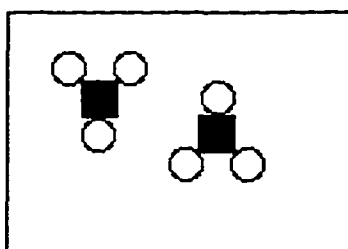
(a)



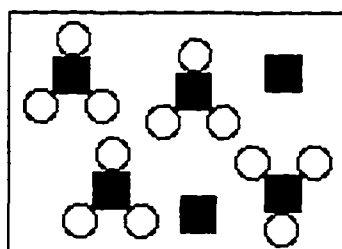
(b)



(c)



(d)

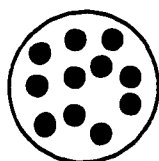


(e)

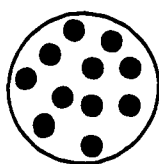
(Nurrenbern and Pickering, 1987; Sawrey, 1990)

**APPENDIX 2. CONCEPTUAL QUESTION CONCERNING GASES**

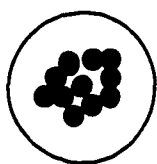
The following diagram represents a cross-sectional area of a steel tank filled with hydrogen gas at 20°C and 3 atm pressure. (The dots represent the distribution of H<sub>2</sub> molecules.)



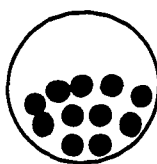
Which of the following diagrams illustrate the distribution of H<sub>2</sub> molecules in the steel tank if the temperature is lowered to -20°C?



(a)



(b)



(c)



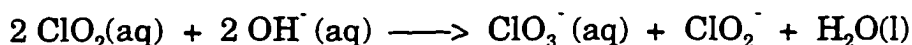
(d)

(Nurrenbern and Pickering, 1987; Sawrey, 1990)

### APPENDIX 3. QUANTITATIVE AND QUALITATIVE QUESTIONS AND DATA CONCERNING RATE LAWS

#### Quantitative Question - Determining a Rate Law

The next two questions pertain to the following information. Please show your work.



Experiment	Initial Concentration, (mol/L )		Initial Rate (mol/(L•sec))
	[ClO <sub>2</sub> ]	[OH <sup>-</sup> ]	
1	0.0500	0.100	5.75 x 10 <sup>-2</sup>
2	0.100	0.100	2.30 x 10 <sup>-1</sup>
3	0.100	0.050	1.15 x 10 <sup>-1</sup>
4	0.150	0.100	?

1. The order of reaction in terms of [ClO<sub>2</sub>] and [OH<sup>-</sup>], respectively, are

- a) 2, 2      b) 2, 1      c) 1, 2      d) 1, 0      e) none of these

Response	a	b*	c	d	e	total	Diff.	Dscr.
n	2	97	2	2	1	104	93	NA

2. The numerical value for the initial rate of reaction in experiment 4 should be

- a) 1.15 x 10<sup>-1</sup>      b) 1.725 x 10<sup>-1</sup>      c) 2.30 x 10<sup>-1</sup>      d) 5.17 x 10<sup>-1</sup>  
e) none of these

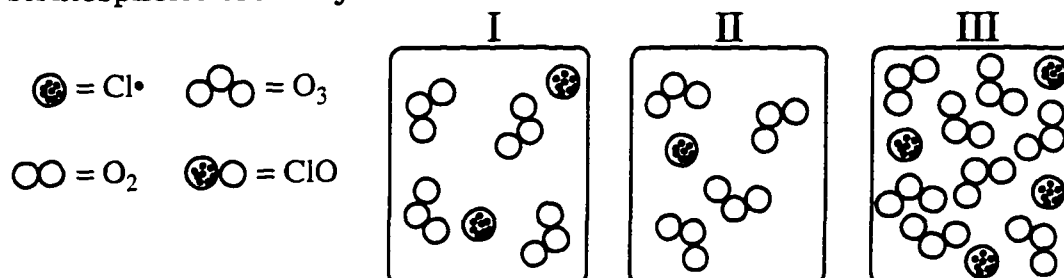
Response	a	b	c	d*	e	total	Diff.	Dscr.
n	7	5	7	71	14	104	68	NA

\* indicates the correct answer

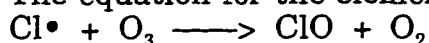
## Qualitative Question - Determining a Rate Law

Questions 3 through 6 refer to the following situation.

Consider the following three molecular pictures that represent the relative numbers of the two reactants involved in one step of the depletion of stratospheric ozone by chlorine atoms.



The equation for the elementary reaction is a bimolecular process:



3. If the three samples represented by I, II, and III are at the same temperature and same volume, compare the relative rates of the reaction in Flask II to Flask I? State your answer in words and select the best choice.

- a)  $\text{RateII} = 2 \text{ RateI}$      c)  $2 \text{ RateII} = \text{RateI}$      e) none of these  
 b)  $2 \text{ RateII} = \text{RateI}$      d)  $2 \text{ RateII} = \text{RateI}$

Response	a	b*	c*	d*	e	total	Diff.	Dscr..
n	33	52	14	1	5	105	64	NA

4. If the three samples represented by I, II, and III are at the same temperature and same volume, compare the relative rates of the reaction in Flask III to Flask I? State your answer in words and select the best choice.

- a)  $4 \text{ RateIII} = \text{RateI}$      c)  $\text{RateIII} = 4 \text{ RateI}$      e) none of these  
 b)  $4 \text{ RateIII} = \text{RateI}$      d)  $\text{RateIII} = 2 \text{ RateI}$

Response	a	b	c*	d	e	total	Diff.	Dscr..
n	19	2	55	19	10	105	52	NA

\* indicates the correct answer

5. The rate law for this reaction is

- a)  $\text{rate} = k[\text{Cl}\cdot]^2 [\text{O}_3]^2$       c)  $k = [\text{Cl}\cdot][\text{O}_3]$       e) none of these  
 b)  $\text{rate} = k[\text{Cl}\cdot][\text{O}_3]$       d)  $\text{rate} = k[\text{Cl}\cdot][\text{O}_3]^2$

Response	a	b*	c	d	e	total	Diff.	Dscr.
n	12	59	8	21	5	105	56	NA

6. If the rate of reaction for the mixture in I is 4.0 molecules/(cm<sup>3</sup>•min) and the concentrations are given in units of molecules/ cm<sup>3</sup>, what is k, the rate constant? Please show your work.

- a) 0.25 min<sup>-1</sup> (molecules/cm<sup>3</sup>)<sup>-1</sup>      d) 4.00 min<sup>-1</sup> (molecules/cm<sup>3</sup>)<sup>-1</sup>  
 b) 0.50 min<sup>-1</sup> (molecules/cm<sup>3</sup>)<sup>-1</sup>      e) none of these  
 c) 2.00 min<sup>-1</sup> (molecules/cm<sup>3</sup>)<sup>-1</sup>

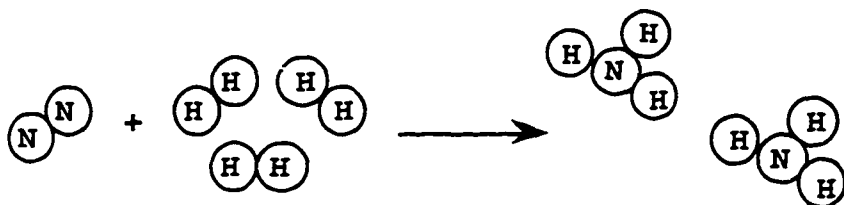
Response	a	b*	c	d	e	total	Diff.	Dscr.
n	13	58	11	12	11	105	55	NA

\* indicates the correct answer

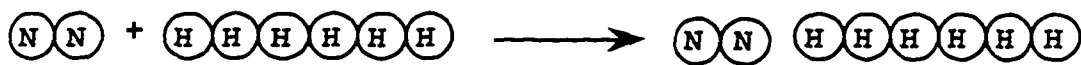
# APPENDIX 4. CORRECT AND INCORRECT REPRESENTATIONS OF A REACTION

representations of the reaction:  $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$

correct student representation



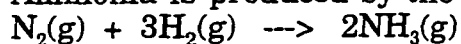
incorrect student representation



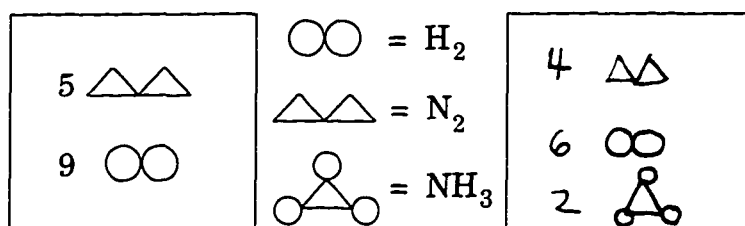
# APPENDIX 5. CORRECT AND INCORRECT STUDENT DIAGRAMS

Student A - correct representation and work

Ammonia is produced by the following reaction:



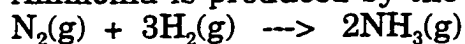
In the diagram, a portion of the flask is shown containing five molecules of nitrogen gas and nine molecules of hydrogen gas. This represents the start of the reaction. Draw the molecular picture showing the contents of this portion of the flask after two molecules of ammonia have formed.



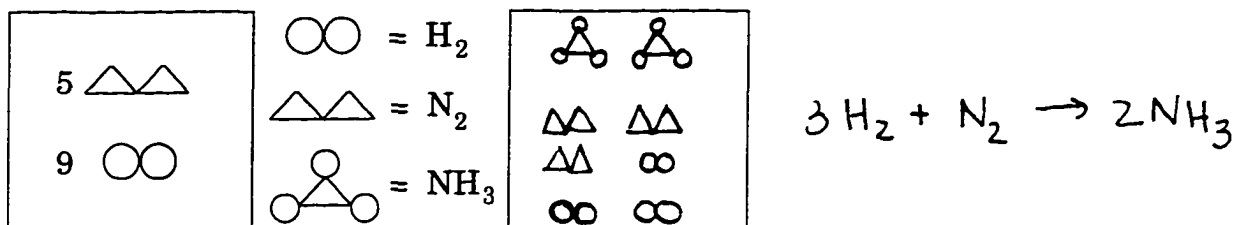
(a more legible reproduction of the student's work)

Student B - incorrect representation (no conservation of mass)

Ammonia is produced by the following reaction:



In the diagram, a portion of the flask is shown containing five molecules of nitrogen gas and nine molecules of hydrogen gas. This represents the start of the reaction. Draw the molecular picture showing the contents of this portion of the flask after two molecules of ammonia have formed.

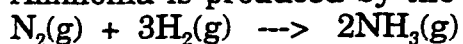


incorrect representation (no conservation of mass)

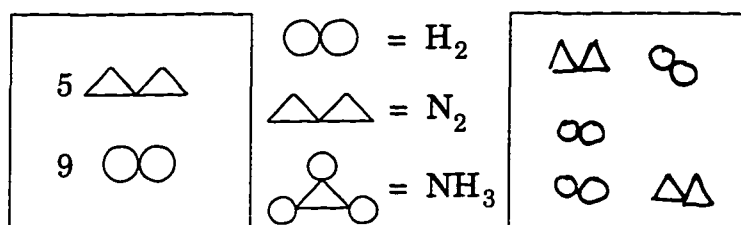
(a more legible reproduction of the student's work)

Student C - incorrect representation (no products)

Ammonia is produced by the following reaction:



In the diagram, a portion of the flask is shown containing five molecules of nitrogen gas and nine molecules of hydrogen gas. This represents the start of the reaction. Draw the molecular picture showing the contents of this portion of the flask after two molecules of ammonia have formed.

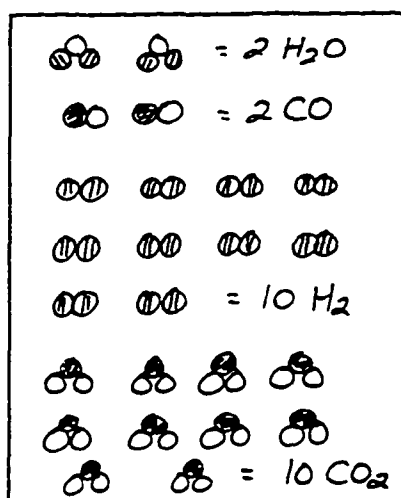
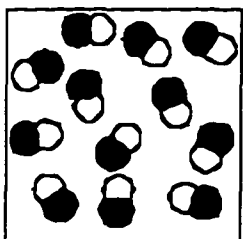
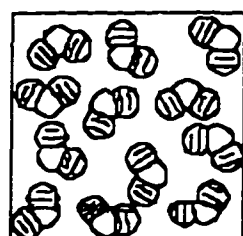
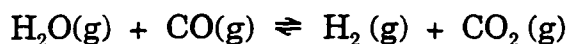


(a more legible reproduction of the student's work)

# APPENDIX 6. CORRECT AND INCORRECT STUDENT EQUILIBRIUM DIAGRAMS

Student A - correct representation and work

4.(4 pts) The figure shown here represents a set of initial conditions for the following reaction:



I	12	12	0	0
C	-x	-x	x	x
E	12-x	12-x	x	x

Draw a molecular picture that approximates what the system looks like when it reaches equilibrium. It is important to count the number of atoms present.

$$K_{eq} = \frac{[\text{H}_2][\text{CO}_2]}{[\text{H}_2\text{O}][\text{CO}]}$$

$$25 = \frac{[x][x]}{[12-x][12-x]} \Rightarrow \frac{[x^2]}{[12-x]^2}$$

$$\sqrt{25} = \sqrt{\frac{(x)^2}{(12-x)^2}} \Rightarrow (12-x) \cdot 5 = \frac{x}{(12-x)} \cdot (12-x)$$

$$\begin{array}{r} 60 - 5x = x \\ +5x \quad +5x \\ \hline 60 = 6x \\ \frac{60}{6} = \frac{6x}{6} \end{array}$$

$$10 = x$$

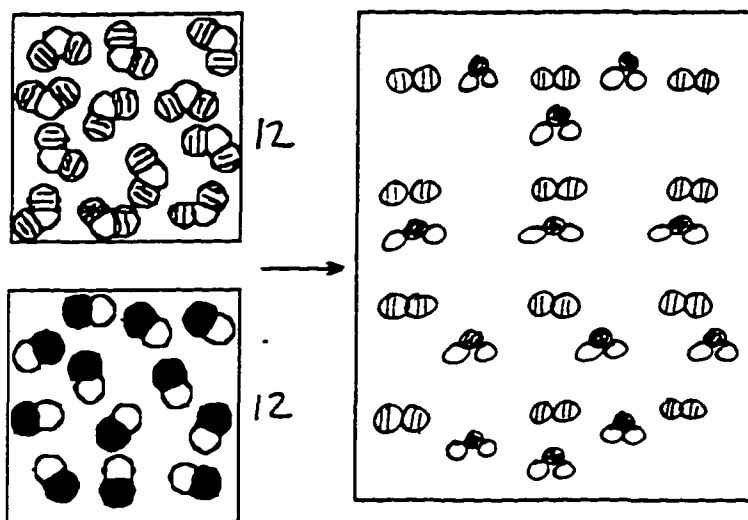
$$((\text{H}_2 + \text{CO}_2) = x = 10)$$

$$((\text{CO} + \text{H}_2\text{O}) = 12 - 10 = 2)$$

(a more legible reproduction of the student's work)

Student B - draws all products, also no written reasoning

4.(4 pts) The figure shown here represents a set of initial conditions for the following reaction:

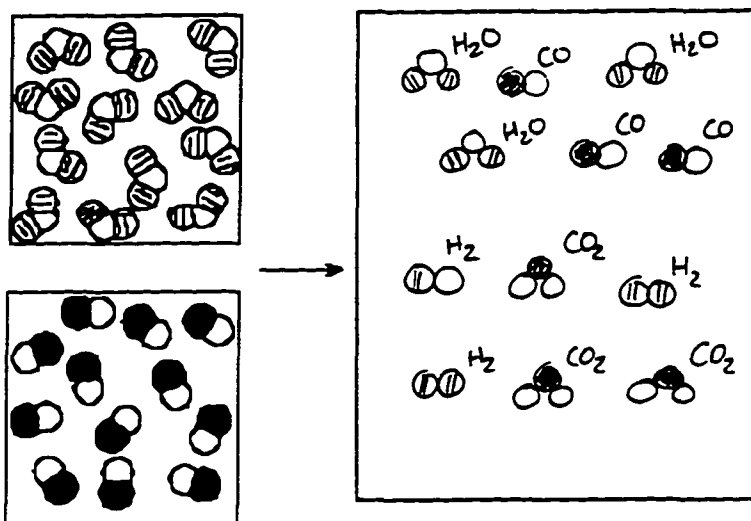


Draw a molecular picture that approximates what the system looks like when it reaches equilibrium. It is important to count the number of atoms present.

(a more legible reproduction of the student's work)

Student C - draws equal numbers of each molecule (no conservation of mass)

4.(4 pts) The figure shown here represents a set of initial conditions for the following reaction: -



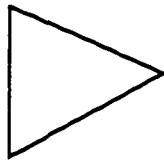
Draw a molecular picture that approximates what the system looks like when it reaches equilibrium. It is important to count the number of atoms present.

(a more legible reproduction of the student's work)

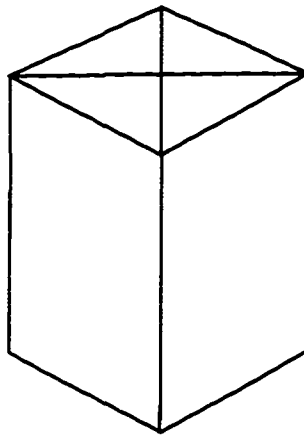
**APPENDIX 7. SAMPLE ITEM FROM THE GROUP EMBEDDED FIGURES TEST**

Here is a simple form which we have labeled "X":

X



This simple form named "X" is hidden within the more complex figure below:



Try to find the simple form in the complex figure and trace it *in pencil* over the lines of the complex figure. It is the SAME SIZE in the SAME PROPORTIONS, and FACES IN THE SAME DIRECTION within the complex figure as when it appeared alone.

(Oltman, P. K., Raskin, E., & Witkin, H. A., 1971)

## APPENDIX 8. STUDENT WORK IN SOLVING A METHOD OF INITIAL RATES PROBLEM

Student A - correct work

1. For the reaction  $2\text{NO} + \text{Cl}_2 \rightarrow 2\text{NOCl}$ , the following data were collected at  $-10^\circ\text{C}$ :

Experiment Number	Initial Concentrations		Initial Rate $-\Delta[\text{Cl}_2]/\Delta t$
	$[\text{NO}] \text{ M}$	$[\text{Cl}_2] \text{ M}$	
1	0.10	0.10	0.18
2	0.10	0.20	0.36
3	0.20	0.20	1.44
4	0.10	0.40	_____

a. (2 pts.) Determine the rate law for this reaction using either:

i. Without using a formula but you must explain your reasoning.

or

ii. Using your calculator and the method of initial rates.

When  $[\text{Cl}_2]$  doubles the rate doubles  $x=1$

When  $[\text{NO}]$  doubles the rate quadruples  $y=2$

$$\begin{aligned}\text{Rate} &= k [\text{Cl}_2]^x [\text{NO}]^y \\ &= k [\text{Cl}_2]^1 [\text{NO}]^2\end{aligned}$$

(a more legible reproduction of the student's work)

## Student B - correct calculation but wrote incorrect rate law

1. For the reaction  $2\text{NO} + \text{Cl}_2 \rightarrow 2\text{NOCl}$ , the following data were collected at  $-10^\circ\text{C}$ :

Experiment Number	Initial Concentrations		Initial Rate $-\Delta[\text{Cl}_2]/\Delta t$
	$[\text{NO}] \text{ M}$	$[\text{Cl}_2] \text{ M}$	
1	0.10	0.10	0.18
2	0.10	0.20	0.36
3	0.20	0.20	1.44
4	0.10	0.40	_____

a. (2 pts.) Determine the rate law for this reaction using either:

i. Without using a formula but you must explain your reasoning.

or

ii. Using your calculator and the method of initial rates.

1→2 Double concentration - Double rate  $m=1$

2→3 Double concentration - quadruple rate  $n=2$

Rate Law =  $\boxed{K[\text{NO}]^2[\text{Cl}_2]^1}$

(a more legible reproduction of the student's work)

Student C - used only one experiment to determine the rate law

1. For the reaction  $2\text{NO} + \text{Cl}_2 \rightarrow 2\text{NOCl}$ , the following data were collected at  $-10^\circ\text{C}$ :

Experiment Number	Initial Concentrations		Initial Rate $-\Delta[\text{Cl}_2]/\Delta t$
	$[\text{NO}] \text{ M}$	$[\text{Cl}_2] \text{ M}$	
1	0.10	0.10	0.18
2	0.10	0.20	0.36
3	0.20	0.20	1.44
4	0.10	0.40	_____

a. (2 pts.) Determine the rate law for this reaction using either:

i. Without using a formula but you must explain your reasoning.

or

ii. Using your calculator and the method of initial rates.

(Ex #2,3)

Ex #1 is "slow" Rxn, intermediates are not used

$$R = k[\text{NO}]^2[\text{Cl}_2]$$

(a more legible reproduction of the student's work)

## APPENDIX 9. STUDENT WORK IN SOLVING FOR THE RATE CONSTANT

Student D - correct units for the rate constant

3. (11 pts.) The following data was collected for the reaction  $M + N \rightarrow P + Q$

Initial Concentration (mol L <sup>-1</sup> )		Initial rate of P
[M]	[N]	(mol L <sup>-1</sup> s <sup>-1</sup> )
0.010	0.010	$2.5 \times 10^{-3}$
0.020	0.010	$5.0 \times 10^{-3}$
0.020	0.030	$4.5 \times 10^{-2}$

What is the order of the reaction with respect to M and N? What is the overall order? What is the value of the rate constant (with correct units)?

$$[M]^1 [N]^2 \leftarrow 3^{\text{rd}}$$

$$r = k [M]^1 [N]^2$$

order w/ respect to M  $\rightarrow 1$

order w/ respect to N  $\rightarrow 2$

overall order of rxn  $\rightarrow 3$

$$r = k [M]^1 [N]^2$$

$$5.0 \times 10^{-3} = k (0.02)(0.01)^2$$

$$5.0 \times 10^{-3} = 2.0 \times 10^{-6} k$$

$$k = 2500 \text{ mol}^{-2} \text{ L}^2 \text{ s}^{-1}$$

$$k = 2.5 \times 10^3 \text{ mol}^{-2} \text{ L}^2 \text{ s}^{-1}$$

(a more legible reproduction of the student's work)

## Student E - no units for the rate constant

3. (11 pts.) The following data was collected for the reaction  $M + N \rightarrow P + Q$

Initial Concentration (mol L <sup>-1</sup> )		Initial rate of P
[M]	[N]	(mol L <sup>-1</sup> s <sup>-1</sup> )
0.010	0.010	$2.5 \times 10^{-3}$
0.020	0.010	$5.0 \times 10^{-3}$
0.020	0.030	$4.5 \times 10^{-2}$

What is the order of the reaction with respect to M and N? What is the overall order? What is the value of the rate constant (with correct units)?

[M] - 1<sup>st</sup> order

[N] - 2<sup>nd</sup> order

overall = 3<sup>rd</sup> order

$$\text{rate} = k [M]^1 [N]^2$$

$$k = \frac{\text{rate}}{[M]^1 [N]^2}$$

$$k = \frac{2.5 \times 10^{-3}}{[0.010][.010]^2}$$

$$= \frac{2.5 \times 10^{-3}}{1.0 \times 10^{-6}}$$

$$k = 2.5 \times 10^3$$

(a more legible reproduction of the student's work)

Student F - incorrect units for the rate constant (incorrect calculation)

3. (11 pts.) The following data was collected for the reaction  $M + N \rightarrow P + Q$

Initial Concentration (mol L <sup>-1</sup> )		Initial rate of P
[M]	[N]	(mol L <sup>-1</sup> s <sup>-1</sup> )
0.010	0.010	$2.5 \times 10^{-3}$
0.020	0.010	$5.0 \times 10^{-3}$
0.020	0.030	$4.5 \times 10^{-2}$

What is the order of the reaction with respect to M and N? What is the overall order? What is the value of the rate constant (with correct units)?

First order because when M was doubled the rate doubled the overall order is  $[M]^1[N]^2$

$$k = \frac{\text{rate}}{[M][N]} \quad \frac{2.5 \times 10^{-3} \text{ mol L}^{-1} \text{ s}^{-1}}{(0.010)(0.010)^2 \text{ mol L}^{-1}} = \frac{.0025}{.0001} = 2.5 \times 10^1 \text{ s}^{-1}$$

$$\frac{5.0 \times 10^{-3}}{(0.020)(0.010)} = \frac{.0050}{.0002} = 2.5 \times 10^1 \text{ s}^{-1}$$

(a more legible reproduction of the student's work)

# APPENDIX 10. STUDENT WORK IN DETERMINING THE TIME OF REACTION TO REACH A CERTAIN CONCENTRATION

Student G - correct work

3. (4 pts.)  $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$  The rate law for this reaction is first-order with respect to  $\text{N}_2\text{O}_5$ . The rate constant is  $1.73 \times 10^{-3} \text{ s}^{-1}$ .

a. Write the rate law expression for this system. **Rate** =  $1.73 \times 10^{-3} \text{ s}^{-1} [\text{N}_2\text{O}_5]$

b. Calculate the rate of reaction when the concentration of  $\text{N}_2\text{O}_5$  will be 0.250 M.

$$\begin{aligned} \text{rate} &= 1.73 \times 10^{-3} \text{ s}^{-1} (0.250 \text{ M}) \\ &= 4.33 \times 10^{-4} \text{ M/s} \end{aligned}$$

c. Predict the time when the concentration of  $\text{N}_2\text{O}_5$  will be 0.010 M, assuming the initial concentration of  $\text{N}_2\text{O}_5$  is 0.250 M.

$$\begin{aligned} \ln [\text{N}_2\text{O}_5] &= -kt + \ln [\text{N}_2\text{O}_5]_0 \\ \ln (0.010 \text{ M}) &= -1.73 \times 10^{-3} \text{ s}^{-1} t + \ln (0.250 \text{ M}) \\ t &= 1.86 \times 10^3 \text{ s} \end{aligned}$$

Information:  $\ln[A]_t = -kt + \ln[A]_0$

(a more legible reproduction of the student's work)

Student H - used wrong formula for calculating the time

3. (4 pts.)  $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$  The rate law for this reaction is first-order with respect to  $\text{N}_2\text{O}_5$ . The rate constant is  $1.73 \times 10^{-3} \text{ s}^{-1}$ .

- a. Write the rate law expression for this system. **Rate** =  $k [\text{N}_2\text{O}_5]^1$   
 $= 1.73 \times 10^{-3} [\text{N}_2\text{O}_5]^1$
- b. Calculate the rate of reaction when the concentration of  $\text{N}_2\text{O}_5$  will be 0.250 M.

$$\begin{aligned} \text{rate} &= 1.73 \times 10^{-3} [0.250] \\ &= 4.33 \times 10^{-4} \text{ M/s} \end{aligned}$$

- c. Predict the time when the concentration of  $\text{N}_2\text{O}_5$  will be 0.010 M, assuming the initial concentration of  $\text{N}_2\text{O}_5$  is 0.250 M.

let the time be X

$$\frac{0.25 - 0.01}{X - 0} = 4.33 \times 10^{-4}$$

$$X = 554$$

$\therefore$  after 554s

Information:  $\ln[A]_t = -kt + \ln[A]_0$

(a more legible reproduction of the student's work)

Student I - used the rate instead of the rate constant in the calculation

3. (4 pts.)  $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$  The rate law for this reaction is first-order with respect to  $\text{N}_2\text{O}_5$ . The rate constant is  $1.73 \times 10^{-3} \text{ s}^{-1}$ .

a. Write the rate law expression for this system. **Rate** =  $1.73 \times 10^{-3} \text{ s}^{-1} [\text{N}_2\text{O}_5]^1$

b. Calculate the rate of reaction when the concentration of  $\text{N}_2\text{O}_5$  will be 0.250 M.

$$\begin{aligned} \text{rate} &= 1.73 \times 10^{-3} \text{ s}^{-1} [0.250 \text{ M}]^1 \\ &= 4.32 \times 10^{-4} \frac{\text{M}}{\text{s}} \end{aligned}$$

c. Predict the time when the concentration of  $\text{N}_2\text{O}_5$  will be 0.010 M, assuming the initial concentration of  $\text{N}_2\text{O}_5$  is 0.250 M.

$$\ln[A]_t = -kt + \ln[A]_0$$

$$\frac{\ln(0.010 \text{ M}) - \ln(0.250 \text{ M})}{-4.32 \times 10^{-4} \text{ M/s}} = t = 7451 \text{ s}$$

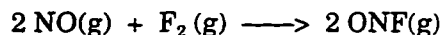
Information:  $\ln[A]_t = -kt + \ln[A]_0$

(a more legible reproduction of the student's work)

## APPENDIX 11. SAMPLE QUESTIONS SHOWING POOR PERFORMANCE OF STUDENTS ON CHEMICAL KINETICS QUESTIONS

### Rate laws - qualitative

Consider the reaction of NO with F<sub>2</sub> to form ONF.



This reaction has the following mechanism:



The figure below shows equal portions of two flasks with initial amounts of NO and F<sub>2</sub> molecules. The temperature is the same in all flasks.

Compare the relative rates of the reaction of Flask A to Flask B.

10 NO  10 F <sub>2</sub>	5 NO  30 F <sub>2</sub>
Flask A	Flask B

- 1) The rate of Flask B is 7/2 times the rate of Flask A.
- 2) The rate of Flask B is 3 times the rate of Flask A.
- 3) The rate of Flask B is 1/6 times the rate of Flask A.
- 4) The rate of Flask B is 3/2 times the rate of Flask A.
- 5) The rate of Flask B is 3/4 times the rate of Flask A.

#### CHEM 164 - Spring 95 - Version A

Response	1	2	3	4*	5	total	Diff.	Dscr.
n	1	13	26	43	2	85	51	0.25

#### CHEM 164 - Spring 95 - Version B

Response	1	2*	3	4	5	total	Diff.	Dscr.
n	22	32	3	14	2	73	44	0.30

#### CHEM 177 - Fall 95 - Version A

Response	1	2	3	4*	5	total	Diff.	Dscr.
n	15	16	34	147	11	223	66	0.38

#### CHEM 177 - Fall 95 - Version B

Response	1	2*	3	4	5	total	Diff.	Dscr.
n	12	20	41	163	4	240	68	0.33

\* indicates the correct answer

## Rate laws - quantitative

The following data were obtained for the reaction of NO with O<sub>2</sub>.

[NO] <sub>0</sub> (M)	[O <sub>2</sub> ] <sub>0</sub> (M)	Initial Rate (M s <sup>-1</sup> )
1 x 10 <sup>-5</sup>	1 x 10 <sup>-5</sup>	2.0 x 10 <sup>-7</sup>
2 x 10 <sup>-5</sup>	1 x 10 <sup>-5</sup>	8.0 x 10 <sup>-7</sup>
3 x 10 <sup>-5</sup>	1 x 10 <sup>-5</sup>	18.0 x 10 <sup>-7</sup>
1 x 10 <sup>-5</sup>	2 x 10 <sup>-5</sup>	4.0 x 10 <sup>-7</sup>
1 x 10 <sup>-5</sup>	3 x 10 <sup>-5</sup>	6.0 x 10 <sup>-7</sup>

The correct expression for the rate law is

- |  |   |
|--|---|
| 1) Rate = k[NO][O <sub>2</sub> ]               | 4) Rate = k[NO] <sup>2</sup>                                |
| 2) Rate = k[NO][O <sub>2</sub> ] <sup>2</sup>  | 5) Rate = k[NO] <sup>2</sup> [O <sub>2</sub> ] <sup>2</sup> |
| 3) Rate = k[NO] <sup>2</sup> [O <sub>2</sub> ] |   |

## CHEM 177 - Fall 95 - Version A

Response	1	2	3*	4	5	total	Diff.	Dscr.
n	37	13	181	5	6	242	75	0.51

## CHEM 177 - Fall 95 - Version B

Response	1	2	3*	4	5	total	Diff.	Dscr.
n	32	15	158	3	16	224	71	0.54

## CHEM 177 - Spring 96 - Version A

Response	1	2	3*	4*	5	total	Diff.	Dscr.
n	28	2	70	2	6	108	65	0.46

## CHEM 177 - Spring 96 - Version B

Response	1	2	3*	4	5	total	Diff.	Dscr.
n	37	12	57	1	6	113	50	0.48

\* indicates the correct answer

## Reaction rates - quantitative

A chemical reaction between compounds A and B is found to be first order in A and second order in B. At what rate will the reaction occur in experiment 2?

Experiment	Initial Rate ( $\text{M}\cdot\text{s}^{-1}$ )	Initial [A]	Initial [B]
1	0.10	1.0 M	0.20 M
2	?	2.0 M	0.60 M

- 1)  $1.8 \text{ M}\cdot\text{s}^{-1}$     2)  $1.2 \text{ M}\cdot\text{s}^{-1}$     3)  $0.60 \text{ M}\cdot\text{s}^{-1}$     4)  $0.20 \text{ M}\cdot\text{s}^{-1}$   
 5) no answer

## CHEM 177 - Fall 95 - Version A

Response	1*	2	3	4	5	total	Diff.	Dscr.
n	123	18	30	36	35	242	51	0.62

## CHEM 177 - Fall 95 - Version B

Response	1*	2	3	4	5	total	Diff.	Dscr.
n	107	23	39	32	21	222	48	0.63

## CHEM 177 - Spring 96 - Version A

Response	1	2	3	4*	5	total	Diff.	Dscr.
n	12	33	20	34	9	108	31	0.56

## CHEM 177 - Spring 96 - Version B

Response	1	2	3	4*	5	total	Diff.	Dscr.
n	9	32	23	42	7	113	37	0.58

\* indicates the correct answer

## Reaction rates - qualitative

For the reaction  $A + 3B \longrightarrow 2C$ , the rate of formation of C may be expressed in relationship to concentrations of A or B as:

$$1) \frac{\Delta[C]}{\Delta t} = - \frac{\Delta[A]}{\Delta t} \qquad 4) \frac{\Delta[C]}{\Delta t} = - \frac{1}{2} \frac{\Delta[A]}{\Delta t}$$

$$2) \frac{\Delta[C]}{\Delta t} = - \frac{3}{2} \frac{\Delta[B]}{\Delta t} \qquad 5) \frac{\Delta[C]}{\Delta t} = - \frac{2}{3} \frac{\Delta[B]}{\Delta t}$$

$$3) \frac{\Delta[C]}{\Delta t} = \frac{2[A]}{\Delta t}$$

## CHEM 177 - Fall 95 - Version A

Response	1	2	3	4	5*	total	Diff.	Dscr.
n	6	51	30	36	119	242	49	0.44

## CHEM 177 - Fall 95 - Version B

Response	1	2	3	4	5*	total	Diff.	Dscr.
n	4	49	25	22	124	224	55	0.40

## CHEM 177 - Spring 96 - Version A

Response	1	2	3	4	5*	total	Diff.	Dscr.
n	3	27	15	20	43	108	40	0.32

## CHEM 177 - Spring 96 - Version B

Response	1	2	3	4	5*	total	Diff.	Dscr.
n	3	32	18	15	45	113	40	0.49

\* indicates the correct answer

## APPENDIX 12. TYPICAL MATHEMATICAL ERRORS

Student J - performed division instead of subtraction (negative time as an answer)

3. (4 pts.)  $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$  The rate law for this reaction is first-order with respect to  $\text{N}_2\text{O}_5$ . The rate constant is  $1.73 \times 10^{-3} \text{ s}^{-1}$ .

a. Write the rate law expression for this system. **Rate** =  $k [\text{N}_2\text{O}_5]$

b. Calculate the rate of reaction when the concentration of  $\text{N}_2\text{O}_5$  will be 0.250 M.

$$\text{rate} = 1.73 \times 10^{-3} \frac{1}{\text{s}} [0.250 \text{ M}]$$

$$\text{rate} = 4.33 \times 10^{-4} \frac{\text{mole}}{\text{L} \cdot \text{s}}$$

c. Predict the time when the concentration of  $\text{N}_2\text{O}_5$  will be 0.010 M, assuming the initial concentration of  $\text{N}_2\text{O}_5$  is 0.250 M.

$$\ln[.010 \text{ M}] = -kt + \ln[.250 \text{ M}] \quad k = 1.73 \times 10^{-3} \frac{1}{\text{s}}$$

$$\ln[.010 \text{ M}] = -1.73 \times 10^{-3} t + \ln[.250 \text{ M}]$$

$$\frac{-4.605}{-1.73 \times 10^{-3} - 1.386} = t$$

$$t = -1,920 \text{ s}$$

Information:  $\ln[A]_t = -kt + \ln[A]_0$

(a more legible reproduction of the student's work)

Student K - student performed division instead of subtraction (changed sign to correct for negative time)

3. (4 pts.)  $2\text{N}_2\text{O}_5(\text{g}) \rightarrow 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$  The rate law for this reaction is first-order with respect to  $\text{N}_2\text{O}_5$ . The rate constant is  $1.73 \times 10^{-3} \text{ s}^{-1}$ .

a. Write the rate law expression for this system. **Rate =**

b. Calculate the rate of reaction when the concentration of  $\text{N}_2\text{O}_5$  will be 0.250 M.

$$\begin{aligned}\text{rate} &= k[\text{N}_2\text{O}_5] \\ &= (1.73 \times 10^{-3} / \text{s})(0.250 \text{ M}) \\ \text{rate} &= 4.33 \times 10^{-4} \text{ M/s}\end{aligned}$$

c. Predict the time when the concentration of  $\text{N}_2\text{O}_5$  will be 0.010 M, assuming the initial concentration of  $\text{N}_2\text{O}_5$  is 0.250 M.

$$\ln[A]_t = -kt + \ln[A]_0$$

$$\ln[0.010 \text{ M}] = -1.73 \times 10^{-3} / \text{s} \cdot t + \ln(0.250 \text{ M})$$

$$\frac{-4.61 \text{ M}}{-1.39 \text{ M}} = -1.73 \times 10^{-3} / \text{s} \cdot t$$

$$\frac{3.32}{-1.73 \times 10^{-3} / \text{s}} = t = |-1.92 \times 10^3 \text{ s}|$$

$$t = 1919 \text{ s} = 1920 \text{ s} \text{ with significant figures}$$

Information:  $\ln[A]_t = -kt + \ln[A]_0$

(a more legible reproduction of the student's work)

### APPENDIX 13. SAMPLE HOMEWORK QUESTIONS

#### Problem 14.2 - Reaction rates

For each of the following reactions, indicate how the rate of disappearance of each reactant is related to the rate of appearance of each product:

- (a)  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$   
 (b)  $2\text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{NOCl}(\text{g})$   
 (c)  $\text{B}_2\text{H}_6(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow \text{B}_2\text{O}_3(\text{g}) + 3\text{H}_2\text{O}(\text{g})$

#### Problem 14.5 - Reaction rates

The rate of disappearance of  $\text{H}^+$  was measured for the following reaction:



The following data were collected:

Time (min)	$[\text{H}^+]$ (M)
0.00	1.85
79.0	1.67
158.0	1.52
316.0	1.30
632.0	1.00

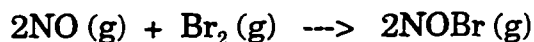
Calculate the average rate of reaction for the time interval between each measurement.

#### Problem 14.7 - Reaction rates

Using the data provided in Exercise 14.5, make a graph of  $[\text{H}^+]$  vs. time. Draw tangents to the curve at  $t = 100$  and  $t = 500$  min. Determine the rates at these times.

## Problem 14.17 - Rate laws

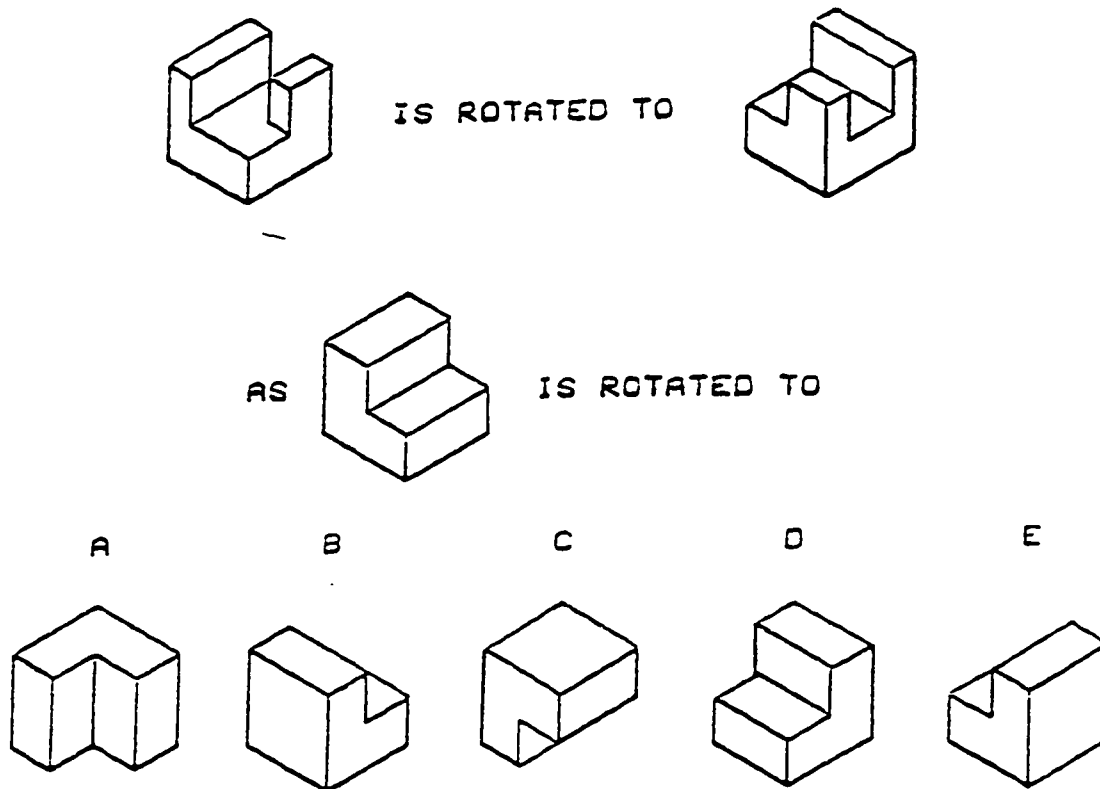
The following data were collected for the gas phase reaction between nitric oxide and bromine at 273 °C:



Experiment	[NO] (M)	[Br <sub>2</sub> ] (M)	Initial rate of appearance of NOBr (mol/L-sec)
1	0.10	0.10	12
2	0.10	0.20	24
3	0.20	0.10	48
4	0.30	0.10	108

(a) Determine the rate law. (b) Calculate the value of the rate constant for the appearance of NOBr. (c) How is the rate of appearance of NOBr related to the rate of disappearance of Br<sub>2</sub>? (d) What is the rate of appearance of NOBr when [NO] = 0.15 M and [Br<sub>2</sub>] = 0.25 M? (e) What is the rate of disappearance of Br<sub>2</sub> when [NO] = 0.075 M and [Br<sub>2</sub>] = 0.185 M?

(Brown, LeMay, Bursten, 1994)

**APPENDIX 14. SAMPLE ITEM FROM THE PURDUE SPATIAL  
VISUALIZATION TEST**

You are to:

1. study how the object in the top line of the question is rotated;
2. picture in your mind what the object shown in the middle line of the question looks like when rotated in exactly the same manner;
3. select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

(Guay, 1976)

## APPENDIX 15. KINETICS PRETEST

### Algebra skill-Quantitative

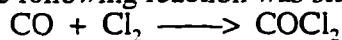
1. The rate expression for a particular reaction is  $\text{Rate} = k[A][B]^2$ . If the initial concentration of B is increased from 0.1 M to 0.3 M, the initial rate will increase by which of the following factors?

- a. 2              b. 6              c. 12              d. 3              e. 9              f. I don't know

Response	a	b	c	d	e*	f	total	Diff.	Dscr.
n	20	11	0	27	71	17	146	49	0.37

### Method of initial rates-quantitative

2. The following reaction was studied by the method of initial rates:



Experiment	$[\text{CO}]_0$ (mol/L)	$[\text{Cl}_2]_0$ (mol/L)	Initial Rate of Formation of $\text{COCl}_2$ (mol/L-sec)
#1	$1.00 \times 10^2$	$1.00 \times 10^2$	$0.66 \times 10^4$
#2	$2.00 \times 10^2$	$1.00 \times 10^2$	$1.32 \times 10^4$
#3	$3.00 \times 10^2$	$1.00 \times 10^2$	$1.98 \times 10^4$
#4	$1.00 \times 10^2$	$2.00 \times 10^2$	$2.64 \times 10^4$
#5	$2.00 \times 10^2$	$3.00 \times 10^2$	$11.9 \times 10^4$

The rate law is:

- |  |  |
|--|--|
| a. $\text{Rate} = k[\text{Cl}_2]^2$            | d. $\text{Rate} = k[\text{CO}]^2[\text{Cl}_2]^2$ |
| b. $\text{Rate} = k[\text{CO}][\text{Cl}_2]$   | e. $\text{Rate} = k[\text{CO}]$                  |
| c. $\text{Rate} = k[\text{CO}][\text{Cl}_2]^2$ | f.     I don't know                              |

Response	a	b	c*	d	e	f	total	Diff.	Dscr.
n	0	34	83	7	0	22	146	57	0.40

\* indicates the correct answer

## Algebra skill-Quantitative

3. For the reaction:  $3 \text{H}_2 + \text{N}_2 \longrightarrow 2 \text{NH}_3$  the relative rate of consumption of  $\text{H}_2$  is \_\_\_\_\_ the relative rate of consumption of  $\text{N}_2$

- a. the same as                      c. 1/3 as fast as                      e. I don't know  
b. 3 times as fast as              d. 6 times as fast as

Response	a	b*	c	d	e	total	Diff.	Dscr.
n	13	98	31	0	4	146	67	0.41

## Order of reactant-quantitative

4. The rate law equation for the reaction:  $2 \text{NO} + 2 \text{H}_2 \longrightarrow \text{N}_2 + 2 \text{H}_2\text{O}$  is:

$$\text{Rate} = k[\text{NO}]^2[\text{H}_2]$$

The overall order of the reaction is:

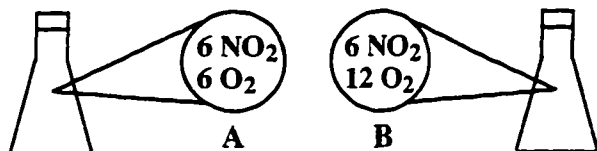
- a. 1                      b. 2                      c. 3                      d. 4                      e. I don't know

Response	a	b	c*	d	e	f	total	Diff.	Dscr.
n	13	29	38	13	51	1	145	26	0.38

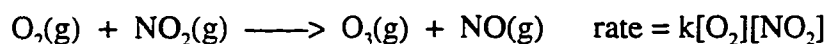
\* indicates the correct answer

## Method of initial rates-Qualitative (conceptual)

## 6. Situation I



Circles "A" and "B" each represent a small, equal volume  $1 \times 10^{-18}$  mL, segment of their reaction flask. Each circle also represents the initial starting conditions for the following reaction:



Each flask is at the same temperature. Complete the following:

The initial rate of reaction in flask A is \_\_\_\_\_ the initial rate of reaction in flask B.

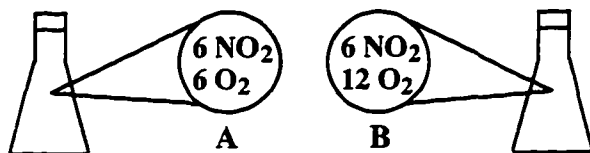
- |                     |   |
|---------------------|---|
| a. the same as      | d. six times slower than                |
| b. half as fast as  | e. none of these statements is accurate |
| c. twice as fast as | f. I don't know                         |

Response	a	b*	c	d	e	f	total	Diff.	Dscr.
n	29	57	23	8	18	11	146	39	0.40

\* indicates the correct answer

## Method of initial rates-Qualitative (conceptual)

## 7. Situation II



Compare the initial rate of disappearance of NO<sub>2</sub> in flask "A" to the initial rate of disappearance of NO<sub>2</sub> of reaction in flask "B". All rates are initial rates.

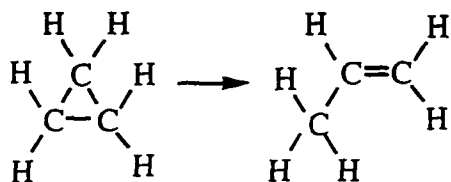
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "B"
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $2 \left\{ -\frac{\Delta[\text{NO}_2]}{\Delta t} \right\}$  in flask "B"
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $\frac{1}{2} \left\{ -\frac{\Delta[\text{NO}_2]}{\Delta t} \right\}$  in flask "B"
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $\frac{1}{6} \left\{ -\frac{\Delta[\text{NO}_2]}{\Delta t} \right\}$  in flask "B"
- none of these statements is accurate
- I don't know

Response	a	b	c*	d	e	f	total	Diff.	Dscr.
n	35	28	37	5	6	35	146	25	0.52

\* indicates the correct answer

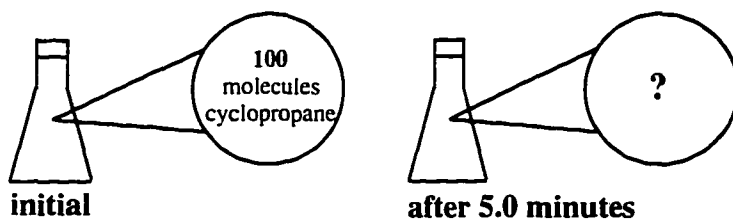
## Rate of reaction-qualitative (conceptual)

8. At high temperature, cyclopropane isomerizes to propene:

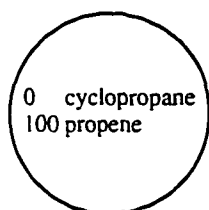


cyclopropane ( $C_3H_6$ )      propene ( $C_3H_6$ )

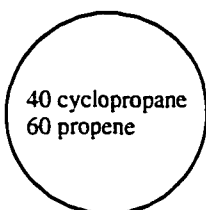
Pure cyclopropane is placed in a sealed container. A small volume of this sample contains 100 molecules of cyclopropane. The reaction proceeds at an average rate of consumption of cyclopropane equal to 8 molecules per minute.



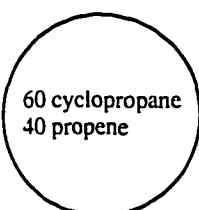
Which diagram best represents what this small volume will look after 5 minutes?



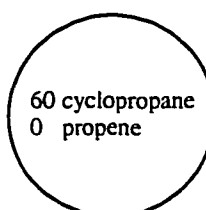
a.



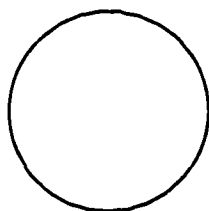
b.



c.

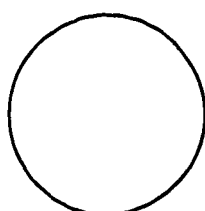


d.



e. none of these.

Put in the correct amounts.



f. I don't know.

Response	a	b	c*	d	e	f	total	Diff.	Dscr.
n	0	30	93	7	4	12	146	64	0.33

\* indicates the correct answer

## Rate of reaction-quantitative

9. What is the average rate of formation of  $\text{NH}_3$  production?

- a. 0.24 mol/(L sec)
- b. 0.16 mol/(L sec)
- c. 0.006 mol/(L sec)
- d. 0.0080 mol/(L sec)
- e. I don't know

Response	a	b	c	d*	e	f	total	Diff.	Dscr.
n	25	20	11	10	75	5	146	7	0.06

## Factors affecting the rate of reaction-qualitative (conceptual)

10. As the temperature of a reaction is increased, the rate of the reaction increases because the

- a. reactant molecules collide less frequently.
- b. reactant molecules collide more frequently on average with greater energy.
- c. activation energy is lowered.
- d. reactant molecules collide less frequently but they do so with greater energy.

Response	a	b*	c	d	total	Diff.	Dscr.
n	4	133	7	1	145	92	0.29

\* indicates the correct answer

## APPENDIX 16. KINETICS POSTTEST

### Method of initial rates-quantitative

1. The following results were obtained for the reaction  $X + Y \rightarrow Z$

Experiment	[X] (M)	[Y] (M)	initial rate (M/s)
1	0.2	0.2	0.004
2	0.4	0.2	0.008
3	0.2	0.1	0.002
4	0.2	0.3	???

a. Determine the rate law for this reaction.

1.  $\text{rate} = k[X][Y]$                       3.  $\text{rate} = k[X]^2[Y]$                       5.  $\text{rate} = k[X]^2[Y]^2$

2.  $\text{rate} = \frac{-\Delta[X]}{\Delta t} = \frac{-\Delta[Y]}{\Delta t}$                       4.  $\text{rate} = \frac{-\Delta \text{conc}}{\Delta t}$

Response	1*	2	3	4	5	total	Diff.	Dscr.
n	108	6	28	12	8	162	67	0.42

b. Determine the rate of reaction when  $[X] = 0.1\text{M}$  and  $[Y] = 0.1\text{M}$ .

1.  $0.001 \text{ l/M}\cdot\text{s}$                       2.  $0.002 \text{ l/M}\cdot\text{s}$                       3.  $0.0005 \text{ l/M}^2\cdot\text{s}$                       4. none of these

Response	1*	2	3	4	total	Diff.	Dscr.
n	93	44	15	10	162	57	0.37

c. Determine the value of the rate constant,  $k$ .

1.  $0.01 \text{ M/s}$                       2.  $0.02 \text{ M/s}$                       3.  $0.1 \text{ M/s}$                       4.  $0.2 \text{ M/s}$

Response	1	2	3*	4	total	Diff.	Dscr.
n	50	16	85	11	162	52	0.46

d. Determine the initial rate for Experiment 4.

1.  $0.003 \text{ M/s}$                       2.  $0.006 \text{ M/s}$                       3.  $0.008 \text{ M/s}$                       4.  $0.018 \text{ M/s}$

Response	1	2*	3	4	total	Diff.	Dscr.
n	34	91	27	10	162	56	0.40

\* indicates the correct answer

## APPENDIX 17. KINETICS PORTION OF THE HOUR EXAM

### Rate of reaction-quantitative

1. For the reaction  $2 \text{N}_2\text{O}_5 \longrightarrow 4 \text{NO}_2 + \text{O}_2$ , the following data were collected:

t (minutes)	$[\text{N}_2\text{O}_5]$ (mol/L)	$[\text{NO}_2]$ (mol/L)	$[\text{O}_2]$ (mol/L)
0.00	$1.24 \times 10^{-2}$	0.00	0.00
10.0	$0.92 \times 10^{-2}$		
20.0	$0.68 \times 10^{-2}$		
30.0	$0.50 \times 10^{-2}$		
40.0	$0.37 \times 10^{-2}$		
50.0	$0.28 \times 10^{-2}$		
70.0	$0.15 \times 10^{-2}$		

The concentration of  $\text{O}_2$  at  $t = 10.0$  minutes is

- |                                |                                |
|--------------------------------|--------------------------------|
| a. $2.0 \times 10^{-4}$ mol/L  | d. $0.64 \times 10^{-2}$ mol/L |
| b. $0.32 \times 10^{-2}$ mol/L | e. none of these               |
| c. $0.16 \times 10^{-2}$ mol/L | f. I don't know how.           |

Response	a	b	c*	d	e	f	total	Diff.	Dscr.
n	6	37	70	19	70	8	210	33	0.40

### Rate of reaction-Quantitative

2. For the reaction:  $3 \text{H}_2 + \text{N}_2 \longrightarrow 2 \text{NH}_3$ , which statement is true?

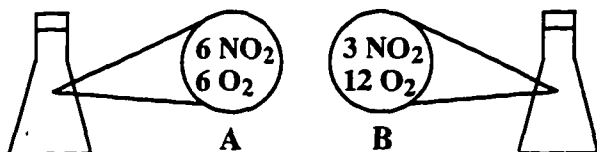
- |  |  |
|--|--|
| a. $\text{rate} = \frac{\Delta[\text{N}_2]}{\Delta[t]} = \frac{3\Delta[\text{H}_2]}{\Delta[t]}$            | d. $\text{rate} = \frac{\Delta[\text{N}_2]}{\Delta[t]} = \frac{\Delta[\text{H}_2]}{\Delta[t]}$ |
| b. $\text{rate} = \frac{3\Delta[\text{N}_2]}{\Delta[t]} = \frac{\Delta[\text{H}_2]}{\Delta[t]}$            | e. I don't know how.   |
| c. $\text{rate} = \frac{1}{3} \frac{\Delta[\text{N}_2]}{\Delta[t]} = \frac{\Delta[\text{H}_2]}{\Delta[t]}$ |  |

Response	a	b*	c	d	e	total	Diff.	Dscr.
n	51	97	50	13	2	213	46	0.46

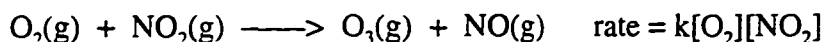
\* indicates the correct answer

## Method of initial rates-Qualitative (conceptual)

6.



Circles "A" and "B" each represent a small, equal volume  $1 \times 10^{-18}$  mL, segment of their reaction flask. Each circle also represents the starting conditions for the following reaction:



Each flask is at the same temperature. Compare the initial rate of reaction in flask "A" to the initial rate of reaction in flask "B". Complete the following sentence.

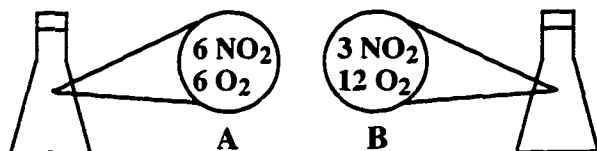
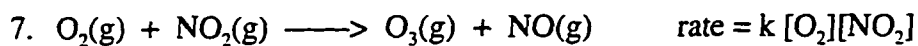
The initial rate of reaction in flask A is \_\_\_\_\_ the initial rate of reaction in flask B.

- a. the same as
- b. half as fast as
- c. twice as fast as
- d. three times as fast as
- e. none of these statements is accurate
- f. I don't know how.

Response	a*	b	c	d	e	f	total	Diff.	Dscr.
n	114	27	49	8	14	1	213	54	0.44

\* indicates the correct answer

## Method of initial rates-Qualitative (conceptual)



Compare the initial rate of disappearance of NO<sub>2</sub> in flask "A" to the initial rate of disappearance of NO<sub>2</sub> of reaction in flask "B". All rates are initial rates.

- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "B"
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $2 \left\{ -\frac{\Delta[\text{NO}_2]}{\Delta t} \right\}$  in flask "B"
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $\frac{1}{2} \left\{ -\frac{\Delta[\text{NO}_2]}{\Delta t} \right\}$  in flask "B"
- $-\frac{\Delta[\text{NO}_2]}{\Delta t}$  in flask "A" =  $\frac{1}{3} \left\{ -\frac{\Delta[\text{NO}_2]}{\Delta t} \right\}$  in flask "B"
- none of these statements is accurate
- I don't know.

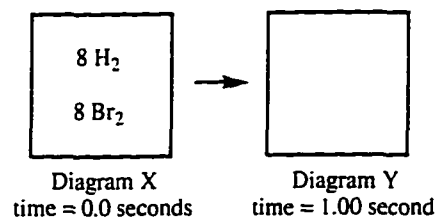
Response	a*	b	c	d	e	f	total	Diff.	Dscr.
n	37	81	74	14	4	1	211	18	0.30

\* indicates the correct answer

## Rate of reaction-Qualitative (conceptual)

8. Consider the following reaction:  $\text{H}_2 + \text{Br}_2 \longrightarrow 2 \text{HBr}$

Diagram X represents a molecular view of the initial conditions. Assume the box represents a volume of  $1.00 \times 10^{-8} \text{ mL}$ .



The average rate of formation of HBr between 0.00 seconds and 1.00 second is

$$\frac{4 \text{ molecules}}{1.00 \times 10^{-8} \text{ mL} \cdot \text{sec}}$$

Which of the following diagrams represents the number of HBr,  $\text{H}_2$ , and  $\text{Br}_2$  molecules (if any) present in this  $1.00 \times 10^{-8} \text{ mL}$  volume after 1.00 second of this reaction?

4 $\text{H}_2$ 4 $\text{Br}_2$ 4 HBr	4 HBr 6 $\text{H}_2$ 6 $\text{Br}_2$	4 HBr 2 $\text{H}_2$ 2 $\text{Br}_2$	4 HBr
a.	b.	c.	d.

e. none of these

f. I don't know how.

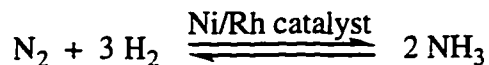
Response	a	b*	c	d	e	f	total	Diff.	Dscr.
n	23	85	65	23	13	3	212	40	0.44

\* indicates the correct answer

## Rate of reaction-Quantitative

9.

An industrial chemist is studying the rate of the Haber synthesis:



Starting with a closed reactor containing 1.24 mol/L of  $\text{N}_2$  and 0.60 mol/L of  $\text{H}_2$ , the chemist finds that the  $\text{H}_2$  concentration has fallen to 0.24 mol/L after 30.0 seconds.

What is the average rate of consumption of  $\text{H}_2$  over this time?

- a. 0.0080 mol/(L sec)      d. 0.24 mol/(L sec)  
 b. 0.012 mol/(L sec)      e. I don't know how.  
 c. 0.020 mol/(L sec)

Response	a	b*	c	d	e	total	Diff.	Dscr.
n	20	161	17	8	2	208	77	0.43

## Rate of reaction-Quantitative

10. At one point during an analysis of the reaction shown,  $\text{NH}_3$  (g) was used up at a rate of 1.2 mol per liter per second. At that same point in time, what was the rate at which  $\text{N}_2$  (g) was being formed?



- a. 0.6      b. 1.2      c. 2.4      d. 4.8      e. I don't know how.

Response	a*	b	c	d	e	total	Diff.	Dscr.
n	151	11	37	3	6	208	73	0.49

\* indicates the correct answer

**APPENDIX 18. KINETICS PORTION OF THE FINAL EXAM****Method of initial rates-Quantitative**

24. The following data were obtained for the reaction of NO with O<sub>2</sub>.

[NO] <sub>0</sub> (M)	[O <sub>2</sub> ] <sub>0</sub> (M)	Initial Rate (M s <sup>-1</sup> )
1 x 10 <sup>-5</sup>	1 x 10 <sup>-5</sup>	2.0 x 10 <sup>-7</sup>
2 x 10 <sup>-5</sup>	1 x 10 <sup>-5</sup>	8.0 x 10 <sup>-7</sup>
3 x 10 <sup>-5</sup>	1 x 10 <sup>-5</sup>	18.0 x 10 <sup>-7</sup>
1 x 10 <sup>-5</sup>	2 x 10 <sup>-5</sup>	4.0 x 10 <sup>-7</sup>
1 x 10 <sup>-5</sup>	3 x 10 <sup>-5</sup>	6.0 x 10 <sup>-7</sup>

The correct expression for the rate law is

- |  |   |
|--|---|
| 1) Rate = k[NO][O <sub>2</sub> ]               | 4) Rate = k[NO] <sup>2</sup>                                |
| 2) Rate = k[NO][O <sub>2</sub> ] <sup>2</sup>  | 5) Rate = k[NO] <sup>2</sup> [O <sub>2</sub> ] <sup>2</sup> |
| 3) Rate = k[NO] <sup>2</sup> [O <sub>2</sub> ] |   |

**Version A**

Response	1	2	3*	4	5	total	Diff.	Dscr.
n	28	2	70	2	6	108	65	0.46

**Version B**

Response	1	2	3*	4	5	total	Diff.	Dscr.
n	37	12	57	1	6	113	50	0.48

\* indicates the correct answer

### Method of initial rates-Quantitative

25. A chemical reaction between compounds A and B is found to be first order in A and second order in B. At what rate will the reaction occur in experiment 2?

Experiment	Initial Rate (M•s <sup>-1</sup> )	Initial [A]	Initial [B]
1	0.10	1.0 M	0.20 M
2	?	2.0 M	0.60 M

- 1) 1.2 M•s<sup>-1</sup>    2) 0.20 M•s<sup>-1</sup>    3) 0.60 M•s<sup>-1</sup>    4) 1.8 M•s<sup>-1</sup>    5) no answer

#### Version A

Response	1	2	3	4*	5	total	Diff.	Dscr.
n	12	33	20	34	9	108	31	0.56

#### Version B

Response	1	2	3	4*	5	total	Diff.	Dscr.
n	9	32	23	42	7	113	37	0.58

### Rate of reaction-Quantitative

26. For the reaction  $A + 3B \longrightarrow 2C$ , the rate of formation of C may be expressed in relationship to concentrations of A or B as:

- 1)  $\frac{\Delta[C]}{\Delta t} = - \frac{\Delta[A]}{\Delta t}$                       4)  $\frac{\Delta[C]}{\Delta t} = - \frac{1}{2} \frac{\Delta[A]}{\Delta t}$
- 2)  $\frac{\Delta[C]}{\Delta t} = - \frac{3}{2} \frac{\Delta[B]}{\Delta t}$                       5)  $\frac{\Delta[C]}{\Delta t} = - \frac{2}{3} \frac{\Delta[B]}{\Delta t}$
- 3)  $\frac{\Delta[C]}{\Delta t} = \frac{2\Delta[A]}{\Delta t}$

#### Version A

Response	1	2	3	4	5*	total	Diff.	Dscr.
n	3	27	15	20	43	108	40	0.32

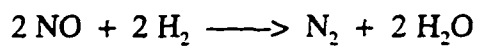
#### Version B

Response	1	2	3	4	5*	total	Diff.	Dscr.
n	3	32	18	15	45	113	40	0.49

\* indicates the correct answer

## Method of initial rates-Quantitative

41. Data for the gas phase reaction  
are as follows:



[NO] (M)	[H <sub>2</sub> ] (M)	Initial Rate (M/sec)
0.05	0.1	1.5
0.10	0.1	6.0
0.05	0.3	4.5

The rate law is

- 1)  $k[\text{NO}][\text{H}_2]$       2)  $k[\text{NO}][\text{H}_2]^2$       3)  $k[\text{NO}]^2[\text{H}_2]$       4)  $k[\text{NO}]^2[\text{H}_2]^2$

## Version A

Response	1	2	3*	4	total	Diff.	Dscr.
n	8	7	58	35	108	54	0.43

## Version B

Response	1	2	3*	4	total	Diff.	Dscr.
n	8	11	56	38	113	50	0.53

\* indicates the correct answer

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