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ABSTRACT

Two groups of high school chemistry students were instructed in the gas laws with one of two possible treatments. One group was taught with a traditional textbook curriculum and one group was taught using constructivist strategies based on the mathematical modeling method. Pretest and posttest data were collected from each group and analyzed to determine if either instructional method would show greater student understanding of the gas laws. Both methods were determined to have statistically significant positive effects on student posttest scores. However, neither method showed a statistically significant higher mean gain in test scores.

THE STUDY OF CONSTRUCTIVIST MATHEMATICAL MODELING FOR INSTRUCTION OF THE GAS LAWS IN A HIGH SCHOOL CHEMISTRY UNIT

A Thesis

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CHAPTER 1

INTRODUCTION

Identification of the Problem

Public education has been criticized considerably for not teaching critical thinking skills. At the other end of the spectrum, there has been a great deal of criticism directed toward insufficient teaching of fundamental concepts in reading, writing, and arithmetic. Though the former is not incompatible with the latter, the push for "the basics" may tend to downplay subjects that enhance critical thinking skills, including science. The pendulum between these two schools of thought has swung back and forth over the last few decades, and has caused widespread changes in curricula as well as in the way standardized tests are written. Some think that teaching critical or cognitive thinking skills meant giving up basic content and vice versa. In addition, it has been the opinion of some psychologists that students below the tenth grade level have not developed their cognitive thinking skills sufficiently to be taught exclusively with a "critical thinking" curriculum. As a result, all these forces pulling the educational system in different directions have made it frustrating for many teachers to decide upon appropriate teaching methods and content which should be included in their instruction.

During the last half century, there has been a push in science education for a more hands-on, problem-solving approach at all grade levels. The conjecture is that when students are engaged with active learning strategies, the teacher can make science more interesting and help students develop critical thinking skills at an earlier age. Some might say that this has also taken away basic content from the science curricula which makes it more difficult for students to really understand fundamental concepts or be exposed to a broad range of topics.

There must be a way to incorporate basic content into hands-on activities if there is to be any sort of compatibility between the two schools of thought. Constructivist curricula are designed to do just that. Constructivism is an approach which allows the student to "construct" a model or idea about specific content. This is done by providing a learning context for the students to perform hands-on activities to solve a problem that has been presented to them by their instructor.

One of the more significant refinements of contructivist curricula has occurred in the subject of physics. For example, a research group at Arizona State University has designed an entire physics curriculum in mechanics, which incorporates a contructivist method known as mathematical modeling. In this instructional method the teacher presents the students with a physical system and directs them to investigate the mathematical relationships among the system's mathematical variables. Students collect data and analyze the variables. The data are analyzed, often graphically, and the students develop a mathematical representation to describe the behavior of the physical system. In this approach, the students subsequently learn the mathematical behaviors of the variables in the physical system instead of simply being given a formula by the instructor. The Arizona State University research has shown a significant improvement in scores on the standardized Force Concept Inventory and the Mechanics Baseline Test over students taught using standard curricula. In addition, it is has been shown that by allowing students to construct their own models of the physical systems, students are better able to overcome any preconceived notions of the concepts involved (Hestenes, 1996).

Though the curricula using the mathematical modeling cycle have been created for physics, little has been done to introduce this method into chemistry curricula. This is, in part, due to the fact that most chemistry concepts do not lend themselves as easily to mathematical models. However, the chemistry topics of density and the gas laws should work quite well with this instructional method since they have quantitative foundations. Both are subjects in which students tend to "plug and chug" the numbers through the equations, but show very little conceptual understanding of the concepts. Mathematical modeling might help students understand these concepts, but might also the students better understand the mathematics behind the concepts.

Statement of Purpose

This study was an attempt to assess the level of student understanding between two groups of high school students who are taught the same subject matter using different instructional strategies. One group was taught the gas laws in a high school chemistry course using traditional textbook approaches, while the other group was instructed to learn the gas laws through the mathematical modeling cycle of constructivism. A unit was developed which incorporated the modeling cycle throughout. Since several similar curricula have already been created for the laws of mechanics in physics, enough related reference material was available to help create an appropriate unit for this particular chemistry topic.

Research Questions. This study had two objectives. First, to determine if either curriculum would result in an improved comprehension of the gas laws. Second, to determine if one curricular method would result in greater comprehension of the gas laws with respect to the other curricular method. These objectives were summarized in the following research questions:

1) Will the constructivist or traditional curriculum unit result in significant pretest/posttest gains?
2) Will either of the two curricular units result in a significantly greater posttest gain?

It was expected that both groups of students would learn the fundamentals of the gas laws. Differences were expected in the understanding of the concepts behind the mathematical principles. Pretest and posttest assessments were given to both groups of students. Part of the assessment was based upon normal textbook questions which assess the level of minimum objectives expected from the authors of the textbook. The second part of the assessment focused on the level of understanding of the concepts and mathematics of the gas laws at a level beyond the minimum expectations. The mean gains in scores between the pretest and posttest were analyzed for any differences between the two groups in the study.

Significance of the Study

Students today are overwhelmed with information. The computer age and the expansion of the Internet have caused students to be exposed to massive amounts of information at a faster pace than at any time in human history. This has created the need for teaching students not only the fundamental content of science, but also how to think and reason, whether as a scientist or as a citizen. By doing so, students can develop the ability to decipher massive quantities of information brought before them. The difficult task of teaching students to be reasoning, thinking citizens is placed on the educators of these students. The mathematical modeling cycle is a contructivist learning tool which can help the educator teach critical thinking skills, and at the same time still teach fundamental content required within the subject area.

Though the mathematical modeling cycle has been incorporated in several physics curricula, there are grounds to expand this instructional method to the subject of chemistry. This must be done in a careful and researched approach. Instructors can meet state and federal science standards using this teaching method. These standards call for incorporating technology in the curriculum, and incorporating students to design and research via inquiry within an adopted curriculum. Though no method is a cure for all the needs of today's educational environment, the mathematical modeling cycle is another tool which might help the teacher become more effective, which in turn, should benefit students.

CHAPTER 2

LITERATURE REVIEW

This chapter is presented in three parts. The first part defines student misconceptions and identifies their causes. The second considers the use of contructivist curricula as a viable alternative to traditional science teaching methods to give students the opportunity to develop understanding of concepts from inquiry-based investigations. The third part looks at one particular type of constructivist teaching method called mathematical modeling, the prototype of which is a physics curriculum developed by a team at Arizona State University. The chapter ends with a summary to clarify the direction of this study.

Student Misconceptions

A major problem facing educators is overcoming incorrect, preconceived assumptions students have about particular events in nature and related explanations. This impacts the ways instructors approach the curriculum. Gil-Perez and Carrascosa (1990) state that, "Misconceptions – at least those most deeply rooted – are associated with intuitive ideas or preconceptions acquired prior to school learning … and for some authors… these ideas are not just learned from experience but built into the hardware of the brain…" (p. 531). For many years, one of the more accepted models of instruction was based on the idea of transferring knowledge from the instructor to the student through various communication channels (Bodner, 1986). This "traditional method" is based on the idea that the student is a passive learner as the instructor controls the instruction of a class. The problem with this approach is that people tend to resist the new information being presented to them if it does not follow their preconceived ideas of the situation, and if it expects them to rearrange their previously constructed knowledge (Nakheih, 1994). Hestenes (1996) explains: "One reason for the failure of traditional instruction is that it overlooks the crucial influence of students' personal beliefs on what they learn. In the traditional setting, naïve student beliefs… are labeled as misconceptions and are likely to be summarily dismissed as unworthy of consideration" (p. 4).

It should be added that these misconceptions are extremely resistant to change. Bodner (1986) explains that "Each of us constructs knowledge that 'fits' our experiences. Once we have constructed this knowledge, simply being told that we are wrong is not enough to make us change our (mis)concepts" (p. 876). In a study involving middle-school teachers participating in a program to evaluate problem solving, it was found that the teachers did show positive changes in their understanding of the various sciences, but regressed to replacing their previously held misconceptions with new misconceptions (Shymansky, et. al., 1997).

A misconception should not be confused with a preconception. Some preconceived ideas may be correct while others completely contradict the facts. Bodner (1986) adds:

> A 'preconception' is a concept or idea which a student has upon entering … a course, and which has some consequence on the person's work…. We shall use the term 'misconception' for concepts or ideas which from the point of view of the average professional … lead to unacceptable solutions or answers to questions or problems in the context of the course …. (p. 876).

This problem of student misconceptions creates a huge challenge for educators. Teachers must decide how to give students an opportunity to overcome their misconceptions without sacrificing too much time in the course. Hestenes (1996) explains: "Many have concluded that student beliefs are so 'deep-seated' that heavy instructional costs to unseat them are unavoidable" (p. 4). Thijs (1992) states that "learning involves the generation and restructuring of students' conceptions .... A process of conceptual change is only likely to occur if students are dissatisfied with their current concepts and feel the need for a new concept" (p. 156). The fact that student misconceptions may be so difficult to overcome has led some researchers to question whether or not educators should even bother to attempt to change a student's understanding of a concept (Gil-Perez & Carrascosa, 1990). There must be an effective way to deal with the problem of helping students overcome their misconceptions while still allowing time to learn the content required for a course.

Constructivist Curricula

To overcome student misconceptions, some educators have begun to throw out traditional curricula in favor of more non-traditional methods of instruction. One curricular approach designed to deal with student misconceptions is based on constructivism. "The constructivist perspective is becoming a dominant paradigm in the field of cognitive psychology. Research findings resulting from this perspective have profound implications for the way in which science instruction is carried out" (Saunders, 1992, p. 136). Carter (1999) adds that "In recent years, ... emphasis on constructivist teaching methods has led to an increased use of activities involving hands-on investigations, social interaction, and classroom discussions" (p. 44). Appleton (1993) contends: "A recent trend in science education research has been an attempt to marry constructivist views of learning with actual practice in teaching science" (p. 269). Yerrick, Pendersen, and Arnason (1998) go further when they say that "*Project 2061*, *Benchmarks*, and *National Science Standards for Education* are forwarding a vision for science teacher educators in which a constructivist teaching perspective is implicit" (p. 619).

Constructivist approaches are based on the idea that a student constructs his or her knowledge from the data gathered. Saunders (1992) says, "Constructivism can be defined as that philosophical position which holds that any so-called reality is, in the most immediate and concrete sense, the mental construction of those who believe they have discovered and investigated it" (p. 136). Carter (1999) adds:

> A constructivist view of learning assumes that students are active builders of knowledge who interact with their environment and other individuals within their environment.... Teachers are viewed as facilitators of activities, discussions, and situations rather than as dispensers of knowledge (p. 44).

Kamii and Ewing (1996) state that constructivist views of education originated from Piaget's constructivism. Kamii and Ewing add the following reasons for basing teaching on Piaget's constructivism:

> 1) it is a scientific theory that explains the nature of human knowledge, 2) it is the only theory in existence that explains children's construction of knowledge from birth to adolescence[,] and 3) it informs educators of how Piaget's distinction among the three kinds of knowledge changes the way we should teach many subjects (p. 260).

The postulate that constructivism is the generation of knowledge from personal experience, which can cause misconceptions in a person's view of the data, leads to an important question. If a person constructs knowledge from his or her own personal views of the world, then how can a group share common knowledge? The answer to this question is to remember that the knowledge learned must agree with reality. The student must build the knowledge and then test it continually to show that it is consistent with the reality of nature (Bodner, 1986). The building of student knowledge can be a true enhancement of teaching students science because, by its very nature, science is a knowledge-building process. Hand and Treagust (1991) support this argument when they state:

> As students develop their own concepts during group discussions and class discussions, teachers need to act more in the role of someone who facilitates learning. Using this framework, science curricula may be able to more effectively ensure that science is more applicable, understandable, and enjoyable for all students (p. 176).

A basic idea behind constructivist-based activities in science is to use the laboratory as a testing and training ground for learning and applying the concepts of science. Roth (1994) states the following:

> Most of the curricula developed in the 1960s and 1970s were designed to make laboratory experiences the core of the science learning process.... Science in the laboratory was intended to provide experience in the manipulation of instruments and materials, which was also thought to help students in the development of their conceptual understanding (p. 197).

Roth (1994) also contends, that though many of these laboratory activities are recognized to help facilitate learning, their potential and use have not yet been completely realized. This could be due to many factors including the lack of teacher preparation in the effective use of laboratory activities, the lack of funding or equipment within the school, and the lack of time for proper preparation for the laboratory activities. Whatever the case, a need for realization of the potential in the use of such activities is indicated.

The use of constructivist curricula in science education is not without its critics. A lack of both preservice and inservice teacher training is a major impediment to acceptance of such reforms in science education. Yerrick, et al. (1998) contends:

> If reforms that promote new ways of teaching and learning are to succeed, they must be accompanied by strategies and lenses through which to alternative perspectives of science and teaching. Reform must balance what is known about the nature of scientific struggles with practical struggles of maintaining a collective classroom construction of knowledge (p. 644).

One reform necessary for instructors to recognize is that "cookbook" labs, in which the students simply follow directions, are not always an effective way to use laboratory activities. Roth (1994) contends:

> When they do cookbook laboratories, students are not concerned with meaning but with completing the exercise by following the step-by-step procedures…. Our students indicated that the very nature of their chemistry cookbook laboratories prevented them from understanding why they completed a particular procedure (p. 215).

The author of this study has drawn similar conclusions from his own experience as a chemistry instructor. However, he has not researched the subject to determine if there is any "truth" to this assertion.

<u>Mathematical Modeling</u>

Many constructivist approaches exist that can be applied to science curricula. In the physical sciences, mathematics is a basis for understanding and reinforcing the concepts. In particular, physics and other topics such as the gas laws in chemistry lend themselves to mathematical constructivist approaches. In 1995, Arizona State University science education conducted a workshop which set out to change the way introductory physics courses are taught. They developed a curriculum based on contructivist ideas to develop the concepts and mathematics of physical phenomena. This mathematical modeling approach was based on the work of the late Malcolm Wells of Arizona State University (Wells, Hestenes, & Swackhamer, 1995). Hestenes (1996) explains:

> Physics can be characterized as a complex network of models interrelated by a system of theoretical principles. Models are units of structured knowledge used to represent observable patterns in physical phenomena.... The primary objective of physics teaching should therefore be to develop student modeling skills for making sense of their own physical experience and evaluating information reported by others. The Modeling Method of instruction ... has been developed to meet this objective (p. 7).

Wells, et al. (1995) says that "a major reason for adopting the modeling approach is to help students develop a more coherent, flexible, and systematic understanding of physics.

The knowledge that students acquire from traditional instruction tends to be fragmented and diffuse (p. 4).

The authors of the mathematical modeling method based their reasoning for using this approach to teach physics, in part, on the results of the Force Concept Inventory test scores, which showed improvement of student understanding for those learning physics through non-traditional methods of instruction versus traditional instruction. The Force Concept Inventory data was derived from over 12,000 students in 100 physics courses in high schools and colleges. The Force Concept Inventory results showed that students taught through traditional courses had a mean gain of 22 percent between pretest and posttest results, whereas students taught through non-traditional methods showed a mean gain of 52 percent (Hestenes, 1996).

A follow-up study was done by Richard Hake at Indiana University. In this study Hake (1998) surveyed Force Concept Inventory scores from 62 introductory physics courses with a total of 6542 students. The findings showed significantly higher gains from students taught using a constructivist approach, which Hake described as interactive-engagement, versus those students taught using a traditional curriculum in physics.

The mathematical modeling method is an approach which allows students to be engaged in all instructional phases of conceptual understanding and mathematical model development. The teacher usually will set the stage with a demonstration, and subsequent class discussion of a question about a physical event. Students will then collaborate, plan, and conduct experiments to test the variables germane to the physical event. The students must then present and justify their conclusions and include the mathematical representations of their data. This presentation will be given to their class peers. The teacher guides the inquiry and discussions with a "Socratic" questioning method. This will allow the students to compare one another's results, and will cause any misconceptions of the results to come to the surface for all to discuss (Hestenes, 1996). This approach to instruction is also supported by Kogut (1996), who states:

> I have used the following strategies to encourage critical thinking skills: Ask questions frequently and direct them to individual students.... Use examples and illustrations that challenge dualistic thinking and reinforce the notion that science does not have many absolutely correct answers.... Promote discussion among students by using in-class assignments and encouraging out-of-class study groups.... Effective use of feedback encourages critical thinking.... Exemplification is critical to fostering critical thinking (p. 220).

Though much research has been done to develop physics curricula based around constructivist teaching methods, the research would indicate that constructivist approaches to chemistry instruction are not as well developed. Kogut (1996) says, "Students entering college chemistry courses typically have received little instruction or encouragement to practice critical thinking skills" (p. 220). A mathematical modeling approach to the teaching of the gas laws would be one way to implement a constructivist approach to this topic and thus employ critical thinking skills.

Summary

The research indicates that constructivist approaches to teaching science appear to be gaining support in the science education community. Many factors have stimulated the desire of some science educators to change the way they teach. Some feel that students do not understand how the content of science instruction can parallel the actual practical use of science (Kogut, 1996). Others find that students are overwhelmed and unable to process information effectively (Nakhieh, 1994). Still others recognize that students have deep-seated misconceptions which cause educators to question how they should deal with these misconceptions to improve the effectiveness of their teaching (Appleton, 1993). Saunders (1992) states, "Unfortunately, however, a vast majority of science programs are textbook-driven and thus often fail to capitalize upon more effective instructional practices stemming from these new insights" (p. 136). In addition, the literature would appear to support the fact that many teachers are unwilling to change their methods of instruction to incorporate a more constructivist type of learning approach into the curriculum. The argument is that there is too much taken away from the content taught in favor of a more focused and in-depth analysis of fewer concepts. In addition, many educators are facing a dilemma with political pressures from those outside the educational system who would have teacher performance based on students' standardized test scores. Some might argue that this, in effect, is forcing the educational community to push for the teaching of test content instead of pushing for a higher quality of outcomes from teaching methods. Society will have to decide which direction it wants education to take if this problem is to be resolved.

Research at Arizona State University and by others appear to back up the idea that the use of non-traditional constructivist methods in teaching science can be effective to help students overcome misconceptions, process information more effectively, and perhaps find more enjoyment in learning the subjects. In addition, the students might find the subjects they learn are more consistent with the nature of science and the science enterprise. This can be especially true in the teaching of physics and chemistry in which the subjects of mathematics and the development of scientific principles combine when studying many topics.

This study will focus on implementing a mathematical modeling curriculum unit to teach the gas laws in a high school chemistry class. This chemistry topic involves the mathematical relationships of Boyle's Law, Charles' Law, Gay-Lussac's Law and the Ideal Gas Law. The mathematical modeling curriculum for physics, which was developed at Arizona State University, will be the basis for creating a curriculum unit on the gas laws. The curriculum will be implemented in two high school introductory chemistry classes while other classes will be taught with more traditional methods. A comparison of pretest and posttest results from all the classes will be used to determine the relative effectiveness of the two instructional methods.

This study is a logical extension of past research done in physics. The research suggests a need to expand constructivist curriculum approaches into the subject of chemistry. These constructivist approaches should augment the teaching of the concepts without omitting content in the curriculum. Though several constructivist approaches have been designed for other topics in chemistry, the research literature contains very little if any discussion regarding the implementation of a mathematical modeling curriculum to the topic of the gas laws. Though this study will only include a unit of the gas laws, the topic of density could be adapted and may be appropriate for research in another study.

CHAPTER 3

METHODOLOGY

This chapter is a complete description of the methodology that was used to conduct the research. It will begin with a description of the target population and the population that was used for the sample. The second section will explain the experimental design of the research. The third section will describe the procedures and instrumentation that was used, and section four will discuss the statistical design of the research. Section five will conclude the chapter with a summary.

Participants

Target Population. This research targeted high school students in a middle to upper-middle income city-suburban school. The population was comprised of mostly white students of European ancestry with less than ten percent comprised of minority students. The city-suburban school population is one of the fastest growing groups in the midwestern United States. These school district populations have been known to contain doctors, engineers, and other scientists. The need to research the best approach to teaching science to this group, as well as the general population, has merit.

Accessible Population. The sample in this study was comprised of six class sections of an elective, first-year high school chemistry course in a middle-to upper-middle class city-suburban school located in south-central Kansas. The chemistry course was an elective class, however it was recommended for college-bound students, and either chemistry or physics must be taken to meet the Kansas Board of Regents qualified admission curriculum.

The high school which the participants attended had a building population of approximately 1100 students. The school district population was comprised of 92 percent Caucasian students, 3 percent Hispanic, 2 percent African American, 2 percent Asian American, and 1 percent Native American. Only 12 percent of the school population was on free or reduced lunches. The six classes chosen for the study were characterized by a similar demographic population. The six classes were made up of a total of 117 students.

The research was designed for a student population sample of approximately 100 students to account for variables which may prevent some students from participating in the study. The average class enrollment was eighteen students; the smallest class had fifteen students and the largest had twenty-one students. The total class population was comprised of 35 percent males and 65 percent females. It was recognized that this is likely a higher percentage of female students than might representative of a national average for students in an advanced science class. However, this sample may be reasonably representative for many Midwestern city-suburban school districts.

<u>Sampling Procedures.</u> Six classes in the same school building were chosen for the research. Two classes were taught by the author and researcher (Instructor 1), while the other four were taught by another instructor in the same school (Instructor 2). The flip of a coin was used to determine which of the two sections taught by Instructor 1 was assigned as Group A. By default, Instructor 1's other class was assigned to Group B. Each instructor had one class which, for the spring semester 2000, had consistently received much lower test scores than the other class sections. The low achieving class taught by Instructor 1 was assigned to Group A. To eliminate the possibility that the two

historically low achieving classes would fall within the same group, the lowest-achieving class taught by Instructor 2 was assigned to Group B. The other three classes were assigned to one of the groups by two consecutive coin tosses. Group A was then selected by a coin toss to use the standard textbook curriculum and Group B would then be assigned the mathematical modeling curriculum by default. This selection process ensured that Instructor 1 taught one class with the treatment and one with the standard curriculum, and Instructor 2 taught two classes with the experimental treatment and two with the standard curriculum. Both instructors had been trained in constructivist teaching methods. Instructor 1 has twelve years of teaching experience and Instructor 2 has over twenty years of teaching experience.

All students in the class were given an informed letter of consent which both the student and the student's parents were required to sign in order for the student to be a participant in the research (see Appendix A for a complete copy of consent form). If a parent or student refused to sign the consent form, that student was not included in the study, but was still taught with the assigned curriculum for that student's class section. In addition to the student consent, a letter of consent from the school's Superintendent of Curriculum and the building Principal were solicited. Instructor 2 was also solicited for his consent for involvement in the research.

Experimental Design

Research Method. The research design was a quasi-experimental design. The classes were distributed for treatments so that each instructor taught an equal number of class sections with the modeling method curriculum and the traditional curriculum.

Both Instructor 1 and Instructor 2 taught the traditional curriculum unit and the modeling method curriculum unit.

The class sections taught with the traditional curriculum unit were assigned as Group A. The class sections, taught via the modeling method curriculum unit were assigned as Group B. The groups assigned to Instructor 1 were given the designations Group C1 and C3. The four classes taught under Instructor 2 were assigned as S3, S4, S5, and S6 (see Table 1). Group A was comprised of classes C1, S3, and S6. Group B was comprised of classes C3, S4, and S5 (see Table 2). For analysis all subgroups of A and all subgroups of B were combined into two groups labeled A and B.

Table 1

Class Sections by Instructor

Instructor 1	Instructor 2
C1	S3
C2	S4
	S5
	S6

Note. Instructor 1 is the author of the research. Instructor 2 is a colleague of the author.

Table 2

Class Sections by Group

Group A (Traditional)	Group B (Constructivist)
C1	C3
S3	S4
S6	S5

Note. Class codes beginning with "C" were taught by the author of the research (Instructor 1). Class codes beginning with "S" were taught by a colleague of the author (Instructor 2).

The independent variable in this experiment was the curriculum unit taught to the class. The traditional curriculum unit represents a more common textbook modality for instruction. The currently adopted chemistry textbook for the school district was used. In general, the traditional approach used lecture and discussion to present the subject material to the students, and as a reinforcement to the lecture, textbook problems were assigned. Laboratory activities were given to reinforce the concepts and give the students a more practical view of the concepts. Group A used a "cookbook" lab design in which the student simply followed the directions printed in the lab. This type of lab is common in most published textbooks and curricula.

In practice, the constructivist modeling method curriculum is performed in a reverse direction. Instead of the instructor imparting end-point knowledge to the students, they must first perform the lab work to determine relevant information for the development of mathematical relationships and concepts. Though the students did perform nearly identical labs in both curricula, the modeling method curricular approach had the students design their own lab procedures rather than follow a printed set of directions. Lab work was followed with discussions of results and homework problem sets in order to reinforce the lab work.

The dependent variable was the change in test scores between the pretest and posttest. The mean change in scores for all subjects within the two groups were compared.

Research Design. The modeling method curriculum was developed by the author of the research. This curriculum was presented in the same time frame as the traditional curriculum. Groups A and B were all administered a pretest on the first day of the treatment. Following the pretest, instruction with both curricula began the next school day. Instructional time for both groups lasted approximately two to three weeks. At the end of this period, a posttest was given to both groups (see Appendix B for copy of testing instrument).

Both Group A and Group B students were instructed in the same school building in nearly identical classroom settings. Classrooms of both Instructor 1 and Instructor 2 were located adjacent to each other. Both rooms shared the same storage area and had identical equipment at their disposal.

The classroom of Instructor 1 had Pentium desktop computers with the Vernier Universal Lab Interface for interfacing pressure and temperature sensors with the computer. The classroom of Instructor 2 had Pentium laptop computers with a Vernier Serial Box Interface attached for interfacing pressure and temperature sensors. The software for both computer systems was version 1.2 of Vernier Logger Pro for Windows. These computer systems were used for the labs in both curricula. Students were instructed on the use of the computer equipment and were directed to use only this equipment for the lab work.

The test, which was given as the pretest and posttest, was designed by the author of the research. The test consisted of multiple-choice and short essay questions designed to evaluate the varying levels of understanding of the gas laws (see Appendix B). All groups of students took the pretest and posttest on the same day, but at different times during the day according to the assigned period for their class section.

The classes were comprised of a total of 117 students. The research methods were designed for approximately 100 students. This provided a buffer for "nuisance variables" which may have interfered with the validity of the research, in addition to the fact that some students or student's parents may have refused to participate in the research. There are many variables which could have interfered with the internal validity of the study. These interfering variables could include the loss of life of a participant extraordinary personal problems for a participant, a participant's change in attitude which might make him or her lose interest in doing well on the test instruments, excessive absenteeism by a participant, suspension or expulsion of a participant, or a participant moving out of the district during the course of the study. If a student were deemed to be a "nuisance variable" for the study, his/her test scores were removed from the experimental data.

External Validity. This study generalized a student population found in many city-suburban school districts throughout the central and midwestern regions of the

United States. Though this study does not represent a cross section of the national population, it should give a reasonable representation of the city-suburban school population.

Research Question. The first goal of the experimental study was to determine if both curricula would result in an increased understanding of the gas laws as evident by pretest/posttest scores. A paired t-test was performed on the pretest and posttest scores for each of the groups to determine if any difference between the mean pretest and posttest scores could be considered statistically significant. The second goal of the experimental study was to determine if both curricula would produce equal results in student understanding of the gas laws. Comparison of the mean posttest scores to the mean pretest scores was used to determine if there was a significant difference in student understanding. An unpaired t-test was performed on the mean gains of the two groups in order to determine statistical significance of any differences.

Procedure

Group A. Group A received instruction with the traditional curriculum unit. The instructors began the unit with a lecture and class discussion concerning the gas law variables. The theoretical mathematical relationships were shown and discussed with the group, and example problems were presented and solved for the students. The discussion of the concepts was followed by assigning textbook problems, which were representative theoretical situations in which to interpret the gas laws. (The textbook which was used for the traditional approach, *Modern Chemistry,* was published in 1990 by Holt, Rinehart, and Winston Publishing.) After the problem sets were completed, the students were assigned lab work in which they followed an instruction sheet designed to have the students verify the mathematical relationships between pressure and volume and between volume and temperature. The labs used were from *Chemistry with Computers*, published in 1998 by Vernier Software Corporation. Vernier Software is also the developer of the computer interfaced lab sensors and software which was used in the labs for both curricula. The lab results were discussed in class and any apparent misunderstandings were resolved at that time. The lab work concluded the curriculum unit and the posttest concluded the unit.

Group B. Group B was given the constructivist modeling method curriculum unit. The unit began with a teacher demonstration in which the teacher filled a syringe with air. The class was asked to determine the variables involved in making the volume of the trapped gas decrease or increase. The teacher was careful not to demonstrate if the volume would increase or decrease. From that point the students were instructed to design an experiment which would allow them to find the relationships between the volume and the other variables which may have been involved. The students presented their designs in class presentations for critical analysis by the other students. When a general consensus was reached for an acceptable experimental design, the students amended their lab procedures and began work to perform the lab. The lab results were then presented by each lab group, and a class average of the results were used to help determine a consensus regarding the accuracy of the data.

The first lab designed by Group B was used to determine Boyle's Law, or the relationship between volume and pressure at a constant temperature. Students were asked to determine the variables that changed in the experiment and those that remained constant. After a full class discussion of the results of the first lab, the students were then asked to determine a relationship between the temperature and volume of the gas in a closed syringe. The students were once again asked to determine the variables that changed, and what remained constant to allow the relationship to be determined.

The second lab design had the students determine the mathematical relationship between pressure and temperature and address which variables had to remain constant. Both labs were an attempt to help the students determine how pressure, volume, and temperature are related. From the data, Boyle's Law and Gay-Lussac's Law were determined. Neither group performed a lab to study the relationship between temperature and volume (Charles' Law). This was omitted due to the fact that it was difficult to get accurate results with the equipment at the instructor's disposal. As a replacement to lab work, a qualitative demonstration was performed for both groups in which the instructor placed a sealed syringe in a freezer, refrigerator, and warm water to see the effect of temperature on the volume of air in the syringe.

Homework problem sets were assigned as a follow-up to the lab work. This homework was written by the author and was designed to reinforce the concepts explored and determined in the lab work. Upon completion of the homework problems, the students presented their work through the use of whiteboard presentations. The students discussed and compared their homework results during these presentations. When all homework presentations were complete, the students were given the posttest.

The pretest for both groups consisted of multiple-choice and short answer questions. These questions were divided into several categories, including Boyle's Law, Charles' Law, Gay-Lussac's Law, Avagadro's Law, and the combined gas law. The test included questions evaluating conceptual understanding for each law, graphic interpretations for each of the laws, and proper use of the mathematical formulas representing each of the laws. The posttest consisted of the same questions as the pretest.

Statistical Design

Using the null hypothesis form, the first research question can be stated: "There will be no statistically significant gain in the mean posttest scores of either curricular method." A paired t-test was conducted on the pretest and posttest scores for each group to determine acceptance or rejection of the null hypothesis. If a probability of 0.05 or less ($p <= 0.05$) is obtained, then the null hypothesis can be rejected. If $p > 0.05$, then the null hypothesis cannot be rejected and the gains in posttest scores cannot be considered statistically significant.

Using the null hypothesis form, the second research question can be stated "There will be no statistically significant difference in the mean gain scores between the students taught with the mathematical modeling curriculum unit and the students taught with the traditional curriculum unit." An unpaired t-test was conducted on the mean gains of each group to determine acceptance or rejection of the null hypothesis. If an alpha coefficient of 0.05 or less is obtained then the null hypothesis can be rejected. If $p <= 0.05$ then the null hypothesis can be rejected and the curricular method with the larger gains in mean posttest scores could be considered favorable for instructional effectiveness. If $p > 0.05$, then the null hypothesis cannot be rejected and neither curricular method can be considered more favorable for instructional effectiveness.

Summary.

The modeling method used in this study was based upon research done at Arizona State University in which an entire curriculum was developed for teaching mechanics in a high school physics course. This research was the logical extension of the Arizona State study by attempting to determine if the use of this constructivist style of mathematical modeling might be an appropriate curriculum for the instruction of the gas laws in an introductory high school chemistry course.

The primary difference between this approach and the traditional curriculum model was the order and style in which lab activities were introduced. In addition, the traditional curriculum was taught through lecture by the instructor whereas students taught with the constructivist curriculum learned the concepts through laboratory work and discussions during student presentations.

The mathematical modeling curriculum design is an attempt to fundamentally change the role of the teacher from a dispenser of knowledge to that of a facilitator. It also attempts to move the students away from the role of a passive learner to an active learner. The research would indicate that this approach could be preferable with helping students gain a deeper understanding of the concepts studied. Some literature suggests that many students who simply read lab procedures and "regurgitate" the knowledge a teacher imparts to them fail to truly grasp the subject content they are expected to learn and understand. The mathematical modeling curricular approach attempts to address this concern by having students actually design and interpret their laboratory activities and develop relationships among the salient variables. In general, this study was designed to determine if both instructional models would demonstrate the same levels of understanding. Though these results will not be a complete validation of either curriculum model, the research should provide a basis for additional research in the use of alternative science curriculum methods and teaching strategies.

Though there is no "one-size-fits-all" method of instruction and there will always be a need to research and expand new approaches and possibilities to improve instructional methods. Educational methods are an ever-changing, dynamic subject which must respond to the needs of society and to pedagogical research. This study was an attempt to provide one more possible way to teach the important subject of the gas laws which are taught in most introductory high school chemistry and high school physical science curricula.

CHAPTER 4

ANALYSIS AND PRESENTATION OF RESULTS

This chapter is divided into two sections. In the first section a summary of the pretest and posttest scores, is reported along with graphs of the distribution curves for the two groups involved in the research. In part two, a summary and analysis of the gains in scores will be reported. Results from the statistical analyses of the mean gains will be reported and analyzed using an unpaired sample t-test on the mean gains. The results will be used to address the two research questions.

Results of Test Scores

Pretest and Posttest Scores. The results of the pretest and posttest scores are shown in Table 3. Group A received the traditional gas laws curriculum unit while Group B received the constructivist unit. A smaller number of subjects participated in Group B due to a smaller number of students enrolled in the class sections and due to the fact that several subjects failed to take the posttest. The tests had 22 total points possible. The results show that both groups had nearly identical mean scores on the pretest with Group B scoring only 0.1 point higher than Group A. The standard deviation was 3.4 for Group A and 3.9 for Group B. The posttest scores show that Group A scored an average of 1.2 points higher than group B. The standard deviation was 3.9 for Group A, and 4.8 for Group B.

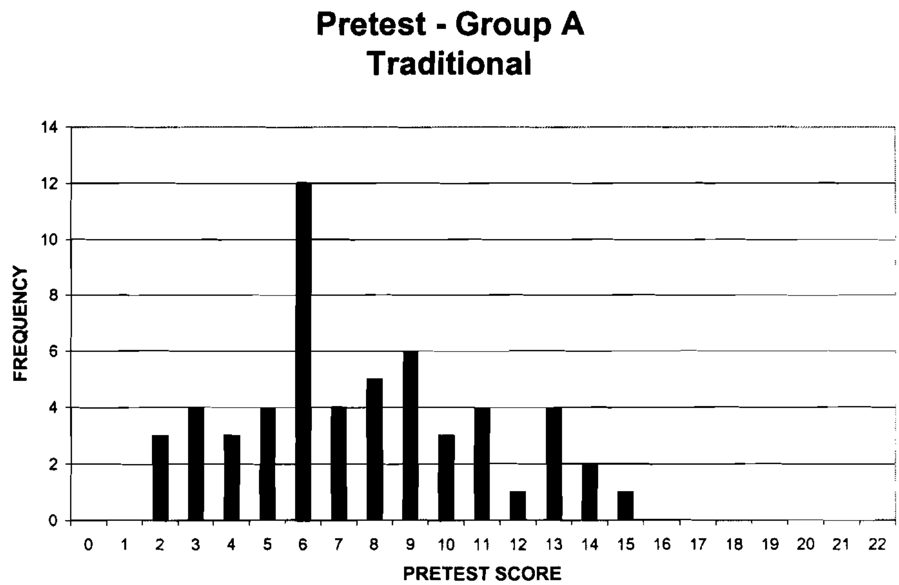
Table 3

Pretest and Posttest Scores and Statistics by Group

Group	N	M (Pre)	SD	M (Post)	SD
Group A (Traditional)	56	7.6	3.4	13.3	3.9
Group B (Constructivist)	41	7.7	3.9	12.1	4.8

Note. N = Sample Number; M = Mean; SD = Standard Deviation; 22 points possible.

Figure 1 shows the distribution of scores for the pretest given to Groups A and B. The graphs show that the scores have a slightly positive skew on the distribution for both groups. This would be expected in a pretest setting if it is assumed that the students have little or no prior knowledge of the subject matter. Figure 2 shows the distribution of scores for the posttest given to Groups A and B. Group A showed the scores to have a slightly negative skew while Group B had a fairly normal distribution. The slightly negative skew could be the result of the fact that several participants dropped out of the research with most falling out of Group B.



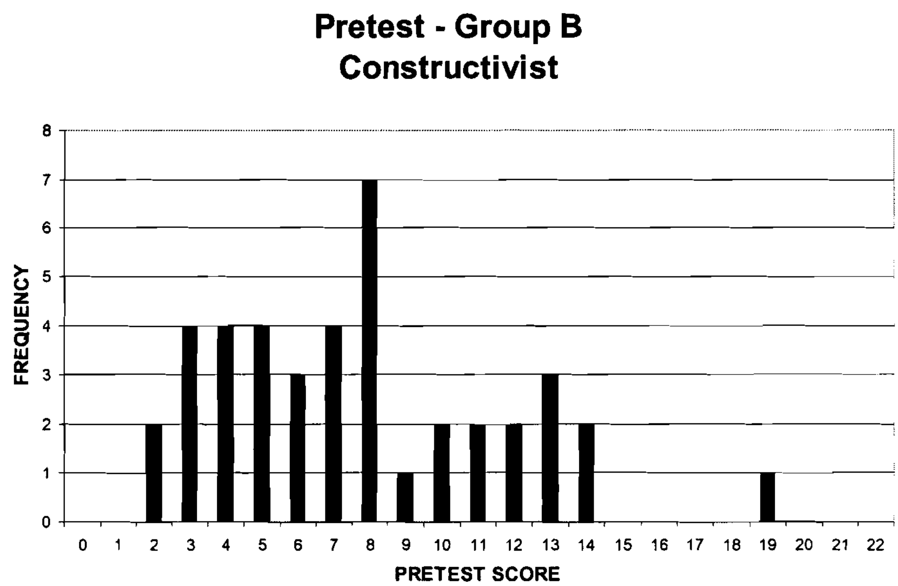
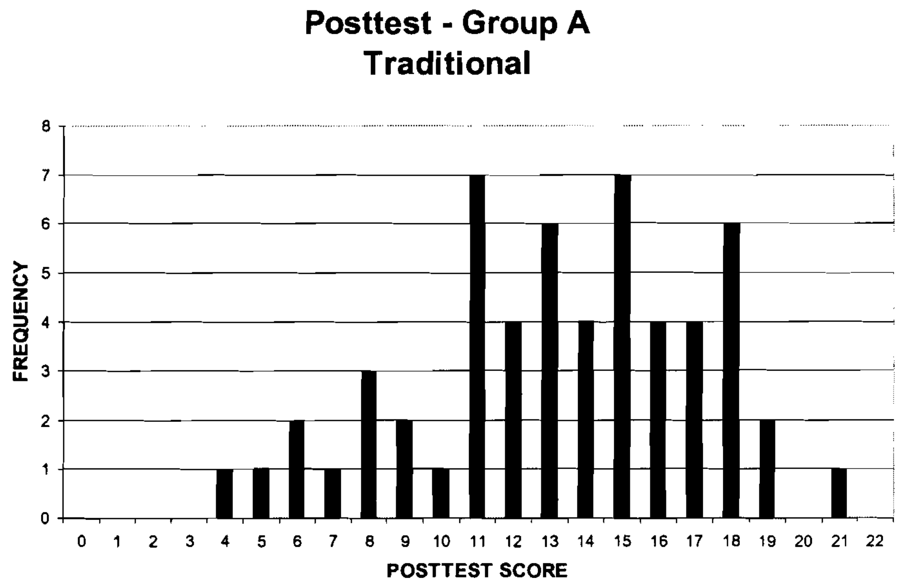


Figure 1. Pretest score distributions for Group A and Group B



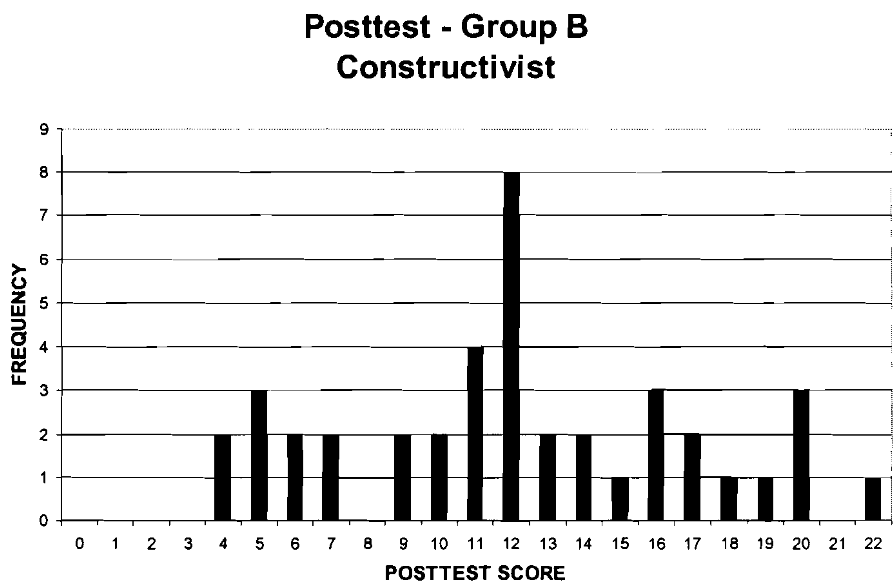


Figure 2. Posttest score distributions for Group A and Group B

Results and Analysis of Calculated Gains

Table 4 shows the mean scores for the pretest and posttest in each group. In addition, the gain in score is calculated and reported.

Table 4

Calculated Gains by Group

Group	N	M (Pre)	M (Post)	Gain
Group A (Traditional)	56	7.6	13.3	5.7
Group B (Constructivist)	41	7.7	12.1	4.4

Note. N = Sample Number; M(Pre) = Pretest Mean; M(Post) = Posttest Mean; Gain = M(Post) – M(Pre); 22 points possible.

In null hypothesis form, the first research question can be stated, "There will be no statistically significant gain in the mean posttest scores of either curricular method." As shown in Table 4, both groups did show an increase in mean test scores. Group A showed a gain in posttest scores of 5.7 points and Group B showed a gain of 4.4 points.

In null hypothesis form, the second research question can be stated, "There will be no statistically significant difference in the mean gain scores between the students taught with the mathematical modeling curriculum unit and the students taught with the traditional curriculum unit." As shown in Table 4, both groups did show an increase in mean test scores. Group A showed a higher gain in posttest scores than Group B with a Group A gain of 5.7 points and a Group B gain of 4.4 points. This is a Group A mean gain 1.3 points higher than Group B.

A study similar to the present research was conducted at Indiana University. This study involved the use of a constructivist physics curriculum in contrast with a more traditional approach. In this study, Hake (1999) describes the use of the Analysis of Covariance (ANCOVA) as a valid type of statistical analysis in order to address the statistical significance in mean gain scores of pretest/posttest research. However, Hake replaced the ANCOVA with average normalized gains. The normalized gain essentially gives a percentage increase in the gain compared to what was possible and in the authors opinion did not seem to have merit for justifying the statistical significance of the data in this study. After careful review, it was determined that either an unpaired t-test or ANCOVA would provide a valid tool for determining significance of the mean gains between the two groups.

To answer the first research question that "There will be no statistically significant gain in the mean posttest scores of either curricular method," a paired t-test was used to determine the significance of the gains on the posttest in each group. In Group A, the mean gain in posttest scores of 5.7 points was significant ($p < 0.0001$). In Group B, the mean gain in posttest scores of 4.4 points was significant ($p < 0.0001$). Based on the results, both curricula produced a significantly higher gain in mean posttest scores with respect to their corresponding mean pretest scores.

To answer the second research question that "There will be no statistically significant difference in the mean gain scores between that of the students taught with the mathematical modeling curriculum unit and the students taught with the traditional curriculum unit," an unpaired t-test was used to compare the mean gains of the two groups. The 1.3 point mean gain increase of Group A compared to Group B was not significant ($p = 0.12$). There was a slight difference in the mean pretest scores which introduced the possibility of a covariant. Therefore, a follow up analysis using an Analysis of Covariance (ANCOVA) was conducted in order to "verify" the results of the t-test. Again the 1.3 point mean gain was not significant ($p = 0.11$). Based on these results, neither curriculum method caused a significantly higher gain than the other, so the null hypothesis cannot be rejected. The conclusion can then be drawn that neither the constructivist approach nor the traditional textbook approach was better with helping the subjects improve their posttest scores and subsequently, their understanding of the gas laws.

CHAPTER 5

DISCUSSION

Overview

In recent years there has been an increase in the use of constructivist-based curricula in the instruction of science. This instructional method has become more popular due, in part, to the fact that it is observation-based and parallels the "pursuit of science." This study was based, in part, on a similar study conducted by Arizona State University. In that study, a constructivist curriculum in physics was compared to more traditional lecture-based curricula. That study produced results which showed that test scores on the Force Concept Inventory were significantly higher for students taught through a constructivist curriculum compared to those taught by more traditional curricula (Hestenes, 1996).

This study adapted the ideas in the physics investigation and condensed them to a single chemistry unit concerning the gas laws. This study showed that both had a positive impact on posttest score gains. However, the results showed no significant difference in the test scores between the two treatment groups and thus, it was concluded that neither curricular method was better than the other in producing greater understanding in the gas laws as measured by test scores. This study does, however, raise some interesting questions which will be addressed in this chapter. In addition, suggestions for improvement of the present study will be given as well as justification for continued research concerning curriculum effectiveness.

Impact of Curricula on Student Test Scores

The fundamental research question was concerned whether either of two curriculum methods would result in significant average test gains over the other. Results clearly indicates that the null hypothesis: "There will be no significant difference in the mean test scores of the two groups" is accepted since the probability shown by the unpaired t-test was greater than 0.05, i.e. "chance" considerations could cause the outcomes. Both groups showed significant gains in the posttest scores over the pretest scores, but neither group showed a significantly greater average gain over the other. Since both methods gave the same level of benefit, it could be concluded that both methods of instruction have merit and could be used. This study does not discount the idea that each method might benefit different learning styles for different students. More research is needed to assess the impact of each method on different learning styles.

Assessment of Findings

An obvious question is raised by this study that may be justification for further research. Why did two independent physics studies show that the constructivist approach gave significantly higher test results while the present study showed no significant difference? One possible explanation could be that there are no significant misconceptions to overcome in the gas laws concepts. Without these misconceptions, the student might not need a constructivist approach to help "undo" a previously learned misconception.

Constructivist curricula are based on the premise that the student should learn and construct his/her own ideas from discovery based activities. Some research has indicated this type of learning is considered the best way to "undo" previously held beliefs and misconceptions because the students discover their misconceptions on their own instead of having somebody tell them of "the way something is." If there are no previously held misconceptions within a subject area, it might be argued that a traditional and constructivist curriculum can work equally well. Further research into what misconceptions might be common with the gas laws will be necessary to address this conjecture. The author of this study did no research into what misconceptions might be commonly held with reference to the gas laws.

Another explanation for the results of the present study could be due to the short time period in which the study was conducted. It is generally accepted that the constructivist approach takes more time to teach the same number of concepts. This is due to the fact that the students must "reason out" and develop their own lab procedures instead of having the teacher or a textbook give a lab procedure. The current study had both groups attempt to accomplish the same level of work in the same amount of time. There may have been an inadequate time for the constructivist group since the instructor did not give them much direct information, but instead facilitated the constructivist students to work on their own throughout much of the unit.

Another explanation for the difference found by this study in contrast with physics research could be the fact that the constructivist curriculum is a new learning paradigm for the student. Most curricula are taught in the more traditional teacher-centered lecture approach. It is reasonable to assume that students have become accustomed to this approach and have adapted their learning styles to this method. One subject in this study, who was also enrolled in a physics class based on a constructivist curriculum, told the author that the subject found the physics class to be very difficult in the first quarter of the year. However, by the beginning of the second semester, the course seemed to become much easier and enjoyable. When pressed for the reason the subject felt this way, the subject replied that it was a whole new way of learning in which the subject was not familiar. However, once the subject adapted to the constructivist curriculum, it was actually considered an easier and more enjoyable way to learn. The author has heard similar comments from other students in the author's physics courses, however, the author has not performed any research to verify that students need time to adapt to a new learning paradigm. This could be a realm for additional research to address the use of constructivist curricula as a viable alternative to more traditional approaches.

Limitations of the Study and Suggestions for Further Research

Several points must be considered when assessing these findings. First, this was one study done with a limited number of classes in one city-suburban high school located in Kansas. In the physics studies cited to in the literature, the studies encompassed thousands of students in hundreds of high schools across the nation. This study has obvious limitations for applicability to the cross section of the nation. Second, there is evidence that some subjects may not have tried to achieve the best posttest scores they could have achieved. Some students appeared to be suffering end of the school year "burn-out," and seemed to have given up on making strides for understanding of the subject matter. In addition, some of the higher-achieving students refused to take part in the study due to the fact they did not see the need for the extra credit offered as an incentive. Lower achieving students did, however, take part due to the fact they saw a need for extra credit. It can not be determined what impact, if any, this may have had on the results.

Though logistical and other considerations put limits on this study, future research might be aided by some changes in the methodology. First, a larger sample size using subjects and instructors from a greater cross-section of society would be beneficial to address the population sample limitations. Second, more time might be given to the constructivist group in order to allow them to assimilate and interpret the concepts they "construct" from the lab activities. Third, a more random sample of subjects should be used. This study had a logistical limitation on the randomness of the sample since the students were already enrolled in specific sections throughout the day. Since class schedules tend to follow abilities of students, it is normal to find one class section to be loaded with the highest achieving students while another section has some of the lowest achieving students. Though this study made an attempt to address this concern, there was no way to completely eliminate the effects of this problem.

Summary

This study does not show constructivist curricula to be any more or less effective than traditional curricula. The study does raise an important question concerning the implementation of constructivist curricula. It suggests that constructivist curricula may not be the "cure all" for providing deeper understanding of the subject matter. In addition, it suggests that constructivist curricula should perhaps apply to all units within a class instead of simply placing a constructivist unit in an otherwise traditional curriculum. Constructivism is a new learning paradigm to which not only the instructor must adapt, but the student must have time to adapt as well.

The use of a constructivst curriculum requires much consideration before it can be implemented. First, it will require a great deal of training and retraining for the instructor since most instructors likely teach the way they were taught. Obviously, that instructional style is teacher-centered and lecture-oriented. In order for teachers to change to a constructivist instructional method, the schools and colleges must provide preservice, inservice, and workshop opportunities that allow teachers to retrain themselves. In addition, future teachers must be oriented to various teaching methods. Though most colleges do provide methods classes for this type of training, many college courses are taught with more traditional methods. Again, future teachers will normally teach in the same manner they were taught.

No curricular method can be the solution for every student's needs, all educators must become familiar with various teaching methods and must retrain themselves to become effective at implementing different instructional styles in order to reach the many different learning styles possessed by the students of this nation. Since this nation chooses to educate all citizens, the educational community continues on a quest to address the needs of all students. For some, traditional instructional methods work well and therefore should not be abandoned just because something new comes along. For some, newer instructional methods such as constructivism have merit, and should be worked into curricula wherever possible in order to reach the needs of students who may not receive full benefit from traditional instructional approaches and vice versa.

REFERENCES

Appleton, K. (1993). Using theory to guide practice: Teaching science from a constructivist perspective. School Science and Mathematics, 93 (5), 269-274.

Bodner, G. M. (1986). Constructivism: A theory of knowledge. Journal of Chemical Education, 63 (10), 873-878.

Carter, T.L. (1999, October). Focusing on learning. Science Teacher, 66, 44-47.

Gil-Perez, D. & Carrascosa, J. (1990). What to do about science misconceptions. Science Education, 74 (5), 531-540.

Hake, R. (1998, June). Interactive-engagement methods in introductory mechanics courses. Paper submitted to the potential new *Journal of Physics Education Research.* Retrieved March 25, 2001 from the World Wide Web: http://www.physics.indiana.edu/~sdi/IEM-2b.pdf

Hake, R. (1999, June). Analyzing Change/Gain Scores. Paper originally posted March 1999 at American Educational Research Associations Division D, Measurement and Research Methodology. Retrieved March 25, 2001 from the World Wide Web: http://www.physics.indiana.edu/~sdi/AnalyzingChange-Gain.pdf

Hand, B., & Treagust, D.F. (1991). Student achievement and science curriculum development using a constructive framework. School Science and Mathematics, 91 (4), 172-176.

Hestenes, D. (1996, August). Modeling methodology for physics teachers. Paper presented at the International Conference on Undergraduate Physics Education, College Park. Retrieved October 11, 1999 from the World Wide Web: http://modeling.la.asu.edu/modeling/ModMeth.html

Kamii, C. & Ewing, J. K. (1996). Basing teaching on Piaget's constructivism. Childhood Education, 72 (5), 260-264.

Kogut, L. S. (1996). Critical thinking in general chemistry. Journal of Chemical Education, 73 (3), 218-221.

Nakhieh, M. B. (1994). Chemical education research in the laboratory environment. Journal of Chemical Education, 71 (3), 201-205

Roth, W. M. (1994). Experimenting in a constructivist high school physics laboratory. Journal of Research in Science Teaching, 31 (2), 197-223

Saunders, W. L. (1992). The constructivist perspective: Implications and teaching strategies for science. School Science and Mathematics, 92 (3), 136-141.

Shymansky, J. A., Yore, L. D., Treagust, D. F., Theile, R. B., Harrison, A. Waldrip, B.G., Stocklmayer, S. M., & Vanville, G. (1997). Examining the construction process: A study of changes in level10 students' understanding of classical mechanics. Journal of Research in Science Teaching, 34 (6), 571-593.

Thijs, G. D. (1992). Evaluation of an introductory course on "force" considering students' preconceptions. Science Education, 76 (2), 155-174.

Wells, M., Hestenes, D., & Swackhamer, G. (1995). A modeling method for high school physics instruction. American Journal of Physics, 63 (7), 606-619.

Yerrick, R. K., Pedersen, J. E., & Arnason, J. (1998). "We're just spectators": A case study of science teaching, epistemology, and classroom management. Science Education, 82 (6), 619-648.

APPENDIX A

Research Participation Consent Letter

Please read this consent form thoroughly. Consent must be given by both the student and the students' parent(s). If you have any questions please contact Brad Cline and he will answer the question.

You are invited to participate in a research study which will investigate the use of an alternative instructional method for the unit on the gas laws in your Chemistry I class. At the beginning of the unit you will be asked to take a pretest. You will then be taught with one of two different instructional methods during a two-to-three week period. You will then be asked to take a posttest. The pretest and posttest will not be used in the calculation of your grade. Your grade will be assessed with a standard class test after the research period has concluded. You can be assured that you will receive the same minimum required amount of instruction regardless of the instructional method you receive.

All information obtained in this research study will be completely confidential. You will only be identified by a code number. Your name will only be used to indicate that you participated in the study.

Your participation in this study is completely voluntary. If you wish to cease your participation in the study, you may do so at any time during the study. Termination of your participation will have no effect on your class grades. There is no risk to you or your grades for participating in and completing this study. You will however, still be required to participate in the class and will still be required to complete your homework, lab activities, and take the class test which will be given after completion of the study and the research posttest. Essentially, the only difference is that you will not be included in the research data and will not take the pretest and/or posttest.

If you have any questions or comments about this study, please contact Brad Cline at Goddard High School, PO Box 189, Goddard, Kansas 67052 Phone: (316) 794-4100 ext. 2808.

Thank you for your cooperation in this matter.

If you are willing to participate please read and sign the next page.

Research Participation Consent

I, ______________________, have read the information on the previous page and will
(please print name)
participate in this research study. I understand that my participation is completely voluntary and that I may remove myself from the research study at any time without any penalty.

______________________ ______________________
(signature of participant) (date)

I have read the information on the previous page and give my consent for my teen to participate in this research study. I understand that the information obtained will be completely confidential. I also understand that I may remove my teen from the research study at any time without penalty to his or her grade.

______________________ ______________________
(signature of parent or guardian) (date)

____
(signature of experimenter)

THIS PROJECT HAS BEEN REVIEWED BY THE EMPORIA STATE UNIVERSITY COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS.

THIS PROJECT HAS BEEN APPROVED BY THE U.S.D. 265 ADMINISTRATION FOR USE IN THE SPRING 2000 SEMESTER OF THE GODDARD HIGH SCHOOL CHEMISTRY I COURSE.

APPENDIX B
TESTING INSTRUMENT

HOUR: ________ **NAME:** ________________________

FILL IN THE BLANK WITH THE PROPER ANSWER. SHOW ALL MATHEMATICAL WORK. ANSWERS SHOULD INCLUDE PROPER UNITS AND SIGNIFICANT FIGURES. FOR MULTIPLE CHOICE ANSWERS CIRCLE THE ONE ANSWER WHICH BEST FITS THE QUESTION OR PHRASE.

---

1. The pressure of a gas in a sealed 400. Liter jar is 4.0 atmospheres with a temperature of 40. Kelvin. If the temperature of the jar is raised to 80. Kelvin, what will be the pressure of the gas in the jar? **(Show all work and label your answer with the correct units)**

Pressure = ________________

2 Figure 1 represents the two identical cylinders in different atmospheric conditions. The pictures represent a walled cylinder containing an ideal gas and have a movable piston inserted in them. Both cylinders contain the same amount of ideal gas. If the outside (barometric) pressure (P) was changed from 2.0 atmospheres (atm) to 6.0 atm. and the temperature for both figures remains at 25 Kelvin (K), what will be the volume (V) of the cylinder two? **(Show all work and label your answer with the correct units)**

Volume (Cylinder 2) = ______________________

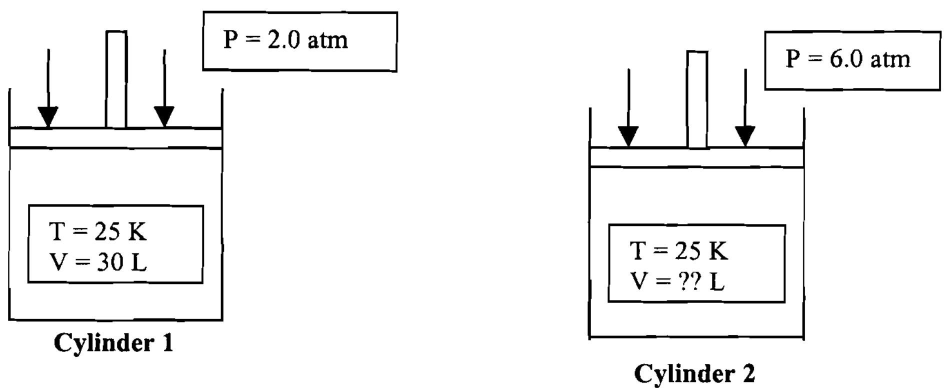


FIGURE 1

FIGURE 1 SHOWS TWO IDENTICAL CYLINDERS WITH A MOVABLE PISTON. BOTH CYLINDERS CONTAIN AN EQUAL AMOUNT OF AN IDEAL GAS WHICH IS AT A TEMPERATURE OF 25 KELVIN. THE FIRST CYLINDER HAS A GAS VOLUME OF 30. L WHILE THE SECOND HAS AN UNKNOWN VOLUME. THE FIRST CYLINDER IS SETTING IN A ROOM WITH AN ATOMOSPHERIC PRESSURE OF 2.0 ATMOSPHERES WHILE THE SECOND CYLINDER IS SETTING IN A ROOM WITH AN ATMOSPHERIC PRESSURE OF 6.0 ATMOSPHERES.

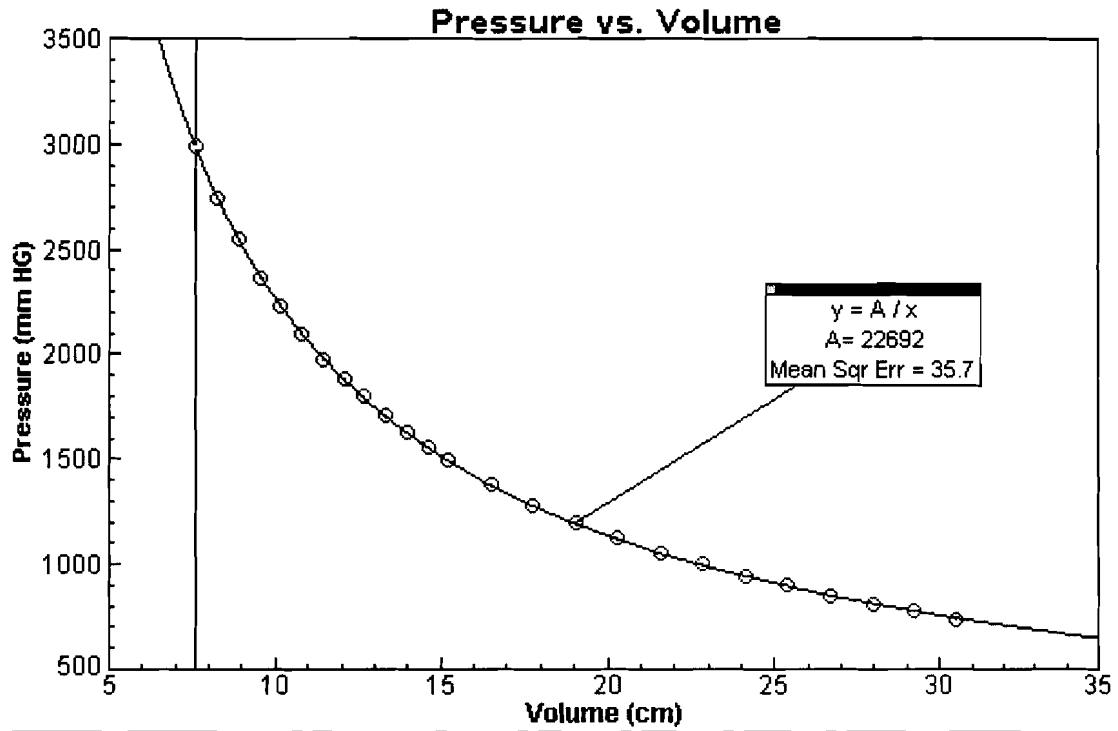


FIGURE 2

3. The graph in Figure 2 shows that when the pressure of a gas is increased from 5000 to 10,000 mm Hg, then the volume of the gas will ________________ by a factor of _______________.
(increase / decrease) (numerical factor)

4. The dependent variable for the data for the graph in Figure 2 is ________________ while the independent variable is ____________________.

5. The mathematical equation which represents the data for Figure 2 is: (circle one)
(a) V = kP (b) V = k/P (c) P = kV (d) P=k/V

6. The two identical cylinders in Figure 4 (below) have a movable piston. If the temperature of the cylinder in Figure 4 is changed to 12.5 Kelvin (K), as shown in figure 4, what will be the volume (V) of the gas in the cylinder? **(show all work and label your answer with the correct units)**

VOLUME = ____________________

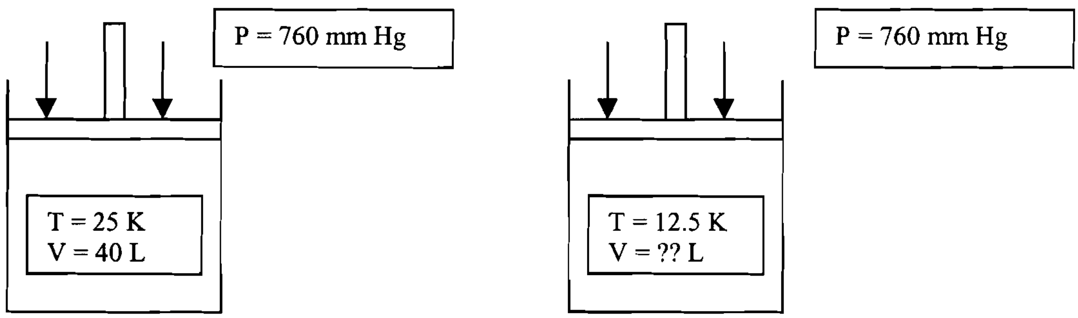


FIGURE 4

FIGURE 4 DEPICTS TWO IDENTICAL CYLINDERS WITH A MOVABLE PISTON. BOTH CYLINDERS ARE IN A ROOM WITH AN ATMOSPHERIC PRESSURE OF 760 mm Hg AND BOTH CYLINDERS CONTAIN AN EQUAL AMOUNT OF AN IDEAL GAS. THE FIRST CYLINDER HAS A TEMPERATURE OF 25 KELVIN WHILE THE SECOND HAS A TEMPERATURE OF 12.5 KELVIN. THE FIRST CYLINDER HAS A VOLUME OF 40 LITERS WHILE THE SECOND HAS AN UNKNOWN VOLUME.

TABLE 1

Row Num	Data Set 1: Data Temp (K)	Volume (mL)
1	136.50000	50.000
2	273.00000	100.000
3	546.00000	200.000
4		
5		
6		
7		
8		
9		
10		

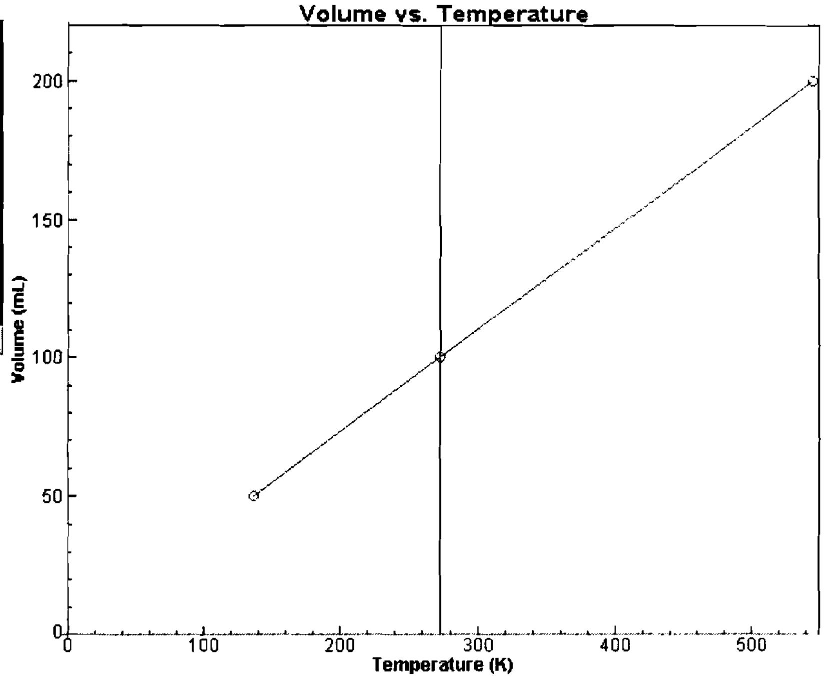


FIGURE 5

7. Table 1 and Figure 5 shows that the volume of a gas (at constant pressure) is ______________________ to the temperature of the gas. (circle one)

(a) directly proportional
(b) inversely proportional
(c) independent
(d) inversely squared

8. Using the data in Table 1 and graph in Figure 5, the volume of a gas at 700 K would be __________________.

9. Use the data table and graph in Figure 5 in answering this question. The volume of gas when the temperature is zero Kelvin would be: ____________________.

TABLE 2

Row Num	Data Set 1: Data Volume (L)	Mol (mol)
1	0.00	0.00
2	5.61	0.25
3	11.21	0.50
4	22.43	1.00
5	44.85	2.00
6		

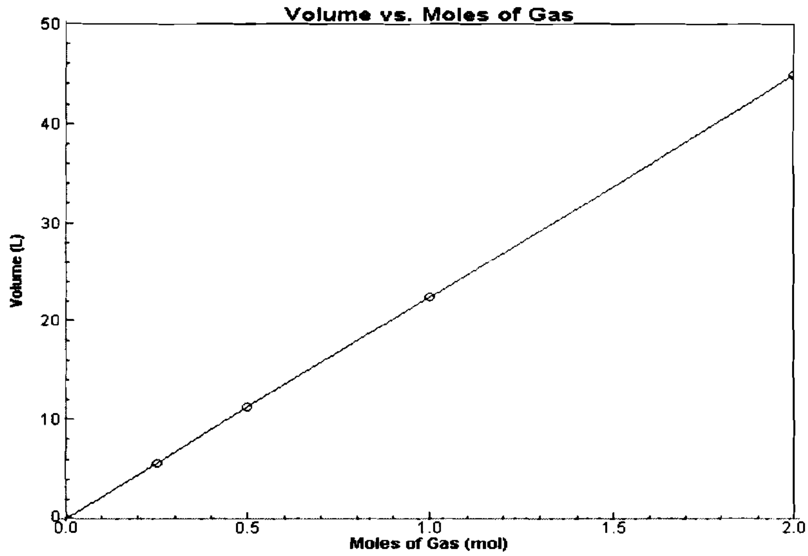


FIGURE 6

THE DATA SET IN TABLE 2 AND GRAPH IN FIGURE 6 DEPICT THE RELATIONSHIP BETWEEN THE NUMBER OF MOLES OF AN IDEAL GAS TO THE VOLUME THAT GAS WILL OCCUPY WHEN ALL OTHER VARIABLES REMAIN CONSTANT. QUESTIONS 10 – 14 REFER TO TABLE 2 AND FIGURE 6.

10. According to the data and graph in Figure 6, the volume of 6.022×10^{23} particles of any gas at standard temperature and pressure would be: ____________________

11. If the number of molecules of a gas at standard temperature and pressure were to triple, the volume of the gas would: ____________________

12. The correct mathematical model for the graph in Figure 6 would be. (V = Volume, n = number of moles, k = constant) **(circle one)**
(a) $V = k/n$ (b) $k = V/n$ (c) $n=kV$ (d) $V = kn$

13. If all other variables are kept constant for the gas depicted in Figure 6, what does the slope represent.
(a) some mathematical relationship which includes the pressure, volume, and temperature
(b) some mathematical relationship which includes the temperature and volume
(c) some mathematical relationship which includes the temperature and number of moles
(d) some mathematical relationship which includes the temperature and pressure

14. If 12.6 moles of an ideal gas occupies a volume of 282 Liters at standard temperature and standard pressure, how many moles of the ideal gas will occupy a volume of 45.6 Liters at the same temperature and pressure? **(show all work and label your answer with the correct units)**

Volume = ________________________

FOR QUESTIONS 15 – 20, SHOW ALL YOUR MATHEMATICAL WORK. INCLUDE PROPER SIGNIFICANT FIGURES AND UNITS WITH YOUR ANSWERS.

15. The volume of a sample of dry oxygen gas is 350 mL when its pressure is 720. mm Hg and its temperature is 258 K. Calculate the volume of the same sample of oxygen gas when the pressure is 645 mm Hg and the temperature is 258 K.

Volume = ____________________

16. The volume of an ideal gas is measured to be 160. mL at a temperature of 320. K and the pressure is 1.2 atm. Calculate the volume of the gas when the temperature is 273 K and the pressure is 1.2 atm.

Volume = ____________________

17. 390 mL of an ideal gas has a temperature of 429 K and a pressure of 729 mm Hg. Calculate the temperature of the gas when it's volume is 250. mL and it's pressure is 729 mm Hg.

Temperature = ________________

18. An ideal gas is contained in a 500. mL sealed glass jar. The original temperature of the gas is 298 K with a pressure of 0.98 atm. What will be the pressure of this gas when the temperature is increased to 387 K?

Pressure = ___________________

19. An ideal gas is contained in a 2.0 liter sealed glass jar. If the original pressure of the gas is 754 mm Hg and the original temperature of the gas is 45 K, what will be the temperature of the gas when the pressure is changed to 876 mm Hg?

Temperature = ______________

20. 2160. mL of an ideal gas is collected at a temperature of 242 K and a pressure of 660. mm Hg. Calculate the volume of the gas at 720. mm Hg pressure and a temperature of 308 K.

Volume = __________________

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APPENDIX C

APPLICATION FOR APPROVAL TO USE HUMAN SUBJECTS

For R&G Use Only	Date approved _______		
File No. ______	Full Review _______	Expedited Review _____	Exempted Review ______

This application should be submitted, along with the Informed Consent Document and supplemental material, to the Institutional Review Board for Treatment of Human Subjects, Research and Grants Center, Plumb Hall 313F, Campus Box 4003.

1. Name of Principal Investigator(s) (Individual(s) administering the procedures): **Bradley L. Cline**

2. Departmental Affiliation: **Department of Physical Sciences**

3. Person to whom notification should be sent: **Bradley L. Cline**

   Address: **10801 Haskell Circle; Wichita, KS 67209-3240** Telephone: **316-729-6717**

4. Title of Project: **A STUDY OF CONSTRUCTIVIST MATHEMATICAL MODELING FOR INSTRUCTION OF THE GAS LAWS IN A HIGH SCHOOL CHEMISTRY UNIT.**

5. Funding Agency (if applicable): **NA**

6. This is a dissertation ______ thesis **X** class project _______ other ________

7. Project Purpose(s): **This study will compare two different curriculum approaches for the instruction of the gas laws in an introductory high school chemistry course. The study will attempt to determine if a constructivist instructional approach gives the subjects an equal level of retention and understanding of the mathematical and conceptual principles governing the gas laws when compared to a more traditional textbook and lecture-oriented instructional approach.**

8. Describe the proposed subjects: *(age, sex, race, or other special characteristics, such as students in a specific class, etc.)* The subjects will consist of high **school students in a midwestern city-suburban public school system. The study will include approximately 100 students divided among six individual class sections taught by two different instructors. Each class will have an average of 18 subjects with a minimum of 15 and maximum of 21. The classes consist of approximately 65% female subjects and 35% male. The majority of the subjects are white with approximately 8% minority subjects. All subjects will be enrolled in a first-year high school chemistry class.**

9. Describe how the subjects are to be selected: **All subjects will be selected by class section. All subjects within a class section will receive one of the two instructional methods. Class sections will be assigned randomly.**

10. Describe the proposed procedures in the project. Any proposed experimental activities that are included in evaluation, research, development, demonstration, instruction, study, treatments, debriefing, questionnaires, and similar projects must be described here. **Copies of questionnaires, survey instruments, or tests should be attached.** *(Use additional page if necessary.)*
    (SEE ATTACHED SHEET)

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11. Will questionnaires, tests, or related research instruments not explained in question #10 be used?
_____ Yes __X__ No *(If yes, attach a copy to this application.)*

12. Will electrical or mechanical devices be applied to the subjects? _____ Yes __X__ No *(If yes, attach a detailed description of the device(s) used and precautions and safeguards that will be taken.)*

13. Do the benefits of the research outweigh the risks to human subjects? __X__ Yes _____ No (If *no, this information should be outlined here.)*

14. Are there any possible emergencies which might arise in utilization of human subjects in this project?
__X__ Yes _____ No *(If yes, details of these emergencies should be provided here.)*
All science lab settings have inherent risks. The labs that the subjects will perform will utilize hot plates and/or Bunsen burners. Therefore, the subjects are at risk for burn injury. In addition, the subjects could be at risk from broken glassware. These risks would be present in the normal high school class setting and are not an additional hazard that has been added because of this research. All subjects will be required to wear proper safety equipment and eye protection and will be under the guidelines of school district policies concerning proper lab safety.

15. What provisions will you take for keeping research data private? *(Be specific.)*
All names of the subjects will be enciphered so that only the principal investigator will know the owner of the testing instrument. Identification codes and all data (written or electronic) for each subject will be kept in a secure place which will be inaccessible to anybody except the principal investigator. Only mean test scores of the two groups will be published in the research. All hard copy and electronically stored data which can identify the work of an individual subject will be destroyed at the conclusion of the project. In addition, no personal information will be solicited from any subject. The testing instrument will only determine the subject's understanding of the material taught.

16. **Attach a copy of the informed consent document as it will be used for your subjects.**

STATEMENT OF AGREEMENT: I have acquainted myself with the Federal Regulations and University policy regarding the use of human subjects in research and related activities and will conduct this project in accordance
with those requirements. Any changes in procedures will be cleared through the Institutional Review Board for Treatment of Human Subjects.

______________________________ ______________________
Signature of Principal Investigator Date

______________________________ ______________________
Faculty advisor/instructor on project (if applicable) Date

10.

This study will attempt to assess the level of student understanding between two groups of high school students enrolled in a first-year high school chemistry course. One group will be taught the gas laws using a more traditional, lecture-oriented textbook approach while the other group will learn the gas laws through a constructivist mathematical modeling cycle.

The traditional approach will begin with a more lecture-oriented instructional setting in which the instructor will present the students with the mathematical and conceptual principles of the gas laws. The subjects will follow up the instruction with problem sets from the textbook intended to reinforce the theoretical principles of the gas laws. The subjects will then be given labs that will allow the student to reinforce the gas laws by graphing the data collected. These labs will be commercially made with written, step-by-step procedures for the students to follow. The subjects will present their lab results for a class discussion.

The constructivist approach will begin with the instructor questioning the subjects about the variables involved to and to determine the proper methods for measurements of the gas variables. The subjects will then be asked to design lab procedures to the mathematical relationships of the variables. The instructor will guide the subjects in the proper direction, but the subject will design the procedure for the lab. After the data is collected and graphed, the subjects will present their results to the class and through discussion the mathematical principles for each of the gas laws will be derived from the lab results. Following the labs, homework will be assigned to reinforce the mathematical and conceptual principles derived from the lab work.

The instructional cycle will take approximately two-to-three weeks. The subjects will take a pretest before instruction of the gas laws begins and will take a posttest at the conclusion of the instructional cycle. The pretest and posttest will be the same and will be designed to assess the subjects understanding of the mathematical and conceptual principles that govern the gas laws. The mean test scores of each group will be used for analysis. A comparison of the improvement in the mean test scores will be used to determine if both instructional methods allowed for an equal understanding of the mathematical and conceptual principles governing the gas laws.

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04/02/01

Date

The Study of Constructivist Mathematical Modeling for Instruction of the Gas Laws in a High School Chemistry Course

Title of Thesis

Signature of Graduate Office Staff

May 2, 2001

Date Received

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