ABQ 4977

Science and Mathematics Education Centre

The Effects of Constructivism and Chaos on Assessment in a High School Chemistry Classroom

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This thesis is presented as a part of the requirements for
the award of the Degree of Doctor of Science Education
of the
Curtin University of Technology

July, 1997

CONTENTS

Abstract

This study comprises three parts. First, to validate the Oral Individualized Classroom Environment Questionnaire (OICEQ) which is used to assess students' perceptions of the learning environment in secondary chemistry classes in the U.S.A. The OICEQ is a modified version of the actual and preferred versions of the Individualized Classroom Environment Questionnaire (ICEQ) (Fraser, 1990). Second, to investigate associations between three types of science educational assessments; predictors of performance, perceptions of the classroom environment, and chemistry academic performance. Third, to address the following two questions:

1. Are chaos and constructivism allies or adversaries to assessments (predictors, perceptions, and performance)?
2. Is action research a valid process of evaluating a constructivist chemistry classroom (examining associations between chaos and constructivism)?

A sample of 473 students from 21 chemistry classes took the Test of Logical Thinking (TOLT), the Myers-Briggs Type Indicator (MBTI), the Individualized Classroom Environment Questionnaire (ICEQ), the Oral Individualized Classroom Environment Questionnaire (OICEQ), pretests, post-tests, and final examinations. The statistical analyses confirmed the reliability and validity of the OICEQ and ICEQ when used with senior chemistry students. Investigation of associations between predictors, perceptions, and performances revealed 29 significant associations with the OICEQ and 21 significant associations with the ICEQ. Findings from the study indicated that: (1) chaos is an adversary to social assessment and personal constructivism is an ally to personal assessment; (2) action research is a valid process for evaluating a constructivist chemistry classroom -- it is a unifying concept for constructivism, chaos, and assessment; (3) through an action research-constructivist process and a cyberchaos research perspective, the impact of a constructivist teaching paradigm and chaos distort the assessment of data in a chemistry classroom.

Acknowledgements

I would like to acknowledge the following people, all of whom helped significantly in the preparation and writing of this thesis:

Darrell Fisher, "The Wizard of Auz", Associate Professor, Science and Mathematics Centre, Curtin University of Technology, your supervision and mentorship have been phenomenal. You have made this an everlasting experience.

Barry Fraser, Professor of Education and Director, Science and Mathematics Centre, Curtin University of Technology, who directs the SMEC centre with vision, imagination, and proficiency.

Angie (A.K.A.), my mental, physical, and spiritual partner who by chance happens to be my wife. Your passion, persistence, and patience have been compelling and inspirational. Completing this challenge together replicates other journeys and adventures we share, as one. The excitement of our existence is our bond.

Margaret and Bill, my alpha associates and role models. It is not what I know that is rewarding, it is where I learned that is paramount. I have learned from the heights of mountains and the depths of the seas when I learn from you.

Ken and J.R., my linear activists and disciples of direction. Dedication and discipline have been the codes you have translated for me in my professional and social essence. I will always cherish what you have given.

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Chapter 1

Introduction

This study focuses on secondary chemistry classroom environments in Maize, Kansas, USA. The chemistry courses (grades 11-12) utilized in this study are nine months in duration (September-May) and are constructivist in nature. The primary focus of learning is project-oriented and discovery-based with emphasis on the solving of chemistry-related problems. This involves the identification and interpretation of chemical processes rather than the memorization of an extensive body of information and facts and accessing, researching, analyzing, and predicting (A.R.A.P.) chemical information.

Predictors of performance (achievement), perceptions of the classroom environment, and performance outcomes are the types of assessment instruments utilized in this research study. The associations between the variables assessed by these instruments are the focus of this study, along with the relationship of chaos to the assessment of learning in this constructivist chemistry classroom in the USA. Action research (McTaggart, 1991) is the method of research adopted and the chemistry classroom teacher is the primary researcher.

1.1 Background to the Study

The constructivist movement is becoming a predominant educational paradigm and epistemology in the United States of America. The high school system in the USA is generally structured for students in grades 9 through 12. Students are usually required to take at least two credits of science; one physical science and one biological science. In most high schools, chemistry is an elective course offered to students during grade 11.

Constructivism is the notion that learners actively construct knowledge through their own interpretation of events (O'Loughlin, 1992), a form of pragmatism promoting the belief that knowledge and truth exist as a form of reality (Von Glasersfeld, 1989). Constructivism has been classified into five subcategories: cognitive constructivism, radical constructivism, critical constructivism, personal constructivism, and social constructivism. The two latter forms are emphasized in this study.

Along with the injection of constructivist teaching strategies into the educational system, alternate assessment strategies are becoming a factor worthy of investigation, review, and evaluation. In the area of chemistry, the constructivist movement has implications for classroom presentation strategies, teacher demonstrations, student laboratories, student-developed laboratories, student research, concept-flow charting (mapping), and the assessment of each of these areas. The impact of constructivism provides a potential for innovative change in education. Thus, the need to research and evaluate the components of constructivism and the effects of internal and external forces (chaos) on the assessment of learning is essential.

Chaos is a term currently used among the scientific community to describe a system in which small changes in initial conditions can have a significant and unpredictable effect on the eventual outcome (Lampton, 1992). Chaos is the search for order within apparent randomness (Chenery, 1991). Those who use the terms "chaos" and "entropy" synonymously are in error; their meanings are not interchangeable. The term "chaos" will be used when addressing the *condition* of disorder and the term "entropy" will be used when addressing the *measurement* of the disorder. The predisposition of thought is that chaos has an omnipresent effect on the systems in our surroundings. The system in this study is the chemistry classroom environment. The chemistry classroom environment, a cybernetic system, must be impacted to a certain magnitude by chaos.

An assessment is any standard (measurement) of comparison, appraisal, or judgment of value. Educational assessment involves traditional pencil and paper tests, skill performance, oral interviews, and a portfolio culture (Duschl & Gitomar, 1991) that places a major emphasis on students evaluating their own conceptual development. In education, the primary focus is on the evaluation, interpretation, and analysis of assessment data for the purpose of making predictions regarding learning. Measuring knowledge constructs is a difficult, and often inaccurate, endeavor. Capturing and measuring knowledge constructs created through personal and social constructivist frameworks is a formidable (perhaps insurmountable) task.

The measures of predictors of student performance used are the *Test of Logical Thinking (TOLT)* developed by Tobin and Capie (1982) and an adaptation of the *Myers-Briggs Type Indicator (MBTI)* (Myers & McCaulley, 1985), *True Colors* (Kalil & Lowry, 1989).

The Test of Logical Thinking (TOLT) is a paper and pencil instrument which evaluates logical thinking (Tobin & Capie, 1981). The TOLT has been shown to be a good predictor of chemistry achievement (performance). The test draws direct correlations between science process skill and formal thinking abilities (Padilla, Okey, & Dillashaw, 1983). The proportional reasoning items are the best predictors on the test (Tobin & Capie, 1982).

Another predictor of student performance, the True Colors personality profile test, an adaptation of the MBTI, has research data that shows a strong correlation between that reported by the MBTI, as well as Dr. David Keirsey (1984) and his temperament theory model. Whereas the MBTI states that human behavior is quite orderly and can be characterized by 16 different personality types, the True Colors personality profile test utilizes four categories. In temperament language (Keirsey, 1984) the four categories are: *Intuitive-Feeling* =

Blue color, *Intuitive-Thinking* = Green color, *Sensing-Judgment* = Gold color, *Sensing-Perception* = Orange color.

Traditionally, research and evaluation in science education have relied heavily, and sometimes exclusively, on assessment, academic performance, and other learning outcomes (Fraser, 1994). However, educational research has made remarkable progress over the last two decades in studies involving classroom environments (Fraser, 1993). Science education researchers have been leaders in developing, validating, and applying assessment instruments to measure classroom outcomes. Research on environments usually assumes that students, curricula, and other internal and external factors, as well as the teacher, affect the learning environment. Research of this type attempts to study the relations among environmental factors and other variables as they occur. This study will enhance previous classroom environment research by including assessments that encompass predictors of performance, students' perceptions of the environment, and academic performance outcomes in senior chemistry classrooms in the USA.

The focus of learning environment research, since the development of the *Learning Environment Inventory (LEI)* (Anderson & Walberg, 1968), has been the investigation of the qualities of the learning environment from the perspective of the student. Recent classroom environment research studies have examined differences between school and class environments (Fisher & Fraser, 1991), student motivation (Lens, 1994), student performance (Gottfredson, Marciniak, Birdseye, Gottfredson, 1995), assessment (McNamara & Jolly, 1995), and constructivist classroom environments (Taylor, Dawson, & Fraser, 1995).

In this study, two classroom environment instruments are utilized, the *Oral Individualized Classroom Environment Questionnaire (OICEQ)*, which is a modified version of the *Individualised Classroom Environment Questionnaire (ICEQ)*. The OICEQ was developed and validated in order to provide a more complete picture of the learning environment in the classes. Many classroom environment research instruments, such as the OICEQ, usually have two versions, an "actual" version and a "preferred" version. While responding to the actual version, students provide information about the classroom environment as they actually perceive it. While responding to the preferred version, students provide information about the classroom environment as they ideally or preferably perceive it. Research studies have implied that an increased consonance between students' actual and preferred environments could enhance student performance outcomes (Fraser, 1994; Fraser & Fisher, 1983b). Teachers that compare the results of the actual environment to the preferred environment are provided an opportunity to modify the classroom environment so that the actual and preferred environments are in alignment. Research studies continue to explore the association between the learning environment and student performance (Moriarty, Douglas, Punch, & Hattie, 1995). An investigation of student perceptions of their classroom environment can be considered a worthy endeavor in its own right, however, the inclusion of constructivism and chaos provides a particular significance for this study.

Teacher-developed tests, the most widely used tests for measurement of learning in the classroom, and possibly the most valid tests, will be the instruments used to measure chemistry achievement. In the USA, students are required to take nationally standardized achievement tests such as the *SAT* (*Scholastic Aptitude Test*) and the *ACT* (*American College Test*) as entrance requirements into American universities. The chemistry pretest and posttest and the final examination used in this study are modeled after the SAT and the ACT in basic structure and content.

Action research is a significant introspective means of evaluating and improving teaching and learning and in this study, the classroom teacher was the primary researcher. Action research is a deliberate, solution-oriented investigation that is group or personally owned and conducted (Kemmis & McTaggart, 1988). It has been employed for various purposes, such as: school-based curriculum development; a professional development strategy; graduate courses in education; and systems planning and policy development. Some writers (i.e., Holly & Southworth, 1990; Jacullo-Noto, 1992; Lieberman, 1988; Oja & Pine, 1989; Sagor, 1992) advocate an action research approach for school restructuring. It can be used as an evaluative tool, which can assist in self-evaluation whether the "self" is an individual or an institution. In the classroom, action research offers an opportunity for teachers to not only share information with the educational research community, but also familiarize their students with many important but subtle aspects of classroom life (Brause & Mayher, 1991). If organized in appropriate ways, discussion of results attained via action research can provide worthwhile stimuli for teachers to reflect seriously about their classrooms and to plan actions that will lead to the improvement of classroom environments.

The study was designed to extend previous research by examining associations between chaos and constructivism. The objectives of the study are:

1. To develop and validate the Oral Individualized Classroom Environment Questionnaire (OICEQ) for chemistry classroom settings in the USA secondary school (The OICEQ is an adaptation of the ICEQ).

2. To investigate associations between predictors of student achievement, student perceptions of learning environment, and academic performance of students in a chemistry classroom.

3. To investigate the relationship of chaos with assessment in a constructivist chemistry classroom environment.

4. To provide a self-reflection on the validity of an action research process examining associations between chaos and constructivism in a constructivist chemistry classroom environment.

The following sections of this chapter explain the significance of the study, present the research questions to be addressed, and provide an overview of the thesis.

1.2 Significance of the Study

Teachers in the United States will benefit from self-research in the science classroom environment -- an avenue of evaluating and improving teaching. Action research is such an avenue of self-research and self-evaluation. Sometimes referred to as "teacher-as-researcher," action research is a significant method of self-evaluation in a science classroom environment. Action research tries out ideas in practice as a means of increasing knowledge about and/or improving curriculum, teaching, and learning (Kemmis & McTaggart, 1988). Action research can be used as an evaluative tool, which can assist in self-evaluation whether the "self" is an individual or an institution. This particular study is individually owned. The method and subsequent results may have primary significance to the teacher/researcher.

Teachers in the United States will benefit from knowing how their students actually perceive their classrooms as well as what they would prefer them to be like, from a teacher-as-researcher standpoint. In the same way, chemistry teachers need to know how their students perceive the totality of the chemistry classroom environment. Utilizing action research, chemistry instructors will have a vehicle for self-generating valuable educational data that will assist in identifying determinants relevant to teaching and learning in the chemistry classroom.

Action research is a valuable form of constructivist teaching that can assist chemistry teachers in assessing the relationships between what students perceive and prefer in a chemistry classroom and potentially why they have particular perceptions and preferences. This will assist science educators in overcoming the socio-cultural constraints that work in concert to counter the development of constructivist learning environments (Taylor 1992, 1993, 1994). Hence, this calls for research in the areas of chemistry classroom environments, constructivism, chaos, and assessment. Research that draws a correlation between these aspects is lacking in the United States. Therefore, this study is most timely and essential.

The findings from this study will:

1. help chemistry teachers teach more efficiently and effectively;
2. suggest ways of improving student learning in the chemistry classroom; and
3. provide teachers in the USA with a valuable tool for assessing their chemistry classroom environments, with a view to improving them.

From a constructivist standpoint, action research will in turn help the students of the classes improve their own learning. In a highly competitive and performance-oriented culture such as the United States, this is of significant consequence. Via action research, teachers achieve an intrinsic ownership that will encourage them to make the necessary changes to their classrooms which will help create a more supportive environment for learning. Self-evaluation in a chemistry classroom will provide teachers who practice action research and their students with insight to learning when taking into account constructivism, assessment, and chaos.

This is a uniquely comprehensive study of secondary chemistry learning environments because of the use of the OICEQ, a modified version of the ICEQ, to assist in the examination of associations between chaos and constructivism and the exploration of the relationship of chaos to assessment.

1.3 Research Questions

As previously indicated, constructivism, chaos, and assessments are the central focus of this study. Validating the OICEQ and examining associations between the three types of educational assessments, predictors, perceptions, and performance, are methods of action research that will be employed to conduct the study. The TOLT and MBTI tests will serve as predictors (BouJaoude, 1995; Tucker, 1993; Baker, 1985; Tobin & Capie, 1981) of performance. The OICEQ and the ICEQ will assess students' perceptions of the classroom environment. Chemistry pretests and posttests (gain score) and a chemistry final examination will be the instruments used to determine student performance outcomes. Because this is the first study to examine the associations mentioned in this chapter (chaos, constructivism, and assessment) along with action research as the method of study, the following two research questions were designed and developed from the objectives mentioned in section 1.1.

Research Question #1:

Are chaos and constructivism allies or adversaries to assessments (predictors, perceptions, and performance)? (objective #3)

Research Question #2:

Is action research a valid process of evaluating a constructivist chemistry classroom (examining associations between chaos and constructivism)? (objective #4)

1.4 Overview of this Thesis

Chapter One has described the significance and background information necessary to place the study in appropriate context. Chapter Two contains a review of the literature discussing research involving the topics of constructivism, chaos, and assessment. Particular attention will be devoted to examining research studies involving chaos and constructivism while also investigating the relationship of assessment to a constructivist perspective.

In Chapter Three, the instrumentation and methodology will be discussed. The development of the classroom environment instrument used in this study, the Oral Individualized Classroom Environment Questionnaire (OICEQ), is described in this chapter. Previous research studies involving the ICEQ, Test of Logical Thinking (TOLT), Myers-Briggs Type Indicator (MBTI), pretest and posttest, and final examination will be provided. The research methodology will utilize a constructivist chemistry teacher as the action researcher. Details are given concerning the design, collection, and analysis of data collected from the three types of educational assessments: predictors, perceptions, and performance.

Chapter Four is a presentation of the validation, reliability, and descriptive information regarding the data collected in the study.

Chapter Five discusses associations between predictors of student performance, students' perceptions of the classroom environment, and student performance outcomes. Additionally, analysis of the data collected will be submitted along with an action researcher's self-reflection of the results.

Chapter Six describes conclusions from the study. Major findings of the study are discussed with reference to the research questions proposed in this chapter, and implications for teachers of these findings are suggested. The limitations of the study and suggestions for future research are also considered in Chapter Six.

Chapter 2

Literature Review

2.1 Introduction

This chapter focuses on a review of the literature involving the topics of constructivism, chaos, and assessment from an action research perspective of learning environments in science education. The literature review revealed that past research studies have used the topic of chaos when discussing educational research, but no previous research has identified or examined associations between chaos, constructivism, and classroom learning environments. Also, only three research articles were located that discussed the topics of chaos and constructivism concurrently. Therefore, from an action research standpoint (teachers conducting classroom research), there is value in examining associations among chaos, constructivism, and assessment in classroom environments.

The extensive literature search that was conducted did not uncover or reveal any associations encompassing all three topics of constructivism, chaos, and assessment under the headings of education, science, or science education. Therefore, in this chapter, each one of the topics (chaos, constructivism, and assessment) will be discussed individually and independently of each other rather than concurrently or as collective associations. The lack of previous research further advocates the singularity (uniqueness) and importance for research of this origin.

Of the studies reviewed, none addressed associations between constructivism and chaos. In research studies reviewed, chaos was not part of, or involved in the actual study. Instead, it was a term used merely as a descriptor. Many of the studies in science education used the term "chaos" in this fashion.

The review of literature on assessment covered the area of science assessment generally rather than being confined to chemistry. Studies have been conducted that involve assessment of learning environments, cognitive ability, aptitudes, and attitudes and their various associations. However, as mentioned in Chapter One, and in the Introduction to this chapter, this research study is unique in that it will focus on a holistic form of assessment, predictors of achievement, perceptions of environment, and performance (achievement) outcomes in chemistry. Therefore, the approach to the review of the literature will emphasize assessment with an action research approach.

Few studies involved the topics of "constructivist assessment." When "constructivist assessment" was identified in the study it was generally in relationship to assessment reform in education (and science education) due to the onset of the constructivist epistemology. Few, if any, studies dealt with personal constructivist assessment or social constructivist assessment. A small number of studies involved pretest, posttest, and final examinations. No research studies have specifically examined predictors of achievement in science education. Also, there were no assessment studies reviewed which encompassed all three areas of assessment used in this research study: predictors of achievement, perceptions of learning environments, and academic performance.

The body of Chapter Two consists of these five sections: 2.2 Classroom Environments, 2.3 Constructivism, 2.4 Chaos/Entropy, 2.5 Assessment, and 2.6 Chapter Summary.

2.2 Classroom Environments in Science Education

The intended approach of this study is to define classroom environment in terms of the shared perceptions of the students and the teacher in that environment. This has a twofold advantage of characterizing the class through the eyes of the actual participants and capturing data which an external observer could miss or consider unimportant. Students and teachers are at a vantage point to make judgments about classrooms because they have encountered many different learning environments and spend adequate time in class to form accurate impressions. Recent studies encourage learning environment research that takes into account a post-positivist view of thinking and a critical perspective (Lorsbach & Tobin, 1995) in an effort to transform science classroom learning environments. Positivism is a philosophical movement characterized by an emphasis upon science and the scientific method as the only sources of knowledge. Positivists regard measurements as the quintessential means through which reality, whatever it may be, can be represented (Eisner, 1992). Post-positivism is a movement toward application of rigorous analytical tools, qualitative as well as quantitative research, to assist in answering normative questions. Examples of qualitative research methods are action research, case study research, and ethnography. For now, post-positivistic educational thought is focused on normative issues. Post-positivist philosophies promote the thought that knowledge is constructed within communities of like-minded people rather than by objective, experimental methods.

Classroom environment research has spanned a period of more than a quarter of a century. Rudolf Moos and Herbert Walberg have initiated much of the educational environment research during this time period. The large amount of research which has been conducted since then has been well documented: books by Fraser and Walberg (1991), constructivist classrooms (Taylor, Dawson, & Fraser, 1995), computer-assisted instructional settings (Teh & Fraser, 1995), individualized classrooms (Fraser, 1990), and student outcomes and learning environments (Henderson, Fisher, & Fraser, 1994).

There are three common approaches to studying classroom environments (Fraser, 1991). One method involves direct observation of events taking place in the classroom by an external observer. A second method uses the case study approach whereby the techniques of naturalistic inquiry and ethnography are applied. The third involves assessing the perceptions of the student and the teacher using a questionnaire. The latter method has the advantage of being less expensive, more objective, and being appropriate for use with a larger population at any one time (that is, not restricted to a small number of classes).

Classroom environment instruments have been used as tools for analyzing and predicting criterion variables in a medley of research studies conducted in schools around the world. Many instruments for assessing classroom environments have evolved through the years. The commonly used instruments are the *Learning Environment Inventory* (LEI) (Anderson, 1973), *Classroom Environment Scales* (CES) (Moos & Trickett, 1974), *Individualized Classroom Environment Questionnaire* (ICEQ) (Fraser, 1990), *My Classroom Inventory* (MCI) (Anderson, 1973), the *Science Laboratory Environment Inventory* (SLEI) (Fraser, Giddings, & McRobbie, 1992), and the *Constructivist Learning Environment Survey* (CLES) (Fraser & Taylor, 1990). These instruments are reliable and have been extensively field-tested (Fraser, 1993). They can be conveniently administered to a group and scored by hand or computer.

There has been a significant amount of research compiled that explores the associations between students' cognitive and affective learning outcomes and their perceptions of their classrooms (Huang & Waxman, 1994). The findings from these studies tend to imply that student outcomes can be improved by creating more conducive environments for learning (Fraser, 1992).

An area of interest in classroom environment research is in the differences between students' and teachers' perceptions of actual and preferred environments. The findings from these studies indicated that teachers generally perceived their classrooms more positively than their students. They also showed that students would like to have a more positive learning environment than is actually present (Fraser, 1992).

For the purpose of this study, the Individualized Classroom Environment Questionnaire (ICEQ) will also be used as an instrument to be administered orally. There will be an oral reader of the written ICEQ, a recorder, and a scale translator of the oral answers. The Oral Individualized Classroom Environment Questionnaire (OICEQ) instrument, as it is applied to chemistry classroom settings, will be designed for use in the USA secondary school. The OICEQ is an adaptation of the ICEQ.

2.3 Constructivism in Science Education

2.3.1 Introduction

Constructivism is a supposition that learners actively construct knowledge through their own interpretation of events (O'Loughlin, 1992). Constructivism is divided into five subcategories: cognitive constructivism, radical constructivism, critical constructivism, personal constructivism, and social constructivism. This literature review will encompass studies of the constructivist *science* paradigm, particularly chemistry, which consists of teaching strategies, methodologies, epistemologies, and philosophies in science education. Constructivist science builds on the observation that scientific knowledge is constructed (Louden & Wallace, 1990) by men and women. The general concept of constructivism will be presented in this section of Chapter Two. Emphasis will be placed on the two subcategories of constructivism -- personal constructivism and social constructivism.

Constructivist science is emerging as a new strategy for teaching. Proponents of constructivist science suggest that school science begins with a student's own construction of reality (Louden & Wallace, 1990). From a constructivist perspective, learning is viewed as the active construction of knowledge in gradually expanding networks of ideas through interactions with others and materials in the environment (Marshall, 1992). The goal of science teaching might be to develop individuals who think for themselves (Newbrough, 1995). Such people have some measure of control over the meaning they make of their experiences and of the ways in which they construct their lives and ideas. Constructivism places primary emphasis on the independence of each person's interpretation of his or her own experience (Roth, 1994). Constructivism is a tool (say a lens) for looking at learning processes in science. Like any tool it draws attention to certain features (for example, prior knowledge) at the expense of directing away attention from other features (chaotic social processes in the classroom, teacher realities) (Van den Berg, 1994).

Constructivism promotes the thought that learners construct knowledge through their experiences. Constructivism is a form of pragmatism--a concept that learning is an endeavor that explores knowledge and truth (Von Glasersfeld, 1989). Some of the general premises of constructivism are as follows:

1. The mind is not a tabula rasa (Fensham, Osborne & Gilbert, 1982).
2. Knowledge is not simply recorded and memorized (Van den Berg, 1994).
3. Knowledge is constructed by the learner based upon personal experiences, beliefs, and pre-existing mental structures (Ernest, 1993).
4. To know something requires receiving information, interpreting it, and relating it to other knowledge (Dean, 1993).
5. The teacher is no longer the active transmitter of knowledge (Van den Berg, 1994).
6. The student is no longer the passive receiver of knowledge (Van den Berg, 1994).
7. Knowledge is dialectical and interactional (Van den Berg, 1994).
8. Knowledge is the tentative and relative result of the learner's own actions (Driver, 1990).
9. Knowledge consists of "conceptual constructs" (Suchting, 1992).

Research has provided evidence that cognitive conflict is an important view of teaching and learning (Case, 1993). To respond to conflict, when seen from a constructivist perspective, learners themselves recognize the conflict, evaluate the relative merits of the conflicting views, and decide to undertake any reconstruction of personal ideas and beliefs (Dean, 1993). Recognition that many learners hold views of teaching and learning which are strongly transmissive, and hence quite antagonistic to constructivist approaches (Cobern; et al., 1995), was an early indicator of the intertwined nature of constructivism and metacognition.

The implications for classroom teaching and learning are widespread. Mitchell and Baird (1986) considered the interaction between science content and constructivist learning, drawing upon substantial classroom research and development. Their central proposition focuses on the discussion that it is desirable to move students' views toward those of scientists. Mitchell and Baird's research promotes the thought that it is more difficult to generate active learning, hence, conceptual change, in theoretical science topics than in those where Scientists' Science can be reached by a process of cognitive conflict.

Constructivist research has identified the need for an educational viewpoint that focuses on the internal, active changes occurring within the student (Swicegood & Linehan, 1995). Science education researchers have developed a learning environment instrument that will assist researchers in assessing the degree to which a particular classroom's environment is consistent with a constructivist epistemology (Fraser & Fisher, 1994). Such an instrument will provide a means of assessment for teachers to reflect upon their epistemological assumptions and reshape their teaching practices. A shift to learning environment assessment serves to reestablish connections with applied cognitive development (Russell, 1990). Therefore, the Constructivist Learning Environment Survey (CLES) was developed to meet this need and to assess the five scales of Personal Relevance, Critical Voice, Shared Control, Uncertainty, and Student Negotiations (Taylor, Dawson, & Fraser, 1995b). The CLES comes in four forms: *Student Perceived*, *Student Preferred*, *Teacher Perceived*, and *Teacher Preferred*. Researchers make use of the CLES in evaluating the impact of constructivist teaching approaches on student outcomes and in guiding action researcher attempts to reflect on and improve classroom environments (Fraser & Fisher, 1994). Research continues on further validation of the CLES with suggestions to potentially revise the CLES for more accurate measures in college classrooms (Cannon, 1995).

The constructivist premises for *teaching* involve discovery experiences, which may be well-structured and guided, and are the central learning activities in the classroom. Students' prior knowledge is recognized as worthwhile and important, even though such knowledge may not be consistent with accepted knowledge in a discipline (Richey, 1995). Process, problem-solving, higher-order thinking, and research skills are emphasized in learning concepts. Learning experiences take into account students' existing knowledge and provide opportunities for students to develop new knowledge by integrating it into, revising, or replacing an existing framework of knowledge. Interactive instructional methods, such as teacher questioning and cooperative student learning, are emphasized (Lazarowitz; et al., 1994). A non-threatening classroom climate is emphasized in which students feel free to exchange and discuss ideas, to contribute and to know that such contributions are valued, and to analyze and interpret information. Process, problem-solving, higher-order thinking, and research skills are emphasized in learning concepts facilitated by the teacher.

As mentioned at the beginning of this chapter, the general field of constructivism can be subdivided into five categories: cognitive constructivism, radical constructivism, critical constructivism, personal constructivism, and social constructivism. Cognitive constructivism centers around Piaget assimilation. The results of learning occur within individual learners and the interactions learners have with the environment (Lebow, 1993). New information is assimilated into existing cognitive structures that assist the learner in developing an understanding of the real world. Radical constructivism is concerned with a theory of knowing, not a theory of knowledge. Von Glasersfeld (1992) asserts that learning is an active, not a passive process. Radical constructivism does away with the traditional concepts of objective truth and knowledge and is closely related to idealist philosophies. Critical constructivism identifies language as a key role in the construction of knowledge. The classroom is considered a cultural site where social reality is constructed by communicative interaction between teacher and students (Gergen, 1995). Personal constructivism is based on Ausubel's theory of prior knowledge (Driver & Easley, 1978) and Kelley's personal constructs (Driver, 1990) -- constructs that are developed to account for personal experiences. The learning that occurs can be rote or meaningful, and prior knowledge directly impacts new learning that takes place. Vygotsky, a social constructivist, follows the credence that social, cultural, and historical factors impact construction of knowledge (Davydov, 1995). Language is a key in the construction of knowledge. Learners interactively co-construct their knowledge in social settings. Learning is not considered to be an individual process.

Distinguishing between the various forms of constructivism is a perplexing, if not equivocal adventure. The subdivisions encourage and add complexity to an essentially simplistic postulate -- learners construct knowledge through experiences. Attempting to further differentiate between personal and social constructivism becomes an even more tedious task.

The topics of *personal* and *social* constructivism will be further developed in the remainder of this chapter along with an examination of the topics of chaos and assessment.

2.3.2 Personal Constructivism

Personal constructivism appears to center on the idea of meaningful learning (Malone & Taylor, 1993). Personal constructs are developed to account for a student's experiences. Personal interpretation is determined largely by existing beliefs, which are prior constructions. In the science classroom, students bring a range of beliefs that may differ from those of established scientific principles and natural phenomenon (Northfield & Symington, 1991). Strictly personal constructions are ephemeral, elusive, and sometimes deceptive features of knowledge formation. This makes it difficult to verify that which exists in the mind prior to and independent of experience. Personal constructivism ontology is largely similar to that of the idealist (Von Glasersfeld's radical constructivism is similar to idealism), there are no structures other than those which the knower constitutes by his very own activity of coordination of experiential particles -- that which exists is only in our minds (Watzawick, 1984).

Phenomenology and personal constructivism share some common bonds. A phenomenologist believes that reality is self-defined, and that knowledge is gained through making personal decisions about what is true -- a personal constructivist perspective. A phenomenologist, like an existentialist, argues that mankind must pursue its "existence." In doing so we first recognize we exist, we then choose, and we then develop into the "essence" or nature of our choice. The phenomenologist espouses a case study (action research) methodology, a philosophy that has methodological implications in education. Action research (Peca, 1992) requires the researcher to be an active participant (not merely an observer) to situation-specific instances of reality to which personal constructions of knowledge (both objective and subjective) will emerge. Through personal constructs a person defines or "finds himself." This implies individual uniqueness, which, in turn, influences particular educational methodology. The phenomenologist, like the constructivist, is concerned with those elements of the curriculum that will nurture discovery and creativity, which, in turn, will provide the individual with the capacity to construct views of his/her own reality. For the phenomenologist, the highest goal of education must always be kept in the mind.

Similarly, constructivism does not deny an outside world; it merely holds that the only world we can know is the world of our experience (Von Glasersfeld, 1992).

The existence of entirely personal ideas and the validity of the "a priori" viewpoint is often questioned (Solomon, 1987). When a student holds a private or personal explanation of a scientific phenomenon it is considered to be affected by culture and language. Personal theories are constructed as conglomerates of concepts and are adapted into the cognitive structures by the processes of assimilation and accommodation (Ernest, 1993). The personal constructivists' model of creation is an individualistic, Robinson Crusoe model of knowledge that leaves aside the necessary social and communitarian dimensions of cognition (Matthews, 1992). However, knowledge is always the result of a constructive activity, and it cannot be transferred to a passive receiver. It has to be built up by every single knower (Von Glasersfeld, 1992). What role do previous conceptions or misconceptions play in the role of constructions of ideas?

Driver and Easley (1978) made a very strong case for examining the prior notions of school pupils:

> It is the problems of the alternative frameworks which arise from students' personal experience of natural events and their attempts to make sense of them for themselves, prior to instruction, on which ideographic studies attempt to throw some light. Here, the focus is on an individual's personal experience.
>
> (p. 62)

Driver and Easley's paper reports that these alternative frameworks are common to many children, and resistant to change, but it does not suggest that there might be a social interpretation for this. As the quotation indicates, the focus is firmly upon personal experience and personal knowledge.

Personal constructivism appears to be more concerned with the *viability* (Von Glasersfeld, 1992) of information, as constructed into knowledge strands within the individual learner, than the universal truths external to the knowledge strands of the learner. Positivism, as indicated by Schrag, (1992) is a philosophy of science that has an attitude toward metaphysics. It separates value from fact, believes science to be the sole source of objective knowledge, and seeks to explain "reality" through an appeal to universal laws. A personal constructivist perspective regards knowledge as being constructed by learners who give meaning to new experiences in terms of their prior knowledge and past experiences (Maor & Taylor, 1994). This perspective emphasizes a cognitively active approach to learning in which students construct knowledge which is viable for them and incorporate it within their views of the world (Pope & Gilbert, 1983).

The idea of personal constructivism fortifies the claim of some researchers that constructivism is flawed because of its inability to come to grips with the essential issues of culture, power, and discourse in the classroom (Cobern, 1993a). Constructivism is considered problematic because it ignores the subjectivity of the learner and the socially and historically situated nature of knowing. It denies the essentially collaborative and social nature of meaning making, and it privileges only one form of knowledge, namely, technical rationale (O'Loughlin, 1992). Taylor (1994b) has presented technical rationality as a component of a critical constructivist epistemology which addresses critical constructivism as the socio-cultural context of knowledge construction and as a vehicle for cultural reform. These particular assertions identify with constructivism from the personal constructivist standpoint without acknowledging the credibility of the other subdivisions (categories).

Personal constructivism -- learning as knowledge construction, as the lone feature in cognitive development, fails to include social construction -- knowledge as socio-cultural construction (Milne & Taylor, 1994).

2.3.3 Social Constructivism

Knowledge is considered to be socially constructed (Malone & Taylor, 1993). Individuals may be thought of as making personal constructions, and later reflective constructions, which would be adopted after participation in classroom discourse (Taylor, 1994a). Clearly, constructions undergo reconstructions that may be socially stimulated. This is compatible with the view of objective knowledge truth as socially constructed out of *communication* among the community members as they seek to test the meanings they each have of their individual subjective constructions (Louden & Wallace, 1990). The social constructivist views the notion of learning as an empowering social activity that enables learners to understand their social reality so that they might act to transform it (Mandeville & Menchaca, 1991). Issues such as the cultural and political nature of schooling and the race, class, and gender backgrounds of teachers and students, as well as their prior learning histories, influence the kinds of meanings that are made possible in the classroom (Cobern, 1995). A shaping process takes place within social interaction that is seen as continually reconstructing meanings.

> As participants take account of each other's ongoing acts, they have to arrest, reorganize, or adjust their own intentions, wishes, feelings and attitudes; similarly, they have to judge the fitness of norms, values, and group prescriptions for the situation being formed by the acts of others.
>
> (Mead, 1972, p. 128)

Vygotsky, Berger, and Luckmen are cited as leaders in the social constructivist camp. Social, cultural, and historical factors are considered to impact construction of knowledge. Language and the belief that learning is not an individual process are considered to be keys in the construction of knowledge. Social constructivism focuses on the conviction that learners interactively co-construct their knowledge in social settings.

Alfred Schutz started from the phenomenological position that only in the stream of lived personal consciousness are the experiences to be found on which we draw for reflection and interpretation (Solomon, 1987). He wrote of the "interchangeability of perspectives" with others who have a social relationship with us, and insisted that the process of giving meaning to experience is only possible for a group of interacting individuals. Hypothetically, the only "pure" form of social constructivism that might occur would be in the form of Aldous Huxley's science fiction writing of "<u>Brave New World.</u>" Humans, from birth, (Alphas, Betas, Deltas, Gammas, and Epsilons) were mentally conditioned by the existing society and no presumed personal constructs existed.

Social constructivism shares a belief system common to those of ethnomethodology and pragmatism (Matthews, 1992). An ethnomethodologist believes that the world, although unknowable, does actually exist apart from our thinking about it through social interaction. There are objects and structures outside of our own mind and thinking. Pragmatism strives to prepare people to live in the world as it exists. Ideas and facts are applied to real world problems. It encourages us to seek out the processes and do the things that work best to help us achieve desirable ends. Like a social constructivist, an ethnomethodologist examines traditional ways of thinking and doing, and where possible and desirable, reconstructs our approach to life to be more in line with the human needs of today (Von Glasersfeld, 1992). Problem-solving is stressed, in a social constructivist paradigm, while acquiring practical skills that promote the evolution of social change through trial and error experiences.

Social constructivism suggests learning to be the social process of making sense of experience in terms of what is already known (Ernest, 1993). A social constructivist perspective promotes a learning environment where discussions are the means of constructing shared knowledge (Wheatley, 1991). Value is measured by norms adopted by the majority. Social constructivism is a form of cellular thinking (like-community thought). It is an attempt to align personally constructed knowledge into a form of community thought (Newbrough, 1995), agreement, and communication. Is it possible our educational paradigm is shifting from a foundation of accuracy to one of precision? What counts as scientific truths depends on constructions of reality shared among groups of scientists -- precision not accuracy. Like scientific knowledge, theoretical accounts of teachers' understanding of their work are constructed within communities of like-minded people (Louden & Wallace, 1990).

Constructivist-oriented science education researchers such as Cobern (1993), Driver (1988, 1990), Miller (1989), Solomon (1987, 1991), Sutton (1989), Tobin (1990), and Wheatley (1991) have added a key focus on teachers' and students' social construction of scientific knowledge. Science education classes are arenas where qualitative studies of students' discourse-reasoning (Mason & Santi, 1994) becomes empirical evidence of the ways in which classroom discussions can stimulate higher levels of reasoning and cognitive partnerships. Similar studies have examined the effects of cooperative learning environments (Geer, 1993), the ability of students, and their perceptions of the science classroom environment.

Learning is regarded as a social activity (Maor & Taylor, 1994), from a social constructivist perspective, in which learners are engaged in constructing meaning through discussions and negotiations between peers, students, and teachers (Edwards & Mercer, 1987). At the same time, students' individual construction of meaning occurs when their ideas are compared, explored, and reinforced in a social setting, with each student having the opportunity to reorganize his or her ideas through talk and listening (Driver, 1988, 1990; Solomon 1987, 1991).

Through social interactions, students become aware of others' ideas, seek reconfirmation of their own ideas, and reinforce or reject their personal constructions. The Technical and Emancipatory Classroom Environment Instrument (TECEI) is a social constructivist instrument (Bowen, 1994) developed for use by teachers and researchers to enhance science learning and teaching.

2.3.4 Summary

The constructivist perspective holds that meaningful learning or understanding is constructed in the internal world (Watzawick, 1984) of the learner. As a result of the students' sensory experiences with the world, understandings or schema tend to resist change, due to disequilibration (Saunders, 1992). Meaning is constructed by the cognitive apparatus of the learner. Consequently, it is not communicated by the teacher to the student (Resnick, 1983). Constructivism emphasizes individual cognitive (reduced chaos) activity, but acknowledges negotiations (increased chaos) with others as a means of determining the viability of knowledge (Taylor, Dawson, & Fraser, 1995a).

A personal constructivist perspective regards knowledge as being constructed by learners who give meaning to new experiences in terms of their prior knowledge and past experiences. This perspective emphasizes a cognitively active approach to learning in which students construct knowledge which is viable for them, and incorporate it within their views of the world (Pope & Gilbert, 1983).

From a social constructivist perspective, learning is regarded as social activity in which learners are engaged in constructing meaning through discussions and negotiations among peers, students, and teachers (Maor & Taylor, 1994). Research studies are recommending that science educators take an instructional view that takes into account teachers' and students' understanding of science in relation to their social and cultural context (Wildy & Wallace, 1995).

Traversing from personal constructivism to social constructivism is a complex journey. However, both subdivisions of constructivism believe that a learner can be annealed by knowledge. Maybe knowledge constructions at the individual level are a social and cultural process mediated by language (Milne & Taylor, 1994). An intermediate position argues that the individual and social components of the learning process are equally important and occur concurrently (Tobin, 1993). Through social interactions, students become aware of others' ideas, seek reconfirmation of their own ideas, and reinforce or reject their personal constructions (Maor & Taylor, 1994).

Implications for science education research in constructivism comes in the form of a promising framework for organizing research and practicing educational and psychological consultation (Cobern, 1993b). Research questions have changed from questions about factors external to the learner, such as; teacher variables, clarity of expression, enthusiasm, use of praise, etc., to questions about factors inside the mind of a learner, such as prior knowledge, personality, misconceptions, memory capacity, information processing capacity, motivation, attention, and cognitive style (Wittrock, 1985).

The science education community is contributing greatly to this body of knowledge. Findings from these research efforts have begun to generate important insights about how students acquire meaning and understanding of science concepts both in and out of school and how prior knowledge can interfere with or enhance student understanding. Constructivist researchers in environmental science education (Robertson, 1994) have designed studies that specifically relate to students' perspectives of environmental issues with a constructivist approach to the evaluation process.

The implications for science classroom instruction include the ample use of hands-on investigative laboratory activities, a classroom environment which provides learners with a high degree of active cognitive involvement, the use of cooperative learning strategies, and the inclusion of test items which activate a higher level of cognitive processes. Also, the main pedagogical implication is that the active learner's construction of his/her own understanding can be facilitated by teachers who provide stimulating and motivational experiences which challenge students' extant conceptions and involve them actively in the teaching/learning process.

The relationship or lack thereof, between personal and social constructivism remains an anomaly. The following description and account of a "thought discrepancy" adequately describes the quandary:

> While working in a developing country, a professor of geology from the local university once informed me that he believed in both evolution and special creation as viable explanations of origins. When I suggested that there was a disparity between these two explanations, he explained that he believed in evolution when he was at work and in special creation at church. After some discussion, he saw no disparity between the two viewpoints. We believe that this example typifies the assertion that many learners hold simultaneously two different viewpoints that provide disparate explanations of naturally occurring phenomena: a "world view" and a "school view".
>
> (Waldrip & Taylor, 1994, p. 143)

The debate of evolution and special creation could be analogous to that of personal and social constructivism, in context only.

Personal constructions of meaning occur when students' ideas are compared, explored, and reinforced in a social setting, with each student having the opportunity to reorganize his or her ideas through social interaction (Maor & Taylor, 1994).

In summary, personal and social constructivism appear to be distinct concepts in theory, but upon closer examination, they appear to be indeterminate entities that have an intertwined co-existence.

The following passage provides ample explanation:

> Science is not just a collection of laws, a catalogue of facts; it is a creation of the human mind with it freely invented ideas and concepts (personal constructivism?). Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions (social constructivism?).
>
> (Einstein & Infeld, 1938, p. 58)

This study is exploring the assessment of a constructivist chemistry classroom through the process of action research. The third objective of this study, as stated in Chapter One, is to investigate the relationship of chaos to assessment in a constructivist chemistry classroom environment. The following section, section 2.4, will discuss the topic of chaos and entropy.

2.4 Chaos and Entropy

2.4.1 Introduction

In the process of constructing knowledge through experiences learners create discrepancies in their thought processes while attempting to give meaning to particular experiences through the imaginative use of existing knowledge. The resolution of these discrepant processes leads to an *equilibrium* state (Malone & Taylor, 1993), whereby new knowledge has been constructed to cohere with a particular experience and prior knowledge, a connotation of order and predictability.

The terms, "chaos" and "entropy", are not synonymous; and therefore, should not be used interchangeably. The term "chaos" refers to the condition of disorder and the term "entropy" refers to the measurement of disorder (Dresden, 1992). The term entropy is embodied in the Second Law of Thermodynamics: In spontaneous change, the universe tends toward a state of greater disorder. The thermodynamic state function, entropy, is a measure of the disorder of a system (Whitten, Gailey, & Davis, 1992). The entropy of the universe increases during a spontaneous process (Wilbraham, Staley, & Matta, 1995). Entropy is the predecessor of the chaos theory. Chaos is a theory developed to describe the behavior of complex adaptive systems (Haynes, Blaine, & Meyer, 1995). The function of the chaos theory is to discover latent patterns in systems that are characterized by both uncertainty and by constant change (Fuhriman & Burlingame, 1994).

Across scientific disciplines in education, our rational, systematic quest for order and predictability are yielding a deeper appreciation for chaos, uncertainty, and change (Steinberger, 1995). As a matter of educational practice, it is important to stress that simple and deterministic laws do not always give rise to simple, intuitively understandable, and predictable behavior.

The remainder of this section includes a review of the topics of entropy and chaos, and the section summary.

2.4.2 Entropy

The second law of thermodynamics gives a precise definition of a property called entropy. Entropy can be thought of as a measure of how close a system is to equilibrium; it can also be thought of as the *measure* of the amount of disorder in the system (Encyclopedia of Philosophy, 1967). The law states that the entropy (disorder) of an isolated system can never decrease. Thus, when an isolated system achieves a configuration of maximum entropy, it can no longer undergo change; it has reached equilibrium (Zumdahl, 1993).

The idea of lowering the "quality" of energy is embodied in the idea of entropy (Hewitt, 1993). The second law of thermodynamics states that in the long run entropy always increases. Entropy can be expressed as a mathematical equation, stating that the increase in entropy ($\triangle S$) in an ideal thermodynamic system is equal to the amount of heat added to a system ($\triangle Q$) divided by the temperature (T) of the system: $S = \triangle Q/T$ (Bazarov, 1964). Gas molecules escaping from a bottle move from a relatively orderly state to a disorderly state. With disorder, entropy increases and energy decreases. Whenever a physical system is allowed to distribute its energy freely, it always does so in a manner such that entropy increases while the available energy of the system for doing work decreases. Relative order becomes disorder. You would not expect the reverse to happen; that is, you would not expect the molecules to spontaneously order themselves back into the bottle and thereby return to the more ordered containment. Such processes in which disorder goes to order, without energy transfer, are simply not observed to happen (Wilbraham, Staley, & Matta, 1995). Disordered energy can be changed to ordered energy only at the expense of some organizational effort or work input (Smoot, Smith, & Price, 1990).

Consider the riddle, "How do you unscramble an egg?" The answer is simple; "Feed it to a chicken." But, even then you won't get all your original egg back, egg making has its inefficiencies too. All living organisms, from bacteria to trees to human beings, extract energy from surroundings and use it to increase their own organization. In living organisms, entropy decreases during a specific time frame. But, the order in life forms is maintained by increasing entropy elsewhere; life forms plus their waste products have a net increase in entropy. Energy must be transformed into the living system to support life. When it isn't, the organism soon dies and tends toward disorder.

In general, any spontaneous change in the physical or chemical state of a system will lead to an increase in entropy. No spontaneous change will occur when the entropy is at maximum (that is when no increase of entropy can occur without changing the conditions of the system) and the system will then be in a state of stable thermodynamic equilibrium (Lowe, 1988). Spontaneous change represents an increase in entropy; therefore, the final state is more random and hence more probable than the initial state (Whitten, Gailey, & Davis, 1992). However, the *final state* is *dependent* on the *initial state*. Spontaneity is indicated only if the total entropy of the system and the surroundings taken together increases (Zumdahl, 1993).

Entropy, like internal energy and enthalpy, is a *state function* (a result of product not process). The entropy, or randomness of a system in a given state is a definite value, and hence, ΔS for a change from one state to another is a definite value depending only on the initial and final states and not on the path between them (Bazarov, 1964). Similarly, the manner in which knowledge constructs are formed may be of no consequence. The initial and final state of the information is the item of importance. No spontaneous change will occur when the entropy is at a maximum, that is, when no increase of entropy can occur without changing the conditions of the system. At this point, the system will then be in a state of stable thermodynamic *equilibrium* (Lowe, 1988).

The concept of entropy originated in the phenomenological thermodynamics and the increase of entropy with time was at first regarded as an invariable law (Masterton & Hurley, 1989). The second stage in the history of the concept was concerned with its statistical reformation. In the third and current stage, entropy has come to be associated with the modern quantitative concept of *information*. G. N. Lewis (1930) considered the problem of separation and diffusion of gases and concluded that gain in entropy means loss of *information*. Claude Shannon, in 1948, developed a theory in which information is not concerned with meaning but with the statistical character of a whole range of possible messages and is, in fact, a measure of the amount of freedom of choice we have in constructing messages -- personal constructivism. Increased orderliness of information due to work input (learning) is "*negative entropy*" also referred to by some as "*negentropy*."

2.4.3 Chaos

Chaos, a part of our physical universe, is a term used by scientists to describe a system in which small changes in initial conditions can have a significant and unpredictable effect on the eventual outcome (Lampton, 1992). Chaos, affiliated with the second law of thermodynamics, is the search for order within apparent randomness. Disorder, *confusion*, and unexpected behavior are stumbling blocks to predictability. Chaos is used extensively in the field of dynamics (Baker & Gollub, 1990), the study of how systems change over time. Chaos is the element of surprise and uncertainty. It is simple things behaving in complicated and often unexpected ways. Some of the systems that scientists consider to demonstrate chaotic behavior are the weather, the stock market, populations of living creatures, the orbits of several planets in our solar system, and even our hearts and our minds.

Quantum mechanics, a theory developed by Planck's quantum theory and Heisenberg's uncertainty principle, is a supporting fragment to chaos research. Quantum mechanics is a mathematical theory of dynamic systems in which dynamic variables are represented by abstract mathematical operators having properties that specify the behavior of the system (De Jong, 1992). This particular theory predicts a number of possible outcomes and tells us how likely each is. That is to say, if one made the same measurement on a large number of similar systems, each of which started off in the same way, one would find that the result of the measurement would be A in a certain number of cases, B in a different number, and so on. One could predict the approximate number of times that the result would be A or B, but one could not predict the specific result of an individual measurement. Quantum mechanics, therefore, introduces an unavoidable element of unpredictability or randomness into science (Hawking, 1988). This premise is analogous to our educational system, its components, and the measurement thereof. Thus, we encounter the paradox of attempting to identify and measure variables in our learning systems; we acknowledge their existence, yet chaos dictates the magnitude and rate of existence (Stewart, 1993). Chaos is proportional to the logarithm of the number of ways a system can exist (Lowe, 1988).

Newton's differential equations could predict with remarkable precision a two-body problem (two variables). By adding a third variable, a three-body problem, the problem becomes a thousand times harder to solve (Lampton, 1992). As you add more variables or objects, the problem grows harder still. These variables are affecting all of the others. Evaluation and interpretation of the problem becomes formidable. How many variables do we use in our educational assessment equations?

Recognition of the repeating patterns within the chaos is formidable. Scientist-mathematician, Robert May, was studying populations of animals as affected by increases and decreases in food supply.

However, he was not studying actual animals, or actual populations of animals. He was actually studying the logistic difference equation: $N_{T+1} = RN_T (1 - N_T)$, which is an example of an iterated equation (Lampton, 1992). An iterated equation must be solved repeatedly to produce meaningful results. May also discovered that there are other factors to take into account, in addition to food supply, when predicting population. He concluded that the equation was very noisy (outside interference from other phenomena that are not related to the phenomena being studied). Can initial conditions be repeated over and over again in learning systems? If not, can iterated equations be applied to these systems? Is learning very noisy?

When an iterated equation is repeated a certain number of times, it <u>may</u> settle down on a single value that is repeated over and over; this value is called an <u>attractor</u> (De Jong, 1992). By using values of R in the logistic difference equation within a specific range (0-4), one attractor is produced. When using values of R outside of the range, two attractors appeared in the equation instead of one. The simplicity of the logistic difference equation fell apart. When a system with a single attractor moves to two attractors, increasing the value of a variable, mathematicians say that the system has *bifurcated* -- split in two (Dresden, 1992). If a system starts bifurcating, it often doesn't know where to stop, thus entering the realm of chaos.

As a singular theory, the Heisenberg uncertainty principle can be used to reinforce the premise of chaos. Heisenberg showed that *position* and *velocity* are entities that cannot be measured simultaneously. In other words, the more accurately you try to measure the position of a particle, the less accurately you can measure its velocity, and vice versa. Limitations to the uncertainty are not restricted to the methodology of the measurement, position or velocity of the particle, or the species of the particle.

Notable scientists have theories that are on the fringe of the chaos theory. "God does not play dice with the universe," is a statement by Albert Einstein that summed up his unwillingness to surrender to the concept that the universe is governed by chance (Einstein, 1990). Heisenberg's uncertainty principle theory implies that particles behave in some respects like waves; they do not have a definite position but are "smeared out" with a certain probability distribution (Hawking, 1988). This gives credibility to the idea that there are predictable patterns within chaotic systems.

The Mandlebrot set (the set of complex numbers that behave in a certain way when subjected to an iterated equation) gives encouragement to the thought of identifiable patterns within chaos (Gleick, 1984). Benoit Mandelbrot began to notice that nature has a penchant for repeating itself, but in a peculiar way. An analogy would be a tree. The branches look like the trunk and the smaller branches look like the bigger branches. The tree, it could be said, is self-similar; the parts look like the whole.

Mandelbrot noticed this was also true of economic phenomena he was studying. When he looked at the way the stock market rose and fell from day to day and graphed it on a sheet of paper, it looked similar to the way the stock market rose and fell from year to year, only on a smaller scale. The parts looked like the whole.

Mandelbrot concluded that *fractals*, things that have the quality of self-similarity, must be an important part of nature. Trees and the stock market are considered to be fractals. Even the human body is fractal (Chopra, 1993).

Chaotic systems also tend to be fractal (Lampton, 1993). An attractor is a region within a dynamical system to which that system is drawn (Hesse, 1991). It can be represented with phase space diagrams (Priesmayer, 1992). Strange attractors are boundaries of a chaotic system that give the system structure and order (Shuster, 1988). A strange attractor, an attractor that consists of a self-similar pattern of numbers that never repeats itself exactly, contains patterns that look the same at every level. The parts look like the whole (Keaten, Nardin, Priblyl, & Vartanian, 1994). A strange attractor, therefore, is a fractal (Peca, 1992). *Learning* might logically be categorized as a *fractal.*

The human body is in utter defiance of chaos, since it is incredibly orderly and capable of adding to its order with even more complexity (Chopra, 1993). Whenever a baby is conceived, the fertilized egg duplicates the process of cell division that has produced billions of babies before it. The cell division is evolution in action, the growth of simpler organisms into more complex, orderly organisms. Clearly, there is counterforce pushing evolution along, creating life, fending off the threat of chaos (Chopra, 1993). According to Chopra, the counterforce is intelligence. At the quantum level, it is the blueprint for DNA.

Research is attempting to apply the chaos theory to the practice of teaching and learning in educational institutions (Maxcy, 1995). The chaos theory of education (Loree & Stupka, 1993), which is modeled after the chaos theory of physics, is based on the premise that educational research data, originally considered random or unexplainable, may yield useful data when studied over a long enough period of time. The application of the chaos theory of education provides a rationale for understanding why little time and effort have been devoted to the study of both the processes (formative evaluation) and outcomes (summative evaluation) when conducting student assessment research (Bobner; et al., 1989). Educational research assumes multiple perspectives yet demonstrates a single perspective on the problem of educational research; it creates a single framework for the solution (Eisner, 1994).

There are three basic outcomes of school science teaching: children's science, teacher's science, and an amalgam of children's and teacher's science (Gilbert, Osborne, & Fensham, 1982). *Confusion* (Solomon, 1987) arises about what is being taught and the students' concept of the topic being taught. Information that is being transmitted and the context of the reception of the information are many times different (Driver & Erickson, 1983). There is no theoretical position to account for the confused outcome of learners. Researchers argue that the use of the burgeoning empirical data about alternative frameworks within school instruction would improve the quality of children's learning. *Chaos* may be the unaccounted for variable that causes *confusion.*

<u>Seven Tenets of the Chaos Theory</u>:

1. Chaotic systems are dynamic, nonlinear, cybernetic, and deterministic (Shuster, 1988) systems.
2. Even slight differences in initial conditions can cause extensive differences in outcomes. Slight microscopic differences in initial values can be magnified, though recursive self-similarities within the system, to produce macroscopic effects (Batterman, 1993).
3. Complexity prevents the ability to precisely quantify all initial conditions (Stewart, 1993).
4. Strange attractors cause bounded patterns of behavior within complex systems (Stewart, 1993).
5. Complex systems are to be viewed as wholes (qualitative) not as isolated (quantitative) parts (Borman, 1991).
6. Iteration causes magnification of system dissimilarities and forms patterns (Lampton, 1992).
7. There can be no valid generalization in the *long-term* about complex systems; prediction can only be made in the *short term* (Heiby, 1995).

2.4.4 Summary

Section 2.4, Chaos and Entropy, has interpreted and distinguished differences between the two concepts. The terms, "chaos" and "entropy" represent two different, yet, associated meanings. The term "chaos" refers to the condition of disorder and the term "entropy" refers to the measurement of disorder. Entropy also refers to the amount of information (Rothwell, 1994) in a system and how crucial it is to social decision-making, a form of assessment. Chaos is the search for patterns in complex systems (Ruelle, 1991). The predisposition of thought is that chaos is omnipresent and has effects (Baeyer, 1995) on our surroundings. Chaos is sometimes referred to as nonlinear-dynamics (Tufillaro, Abbott, & Reilly, 1992) systems.

Dynamics deal with the motion, change, and equilibrium of systems under the action of forces usually outside the system. The dynamic system in this study is the classroom environment, which could be considered a cybernetic system (cybernetics is the science of communication and control) (Rapoport, 1968). The way in which communication serves to control the information (entropy) and behavior of a given environment or dynamic system is the essence of cybernetics (Deutsch, 1948). Cybernetics provides the framework for analyzing the behavior of many complex systems, focusing on feedback and environment (Maryuma, 1963). Feedback is a communication process whereby some or all of the information output of a system is used as an input for the system in order to regulate behavior of the system (Littlejohn, 1992).

The classroom environment, a dynamic and cybernetic system, must also be impacted (Baeyer, 1995 & Rockler, 1991) to a certain degree by chaos. Both nonlinear dynamics (chaos) and cybernetics have been associated with studies that examine patterns of complex adaptive systems (Levine & Fitzerald, 1992).

The chaos theory of education suggests effective new processes do not need to be clearly understood or based on traditional beliefs to yield consistent outcomes (Loree & Stupka, 1993). The chaos theory may assist researchers in the design of sensitive initial conditions and the interpretation of continuous, nonlinear data assessment (Heiby, 1992). A more thorough understanding of the chaos theory is due in part to breakthroughs in chemistry, biology, and quantum physics. This in turn can help educational leaders address the complexities of educational change (Wheatley, 1992).

In educational research, little or no attention is given to the initial and final state of the relevant variables. Subsequently, verification of the relevant variables may not have been established from the onset which makes verification of the final result suspect.

Since chaos theory is essentially systems-oriented, one way to organize potential applications in educational settings is by level of system (Bobner; et al., 1989). Using this approach, students, classrooms, buildings, and district-centered categories could serve as a framework for organizing research (Bobner; et al., 1989).

A primary focus of this research is to examine associations between chaos and constructivism, and to explore the relationship of chaos to assessment. As stated in Chapter One, the second objective of this inquiry is to investigate associations between the three types of assessment; predictors, perceptions, and performance in science education classrooms. Section 2.5 will discuss assessment in science education from a constructivist, action research perspective.

2.5 Assessment in Science Education: A Constructivist Perspective

2.5.1 Introduction

Assessment is a multi-faceted dimension in science education. The design and implementation of the processes and formats for the assessment instruments is tremendously diverse. Evaluation in science education extends from the classroom environment, to the laboratory environment, and often into the field. The strategies that enhance learning, and evaluation of learning, in constructivist science classroom range from individualized, to cooperative groups (Geer, 1993), with a myriad of variations in between. Pretests, posttests, final examinations (Summer & Kruger, 1994), practical examinations, portfolios (Duschl & Gitomer, 1993), classroom environment surveys, and standardized multiple-choice examinations (Bock; et al., 1993) have all been utilized to assess learning. Measurement of process objectives and *performance/product* objectives (Aschbacher, 1992) are also included in assessment formats. Along with these forms of assessment there are three common approaches to studying the classroom environment: systematic observation, case studies, and assessing student and teacher perceptions (Fraser & Fisher, 1994). In addition, there are both quantitative and qualitative methods (Ebenezer & Zoller, 1993) for assessing research-based constructivist (Mercer, Jordan, & Miller, 1994) approaches to evaluating the classroom learning. In the constructivist psychology community, personal constructions are being assessed by repertory grids (rep grid) and implications grids (imp grid) for the purpose of measuring the relatedness of constructs within system structures (Dempsey & Neimeyer, 1995). Repertory grids are maps or charts of a student's skills, aptitudes, or test scores. Implication grids are similar maps or charts that establish conditions present in a student's environment that, by inference, impact a student's repertory grid.

The remainder of this section will discuss background information regarding assessment in science (section 2.5.2) and the section summary (section 2.5.3).

2.5.2 Background

An assessment is any standard (measurement) of comparison, appraisal, or judgment of value (Kane & Khattri, 1995). Assessment is recognized as a systematic, multi-step process involving the collection and interpretation of educational data (National Science Education

Standards, 1995). In education, the primary focus is on the evaluation, interpretation, and analysis of assessment data for the purpose of making predictions regarding learning. Enthusiasm for *performance* assessment in science education reflects desire within the educational community for school reform and increased improvement in students' academic *performance* (Aschbacher, 1992).

Although few educators would dispute the worth of outcome measures, they do not give a complete picture of the educational process (Fraser & Fisher, 1994). Teachers often view their position in the science classroom as being concerned with revealing or transmitting the logical structures of their knowledge, and directing students through rational inquiry toward discovering the predetermined universal truths expressed in the form of laws, principles, rules, and algorithms (Berman, 1995). Assessment in many science classrooms requires the level of knowledge to be an important determinant of difficulty, while cognitive demand is not (Enright; et al., 1995). Research of assessment of student learning in science addresses effective science learning and alternative methods of performance assessments that support curriculum and instruction that are exemplary for science education reform (Smith; et al., 1993).

Recently, developments in history, philosophy, and sociology have provided educators with a better understanding of the nature of knowledge development. At the level of the individual learner, there has been a realization that meaningful learning is a cognitive process of making sense (Berzonsky, 1994), or purposeful problem-solving of the experiential world of the individual, in relation to the totality of the individual's already constructed knowledge. Because the individual belongs to a world populated by significant others, the sense-making process involves active negotiation (Shepardson, Moje, & Kennard-McClelland, 1994) and consensus building for the duration of the individual's life-time, regardless of the learning context.

While there does seem to be wide-spread support for the notion that students construct beliefs about many phenomena, the techniques used and the manner in which the frameworks are articulated vary considerably. This diversity results in some *confusion*, especially when an attempt is made to compare the findings between one or more students (Driver & Erickson, 1983). Comparison between classes, schools, states, and nations becomes even more complex. The confusion stems in part from the unit of analysis adopted by the researcher to define student frameworks. Some have opted to define frameworks as individual constructs, while others have described them as "a composite picture based upon ideas shared by a number of pupils" (Watts, Gilbert & Pope, 1982). Researchers have used various approaches to try to capture some aspects of students' cognitive commitment. In an effort to accomplish this task, a proliferation of terms, techniques, and supporting theoretical rationales have been developed. The net result is considerable *confusion* over the types of cognitive commitments which should be identified and described, a debate over appropriate data gathering and data analysis techniques, and difficulties in extending or even replicating existing studies.

From a constructivist perspective, it is argued by researchers that assessment of science learning requires developmental research (Lijnse, 1995) that measures processes of conceptual change rather than conceptual transmission. Other science education researchers suggest an assessment framework that assesses a broader view of the science classroom: teacher confidence, the structure of the discipline, student motivation, trust, and the cultural context of learning (Wildy & Wallace, 1995). Constructivist research studies have concluded that assessment of science students should be done in an atmosphere conducive to student investigation of phenomena of their own interest and a problem-rich learning environment where students develop complex problem-solving skills (Roth, 1994). Research that has been conducted on the evaluation of *thinking* has used the personal construct psychology theory to determine that *thinking*, within the constructivist framework, can be enhanced by the use of multi-method approaches (Pope & Denicolo, 1993). This idea supports a basic premise of the research being conducted in this study; a holistic (multi-method) (Heward & Cooper, 1992) approach to assessment (predictors, perceptions, and performances as achievement outcomes) is representative of a constructivist approach to assessment.

Roth and Bowen (1995), directed a study in the science classroom that examined student learning in an environment which encouraged students to be actively involved in their own learning. Assessment of the learning outcomes was organized in mathematical representations of data, problem-solving, attitudes and achievement, and scores on the Constructivist Learning Environment Scale (CLES) (Taylor, Dawson, & Fraser, 1995a) -- a holistic (multi-method) approach to assessment.

Assessment of a student's conceptual framework is a painstaking and complex onus. By the construct "conceptual framework" we shall mean the mental organization imposed by an individual on sensory inputs as indicated by regularities in an individual's responses to particular problem settings (Driver & Erickson, 1983).

In compliance with the post-positivist philosophy, assessment today is a qualitative endeavor involving observation, sensory systems, interviews and researchers' reactions, as described by the following quote:

> The common-sense representation of qualitative empirical regularities is tied to complex interactions between the sensory system, the environment that supplies the information of our sensory systems and the mental structures through which we organize the sensory information and which guides our behaviors. Individuals' common-sense knowledge about qualitative physical concepts is no different today than in the times of say, Aristotle.
>
> (Strauss, 1981, p. 297)

2.5.3 Summary

Assessments are deliberately designed to have explicitly stated purposes, to have a clear relationship between the data and decisions, and to be internally consistent (Kulm & Malcolm, 1991). A constructivist approach to assessment is more likely to develop a psychological sense of mastery in learners (Ritchie & Carr, 1992). Such assessment seems more likely to result in learners feeling that there are gaps in their knowledge, yet also having a sense that they have mastered some ideas.

Measuring knowledge constructs is a difficult and often inaccurate endeavor (Raskin, 1995). Assessment appears to be a social means of measuring those personal knowledge constructs to produce socially viable constructs. Capturing and measuring knowledge constructs created through personal and social constructivist frameworks is a formidable task. Outside of general parameters and interpretations, the reliability and predictability of information provided from assessment of knowledge constructions may be considered suspect.

The challenge of the constructivist model of assessment of learning is to develop a reliable and realistic system of evaluating learner conceptions and reflections. Educational researchers have conducted studies that assess the effectiveness of reflective learning (Thorpe, 1995). The adequacy of using a quantitative performance (achievement) of students for performance success is questioned on two counts: (1) the quality of learning has not been considered, and (2) the theory underlying the practice has been undermined. In Thorpe's 1995 study on reflective learning, it was discovered that the integration of a reflective component in assessment of the course was effective; students reported changes most frequently at the level of general awareness of the purpose of study and learning transfer.

Other research (Meltzer & Reid, 1994) has revealed models of assessment that have been influenced by the constructivist epistemology. The focus on the diversity of assessment approaches is due to the varying degrees to which assessment systems incorporate constructivist principles. New assessment approaches that incorporate constructivist characteristics have raised new problems: practicality, cost-effectiveness, accountability, reliability, and validity (Meltzer & Reid, 1994). The constructivist influence is permeating much thinking on instructional design and newer, expanded needs-assessment orientation. Changes in instructional-system design models (Richey, 1994), ISD, are likely to be the driving forces among constructivist practitioners in the future. Design models of the future are likely to incorporate more formative and summative evaluation (Richey, 1994).

Researchers in science education have developed qualitative research techniques that document and analyze teachers' conceptions about teaching science. The Conceptions of Teaching Science (CTS) Tasks Interview (Jones & Beeth, 1995) is designed to assist teachers in assessing their own conceptions of teaching science and to better understand how to modify their science teaching as they incorporate principles of conceptual change into their instruction.

Researchers of science assessment have identified some studies where no change in perceptions, attitudes, or performance have occurred in learners due to constructivist approaches to science curriculum and science education (Ebenezer & Zoller, 1993).

A general assumption exists in educational arenas that assessment of learning, under carefully designed and monitored conditions, is possible. Also, if these preordained conditions are carefully scrutinized, the data we recover can be considered an <u>accurate</u> and <u>reliable</u> means of measuring specific knowledge constructs that evolve as a result of learning.

Assessment, being a measurement, collection, and interpretation of educational data for the purpose of making predictions regarding learning, is a key feature of this research study. The relationships between chaos, constructivism and assessment are the primary variables considered in the analysis of the data for this study.

2.6 Chapter Summary

The literature review conducted has concentrated on the topics of constructivism, chaos and assessment, from an action research perspective of learning environments, in science education. Educational environment research has grown out of the research studies of Moos and Walberg since the late 1960s and early 1970s. The study of classroom learning environments has received considerable attention in the research literature during the past two decades and major syntheses of research on learning environments (e.g. Fraser, 1986a; Waxman, 1991) documents the importance of assessing and understanding learning environment characteristics. Science education researchers have led the world in terms of developing, validating, and applying environment assessment instruments (Fraser, 1993).

Constructivism promotes the thought that learners construct knowledge through their experiences, an endeavor that explores knowledge and truth (Von Glasersfeld, 1989). The most recognized principle of constructivism is that learners actively construct their own knowledge rather than passively receive it intact from sources external to them. Knowledge is not a commodity that can be transmitted in communication (Malone & Taylor, 1993). Emphasis was placed on the two subcategories of constructivism: personal constructivism and social constructivism. Personal constructivism advocates that people construct their own interpretation of communications and experiences (Northfield & Symington, 1991). Social constructivism views learning as a social activity where learners collectively construct knowledge in interactive scenarios (Mandeville & Menchaca, 1991).

The terms "chaos" and "entropy" refer to the condition and measurement of disorder, respectively. The second law of thermodynamics defines entropy as the measure of how close a system is to equilibrium. Entropy also refers to the amount of information (Rothwell, 1994) in a system. Chaos is the search for order within apparent randomness. Chaos is used to describe how small changes in the initial conditions of a system can create unpredictable results in the final outcome of the system. The chaos theory, on the other hand, is sometimes referred to as a nonlinear-dynamic system, which deals with motion, change, and equilibrium of systems. The seven tenets of the chaos theory are included in the chaos and entropy summary, section 2.4.3.

Assessment is the measurement and interpretation of data. Educational assessment is a multi-step process that involves the collection and evaluation of educational data (National Science Education Standards, 1995) utilized for comparison, appraisal, or judgment of value (Kane & Khattri, 1995). Quantitative and qualitative measurements are the two general categories of assessment. Science assessment in some educational institutions is shifting from norm-referenced to curriculum-referenced assessment (Russell, 1990). Also, there has been a shift in science educational research and practice from empiricism and outcome-oriented intervention toward holistic/constructivist approaches (Heward & Cooper, 1992).

In summary, the extensive literature search conducted did not identify any antecedent research that encompassed associations between the topics of chaos, constructivism, and assessment in classroom environments.

Although past studies have examined associations between student perceptions of the learning environment in science classes and student outcomes (Fraser, 1993), this study is unique in that it: (1) reports the first application of the Oral Individualized Classroom Environment Questionnaire (2) is the first to examine associations among constructivism, chaos, and, assessment (3) examines chemistry assessment in three distinct areas -- predictors of achievement, perceptions of environment, and academic performance outcomes. Furthermore, this study is distinctive in that it focuses on students in chemistry classes, whereas, most previous research of the science classroom environment has primarily centered on other areas of science.

Chapter 3

Instrumentation and Methodology

3.1 Introduction

This chapter focuses on the instrumentation and the research methodology utilized in this study. The approach to this study is a synergistic and holistic/triangulation approach. This is accomplished by employing instrumentation and methodology that measures student predictors, perceptions, and performances. The instruments applied are the TOLT (predictor), True Colors (predictor), ICEQ (perceptions), OICEQ (perceptions), pretest and posttest (performance), and a final written exam (performance). The methodology is action research.

To date, most instrumentation developed to measure psychosocial characteristics of classroom learning environments has been designed to measure student perceptions with paper and pencil measures (Loup, et al, 1992). While this methodology has proven quite useful, other methodologies such as case studies and direct, systematic observation are possibilities as well (Cassara, 1991). Use of alternative research methods (predictors, perceptions, and performances used synergistically/holistically) may generate broader conceptualizations, definitions and perspectives on variables that constitute a learning environment than those variables currently operationalized by more traditionally used paper and pencil measures of student perceptions (Schon, 1995).

Action research (Warner & Adams, 1996) is the methodology incorporated into this study. There is a need for action research in science classrooms in the USA (Warner & Adams, 1996), research in which the classroom teacher becomes the observer, collector of data, and analyzer of data. Research and information can become incestuous when they continually originate and stream strictly from the annals of professional, post-secondary, educational researchers (Somekh, 1995). Rather than regarding teachers as the traditional consumers of educational research, teachers are adopting a professional research perspective on the problems that they confront daily in their curriculum, assessment planning, and in their classroom teaching (Brause & Mayher, 1991). The influx of findings from action research by researchers at secondary school levels has potential for revising and revolutionizing teaching strategies and methodologies. The infusion of action research by teachers in secondary schools with research from post-secondary sources is vital to achieving a revitalized, viable, and reliable form of science educational research.

Action research is designed, conducted, and implemented by teachers themselves to improve teaching in the classroom (Johnson, 1993). This type of research promotes reflective teaching, critical inquiry, self-evaluation, and professional dialogue, thereby creating a more professional culture in schools (Warner & Adams, 1996). Action research provides teachers with the opportunity to gain knowledge and skill in research methods and applications and to become more aware of options and possibilities for change. Action research demands the re-evaluation of current theories and influences what is known about teaching and learning (Glasgow, 1994).

Action research is a valuable form of constructivist teaching that can assist chemistry teachers in assessing the relationships between predictors, perceptions, and performance -- a reflective feature of professional action (Elliott, 1993a). Results attained via action research can provide worthwhile stimuli for teachers to reflect seriously about their classrooms and to plan actions which will lead to the improvement of classroom environments. Of special significance is the ability of action researchers to evaluate continually the consequences of their curriculum innovations.

Action researchers are critically reflective (Lorens, 1994) practitioners who maintain an iterative (Warner & Adams, 1996) approach to evaluation of their own ideas and remain open to new (and old) ideas, and who challenge themselves and their colleagues to put their ideas to the research test. Reflection constitutes, or allows, researchers a certain intellectual emancipation to ruminate and deliberate about the process and products that culminate from a particular research project. Consequently, the results of action research have a reflexive influence on the types of problems that are being identified and addressed.

Reflection is an active process of self-scrutiny and self-challenge. Through reflection practitioners have access to their tacit understandings and are capable of strategic action to transform their institutional setting (Somekh, 1995). Action research, in some instances, acts as a means of personal empowerment -- personal constructivism. The practitioner develops the capacity for reflection through action research. Action research is something done through practice rather than by following a set of prescribed methods or techniques (Stenhouse, 1985). At the deepest level, reflection in action research is a complex, holistic process (Somekh, 1995), interdependent with decision-making. Action research concerns itself primarily with processes of development and change in social situations, and these can never be amenable to the demand for certainty. Elliott (1993a) has produced a systematic and holistic procedure for professional education and the assessment of professional competence -- action research.

Professional researchers contribute significantly to the body of knowledge in education, yet this form of research is deficient of the iterative component (a chaos term that refers to repetition, and equations that repeat themselves over and over) of educational research. However, action researchers in concert with professional researchers have the capacity to facilitate research studies that are reflexive, formative, and summative in nature. Professional researchers, utilized as external evaluators (social assessment-social constructivism-positive entropy) in conjunction with internal evaluators, action researchers (personal assessment-personal constructivism-negative entropy), would provide significant contributions to the development of innovative curricula, assessment schemes, and teaching materials. This would allow judgments to be made about the efficacy of new curricula that is rigorous and reliable.

Action research is both a personal and social constructivist approach (iterative) that is continuous throughout the data collection and analysis period of the research study. It is a formative model (Elliott, 1993b) characterized by a continuous and spiral process of development, trialing, evaluating, and redevelopment, similar to the process of research adopted for this project; research, read, write, and refine-revise (Access, Research, Analyze, & Predict---A.R.A.P). Action research also produces summative data with the realization that the data is a product that is relative, and subjective, in time and nature. Although a theoretical framework is established relatively early, the iterative process between evolving research questions and the construction of a theoretical framework usually continues for the duration of the project. On-going assessment (a form of entropy), communication of measurement, can result in continuous modifications to the project design. Action research lends itself to the formative and summative model of curriculum development and evaluation and to a conception of curriculum as an evolutionary, iterative process of teaching and learning, a constructivist approach to assessment.

Action research is a new paradigm for curriculum restructuring that views the old model as competitive, one-dimensional, reactive, and based on external change agents. This model views the teachers as passive participants. The new model, action research concept, is cooperative, three dimensional, responsive, and based on internal change agents. This model views teachers as reflective and active participants (Johnson, 1992). The reflection will be a process of continuing assessment of the chaos equated, from a personal and social constructivist action researcher's perspective of the formative and summative phases evaluated in a science classroom.

Action research is a quintessential experience for a constructivist chemistry teacher-researcher. The constructivist perspective holds that meaningful learning or understanding is constructed in the internal world of the learner (Watzawick, 1984). From a constructivist point of view, scientific and mathematical knowledge does not exist independent of the person (Wheatley, 1991) and constructivist science places primary emphasis on the independence of each person's interpretation of his or her own experiences (Roth, 1994). From a constructivist standpoint, action research is a methodology that is inundated with a remarkable number of episodes and events of teaching and learning that develop personal intellectual competence and performance that occur in a constructivist chemistry teacher's classroom. Action research is the practice, and a form, of constructivist (personal and social) teaching and philosophy.

Teachers can contribute to educational improvement by conducting classroom research (Miller & Pine, 1990). The evolving role of teachers in educational research involves focusing on teacher empowerment (Houser, 1990). Teachers engaged in action research are involved in a process that focuses on how they, and their students, construct and reconstruct learning experiences, thereby extending and creating additional learning experiences for students (Lafleur, 1992). Literature indicates a trend toward teacher empowerment via involvement in the research process (Houser, 1990).

The complete study described in this thesis occupied three to four years and the action research component was a continuum of 16 years.

The following sections, 3.2 and 3.3, discuss the instrumentation and methodology utilized in this study.

3.2 Instrumentation

Six instruments were used in this study to measure *three* student-related variables: predictors of student performance; student perceptions of classroom environment; and performance.

Two of the six instruments were used to measure each of the three student-related variables. The TOLT and True Colors tests were used as predictors of student chemistry performance. The OICEQ and ICEQ were used to measure students' perceptions of the chemistry classroom environment. Pretest-posttest and a final written examination were used to measure students' chemistry academic performance.

3.2.1 TOLT (Predictor of Student Performance)

This test has been used with students from grades seven to college. The range of scores possible on the test is 0-10 and the average score for eleventh grade chemistry students is approximately 4.5 out of 10. The reliability of this test ranges from 0.80 to 0.85 (Tobin & Capie, 1981). In evaluating the overall TOLT score for an individual student, a score below 5 would predict that the student may have difficulty with chemistry, especially with quantitative aspects (Tobin & Capie, 1981). The TOLT provides a convenient means of obtaining valid and reliable measures of formal reasoning ability and is, therefore, a useful tool for predicting individual student performance in chemistry (Tobin & Capie, 1981). The TOLT has potential applications for research in teaching and learning. It can be used as the dependent measure in studies concerned with variables influencing formal reasoning.

Development of the TOLT was directed primarily toward a paper and pencil test of formal reasoning ability with rigorous psychometric properties (Tobin & Capie, 1981). Three samples were used in the investigation of the reliability and validity of the TOLT. It was administered to a sample of 353 students in middle school grades 6, 7, and 8; a sample of 82 physics students from grades 11 and 12; and, 247 students enrolled in college science courses (Tobin & Capie, 1984). Prior research (Renner & Grant, 1978) had shown the developmental levels of physics students to be distributed differently from developmental levels of other students.

The internal consistency of the TOLT was assessed from the complete data set (n=682) using the alpha reliability coefficient (Cronbach, 1951) which was 0.85 (Tobin & Capie, 1980). The internal consistency of each two-item subtest ranged from 0.56-0.85 (Tobin & Capie, 1980). These figures exceed the threshold of 0.60 given by Nunally (1967), except for one pair (0.56), as being acceptable reliability for research. Descriptive data related to the items and subtests of the TOLT are contained in Table 3-1.

Table 3.1 Descriptive Data for the TOLT

Item Coefficient		Possible Score	Mean	Standard Deviation	Alpha
Item 1:	Proportional Reasoning	1	.24	.42	
Item 2:	Proportional Reasoning	1	.18	.38	
Subtest:	Proportional Reasoning	2	.41	.75	.82
Item 3:	Controlling Variables	1	.33	.47	
Item 4:	Controlling Variables	1	.36	.48	
Subtest:	Controlling Variables	2	.69	.87	.82
Item 5:	Probabilistic Reasoning	1	.33	.47	
Item 6:	Probabilistic Reasoning	1	.38	.48	
Subtest:	Probabilistic Reasoning	2	.71	.81	.61
Item 7:	Correlational Reasoning	1	.41	.49	
Item 8:	Correlational Reasoning	1	.28	.45	
Subtest:	Correlational Reasoning	2	.69	.78	.56
Item 9:	Combinatorial Reasoning	1	.21	.41	
Item 10:	Combinatorial Reasoning	1	.23	.42	
Subtest:	Combinatorial Reasoning	2	.44	.73	.71
Total:		10	2.94	2.94	.85

n = 682
p<.001
Table reproduced from Tobin & Capie, 1980

3.2.2 True Colors (Predictor of Student Performance)

True Colors is a professionally developed and marketed adaptation of the Myers-Briggs Type Indicator, MBTI. Whereas the MBTI states that human behavior is quite orderly and can be characterized by 16 different personality types (Myers, 1962), the True Colors personality profile test utilizes four categories (Kalil & Lowery). Research information for True Colors has been accumulated for over 16,000 individuals (Kalil & Lowery, 1989). These data show a strong correlation between that reported by Myers-Briggs, as well as Keirsey and his temperament theory model (Keirsey, 1984).

Research has shown correlational comparisons (Tucker & Gillespie, 1993) between the Myers-Briggs Type Indicator and the Keirsey Temperament Sorter. Values of 0.68 to 0.86 ($p < 0.001$) suggest that there is a distinct correlation between the MBTI and Temperament Sorter. Additional research has shown that both instruments are reliable tools for determining an individual's personality type (Quinn, Lewis, & Fischer, 1992).

Research on the MBTI, like True Colors, has discovered relationships with the Gregoric Style Delineator (Drummond & Stoddard, 1992). For example, the correlation between Concrete Sequential and Sensing was 0.615 ($p < 0.001$), between Concrete Random and Sensing was -0.650 ($p < 0.001$), between Abstract Sequential and Sensing 0.337 ($p < 0.001$), and between Abstract Random and Sensing -0.356 ($p < 0.001$)

(Drummond & Stoddard, 1992). Similar correlations were compiled with Intuition.

Keirsey has been refining the work of Myers Briggs for the past 35 years. His book, *Please Understand Me,* reflects the basis of the "True Colors" philosophy. In True Colors language, which is developed from Keirsey's temperament theory model, the True Colors personality profile test utilizes four categories. In temperament language (Keirsey, 1984) the four categories are: *Intuitive-Feeling* = Blue, *Intuitive-Thinking* = Green, *Sensing-Judgment* = Gold, *Sensing-Perception* = Orange. The True Colors program is based on a large body of research (The 21st Century School Improvement Program, 1995) which indicates that people are predisposed to be motivated by certain messages and will respond with positive behaviors to specific enhancing messages and experiences. The True Colors personality profiles test attempts to provide information in order to easily convey messages to simplify understanding, to identify and teach individual learning styles, and to capitalize on the natural motivational characteristics of each individual.

The learning style for a student with a predominantly Orange personality profile is one of an active hands-on learner. This type of student prefers to participate actively in learning activities and is sometimes considered hyperactive with excessive energy. Teachers characterized as Orange like a management style that is unencumbered by theoretical approaches and includes activities that show direct and immediate benefits. Spontaneous by nature, this teacher prefers an informal and unstructured learning environment. An Orange teacher designs learning activities that are action-oriented and stimulated through competition and accomplishment.

The learning style for a student with predominantly Gold personality profile is primarily a structured learner who does best in an orderly classroom environment. This type of student expects to have clear instructions and will follow rules easily. Teachers characterized as Gold place great value on creating a structure that promotes responsible behavior. The classroom environment must be orderly and assigned seating is a norm. A Gold teacher is an organizer by nature and prefers to keep a class focused on the current task and moving toward a defined goal.

The learning style for a student with a predominantly Green personality profile is an interactive learner who does best when in communicative, interactive groups. This type of student is very responsive to people-related learning activities. Teachers characterized as Green are independent by nature and frequently implement structure only to discover it limits individual autonomy. The highest priority for a Green instructor in the teaching-learning process is to organize and design a "perfect" environment.

The learning style for a student with a predominantly Blue personality profile is an independent learner who prefers learning more abstract principles and likes research and independent study projects. Teachers characterized as Blue create classroom environments that are informal in order to foster teacher-student interaction. The development of students' potential is of key importance.

True Colors is a test used by school districts in the United States to categorize student learning styles by personality types. The True Colors adaptation to the MBTI was chosen for this study because it has been used widely to assess scientific personalities (Myers, 1962). Baker (1985) has reported the predictive validity of personality on science achievement.

This instrument has been developed and tested professionally in educational settings since 1988 and used in this action researcher's chemistry classroom since 1990. Studies overviewed by Fraser (1986a) show that other researchers have illustrated that classroom environment varies with such factors as personality, specifically teacher personality (Kent & Fisher, 1997). Therefore, the classroom environment could be expected to vary with the students' personalities. The use of True Colors as a predictor of academic performance is another feature unique to this study. A copy of the True Colors test is in Appendix A of this thesis.

3.2.3 ICEQ & OICEQ (Perceptions of Learning Environments)

3.2.3.1 Development and Description of the ICEQ

The ICEQ instrument was developed particularly for use in science education research to assess students' perceptions of classroom learning environments. Students' perceptions of a chemistry classroom environment were measured by the ICEQ short form (Fraser, 1990).

The initial development of the ICEQ long form was guided by several criteria, as described by Rentoul and Fraser (1979) and Fraser (1980b). First, dimensions chosen characterized the classroom learning environment described in individualized curriculum materials and in the literature of individualized education, including open and inquiry based classrooms (Rathbone, 1971; Walberg & Thomas 1972; Weisgerber, 1971). Second, extensive interviewing of teachers and secondary school students ensured that the ICEQ's dimensions and individual items were considered salient by teachers and students. Third, in order to achieve economy in answering and processing, the ICEQ was designed to have a relatively small number of reliable scales. Fourth, data collected during field testing were subjected to item analyses in order to identify items whose removal would enhance scale statistics.

The final published version of the ICEQ long form (Fraser, 1990) contains 50 items. An equal number of each of the 50 items is assigned to one of five scales: Personalization, Participation, Independence, Investigation, and Differentiation. The use of these scales provides coverage of the three dimensions identified by Moos (1974) for conceptualizing all human environments. Table 3.2 shows the classification of each scale of the ICEQ according to Moos' scheme and provides a descriptive example for each scale.

Students respond to each item of the ICEQ on a five-point Likert scale, with the alternative responses being *Almost Never*, *Seldom*, *Sometimes*, *Often*, and *Very Often*. The scoring direction is reversed for many items. Many classroom environment research instruments, such as the ICEQ, have two versions, an "actual" version and a "preferred" version. While responding to the actual version, students provide information about the classroom environment as they actually perceive it. When responding to the preferred version, students provide information about the classroom environment as they ideally or preferably perceive it. Also, the ICEQ long form can be taken by both students and teachers. Research into differences between forms reported by Fisher and Fraser (1983) revealed that first, students preferred a more positive classroom environment than they perceived to be present, and, second, teachers perceived a more positive classroom environment than did their students in the same classrooms.

Table 3.2 Descriptive Information for Each Scale of the ICEQ

Scale Name	Moos Category	Sample Item
Personalization	R	The teacher talks to each student.
Participation	R	The teacher talks rather than listens.
Independence	P	Students choose their partners for group.
Investigation	P	Students draw conclusions from information.
Differentiation	S	All students in the class use the same textbooks.

R: Relationship Dimension; P: Personal Development Dimension; S: System Maintenance and System Change Dimension.

Source: Fraser (1993b)

The ICEQ (Fraser, 1990) measures students' perceptions of learning environments. Instruments like the ICEQ, that are measures of learning environments, generally measure attitudes and motivation rather than ability and achievement (Fraser, 1993b). In summary, the ICEQ has several distinguishing features. First, it assesses those dimensions which distinguish individualized classrooms from conventional ones (Personalization, Participation, Independence, Investigation, and Differentiation). Second, in addition to measuring the actual classroom environment, it has a form that assesses the preferred classroom environment. Third, it can be used with either students or teachers. Fourth, the instrument has a short form which can be used to provide a rapid and economical measure of classroom environment as requested by some researchers and teachers (Fraser & Fisher, 1983c).

Table 3.3 Internal Consistency (Cronbach Alpha Coefficient), Discriminant Validity (Mean Correlation with Other Scales) for Two Units of Analysis of ICEQ Long Form

Scale	Unit of Analysis	Alpha Reliability		Mean Correlation with Other Scales	
		Actual	Preferred	Actual	Preferred
Personalization	Individual	0.79	0.74	0.28	0.31
Participation	Individual	0.70	0.67	0.27	0.29
	Class Mean	0.80	0.75	0.32	0.32
Independence	Individual	0.68	0.70	0.07	0.12
	Class Mean	0.78	0.79	0.16	0.17
Investigation	Individual	0.71	0.75	0.21	0.27
	Class Mean	0.77	0.83	0.29	0.31
Differentiation	Individual	0.76	0.75	0.10	0.16
	Class Mean	0.91	0.92	0.19	0.20

n = 1849 for the actual form
n = 1858 for the preferred form
The sample consisted of 150 classes.
Source: Fraser (1993)

The development of the short form of the ICEQ provided an instrument that was reduced to 25 items instead of 50 which provides greater economy in administering, testing, and scoring. The ICEQ short form used in this study is a five scale test with 5 items in each scale. Unlike the long form of the ICEQ, the short form does not make use of a separate answer sheet since all items and space for responding fit on a single page. The selection of items for the ICEQ short form was based largely on the results of several item analyses that indicated which items retained acceptable internal consistency and discriminant validity (Fraser & Fisher, 1983d).

Copies of the 'Actual' and 'Preferred' versions of the 25-item ICEQ used in this study are given in Appendix B of this thesis.

3.2.3.2 Reliability and Validity of the ICEQ in Previous Research

Rentoul & Fraser (1980) and Wierstra (1984, 1987), reported field testing of the ICEQ in Australia and The Netherlands confirmed this instrument's reliability and validity. The studies have involved both junior high and secondary students in science classes. The studies involved outcome measures such as achievement, attitudes, and inquiry skills.

Fraser & Fisher (1983d) reported reliability and validity of the ICEQ short form. The figures in Table 3.4 show that the correlations between the ICEQ long form and the ICEQ short form ranged from 0.84 to 0.97. The alpha reliability coefficients for each scale ranged from 0.74-0.92 in the ICEQ long form to 0.63-0.85 in the ICEQ short form. Mean interscale correlations are low enough (0.17-0.37 ICEQ long form, 0.13-0.36 ICEQ short form) to confirm discriminant validity of the ICEQ short form, indicating that each scale measures distinct (although somewhat overlapping) aspects of the classroom environment.

Table 3.4 Correlation between Long Form ICEQ and Short Form ICEQ and Alpha Reliability (Internal Consistency), Mean Correlation with Other Scales (Discriminant Validity)

ICEQ	Correl. between Form Short Form & Long Form		Alpha Reliability		Mean Correl. with Other Scales	
			Long Form	Short Form	Long Form	Short Form
Personalization	0.95	Actual	0.88	0.83	0.36	0.30
	0.94	Preferred	0.82	0.73	0.35	0.35
Participation	0.92	Actual	0.78	0.73	0.35	0.29
	0.91	Preferred	0.74	0.70	0.37	0.36
Independence	0.84	Actual	0.78	0.70	0.16	0.15
	0.84	Preferred	0.79	0.75	0.17	0.20
Investigation	0.91	Actual	0.74	0.69	0.32	0.34
	0.93	Preferred	0.83	0.63	0.37	0.36
Differentiation	0.97	Actual	0.92	0.85	0.29	0.25
	0.97	Preferred	0.88	0.84	0.18	0.13

Source: Fraser & Fisher (1983c)

3.2.3.3 Previous Studies Involving the ICEQ

Fraser (1993) has tabulated a set of 40 past studies in which the effects of classroom environment on student outcome were investigated. Fraser's research shows that studies of associations between outcome measures and classroom environment perceptions have involved a variety of cognitive and affective outcomes measures, classroom environment instruments, and samples.

The practical application of research investigating associations between student outcomes and classroom environment is that student outcomes might be improved by creating a classroom environment found empirically to be conducive to learning (Fraser, Giddings, & McRobbie, 1991). A preliminary study involving the use of the actual form of the ICEQ among 285 students in 15 classes revealed that ICEQ scores were significantly related to an attitudinal outcome but not with two cognitive outcomes (Rentoul & Fraser, 1980).

The ICEQ permits exploration of whether students achieve better when there is higher similarity between the actual and preferred classroom environments. Such research is an example of what is referred to as person-environment fit research (Hunt, 1975). The Rentoul and Fraser (1980) study, using the student as the unit of analysis, and multiple regression analyses, showed that student outcomes were enhanced only among students who had higher preferences for individualization. Conversely, higher levels of actual individualization seemed to diminish achievement outcomes among students with lower preferences for individualization.

The initial person-environment fit study has been replicated with a large sample consisting of 116 classes (Fraser & Fisher, 1983b). Fraser and Fisher (1982) reported a study of the effects of classroom environment on student outcomes involving a representative sample of 116 Grade 8 and 9 science classes, each with a different teacher, in 33 different schools. This study also indicated that students achieved better results when operating in their preferred classroom learning environments.

Another study involving 320 students in 14 science classes confirmed the existence of associations between several attitudinal outcomes and the degree of classroom individualization as measured by the ICEQ (Fraser, 1981; Fraser & Butts, 1982).

Further research reported by Fisher and Fraser (1983) revealed that, first, students preferred a more positive classroom environment than was perceived to be present, and second, teachers perceived a more positive classroom environment than did their students in the same classrooms. These patterns were also apparent in other studies in school classrooms in the USA, Israel, and Australia (Fraser, 1993a). Other studies, similar in nature to this investigation, have confirmed specific associations between the ICEQ and academic performance (Wiestra, 1987; Payne 1974-75; Ellett, 1977; Ellett & Walberg, 1979).

3.2.3.4 Development of the OICEQ

The OICEQ is a modified version of the ICEQ, as described earlier. The modification of the instrument entailed administering the ICEQ orally, rather than with pencil and paper. This required the use of a reader, recorder, and reporter. Other than administering the test orally, the OICEQ is the same as the ICEQ short form (five scales with five items in each scale). The figures presented in Table 3.5 show correlations between the ICEQ short form and the OICEQ short form for each scale which ranged from 0.56 to 0.81. The alpha reliability coefficients for each scale ranged from 0.42-0.83 in the ICEQ short form to 0.60-0.81 in the OICEQ short form. Mean interscale correlations are low enough (0.13-0.36 ICEQ short form, 0.17-0.35 OICEQ short form) to confirm discriminant validity of the OICEQ, indicating that each scale measures distinct (although somewhat overlapping) aspects of the classroom environment.

Table 3.5 Validation of OICEQ Short Form: Correlation between Short Form ICEQ and Short Form OICEQ and Alpha Reliability (Internal Consistency), Mean Correlation with Other Scales (Discriminant Validity)

Scale	Correl. between ICEQ & OICEQ Short Form	Form	Alpha Reliability ICEQ Short Form	Alpha Reliability OICEQ Short Form	Mean Correl. with Other Scales ICEQ Short Form	Mean Correl. with Other Scales OICEQ Short Form
ICEQ & OICEQ						
Personalization	0.81	Actual	0.83	0.81	0.30	0.17
	0.79	Preferred	0.73	0.76	0.35	0.21
Participation	0.67	Actual	0.73	0.60	0.29	0.24
	0.68	Preferred	0.70	0.61	0.36	0.33
Independence	0.57	Actual	0.70	0.73	0.15	0.22
	0.60	Preferred	0.75	0.85	0.20	0.24
Investigation	0.61	Actual	0.69	0.72	0.34	0.32
	0.62	Preferred	0.63	0.77	0.36	0.35
Differentiation	0.57	Actual	0.56	0.69	0.25	0.34
	0.54	Preferred	0.42	0.74	0.13	0.28

n = 473 The values for the OICEQ sample consisted of 473 secondary chemistry students in 21 classes.
The values for the ICEQ see Fraser & Fisher, 1984.

Like the ICEQ, the OICEQ has an "actual" version and a "preferred" version. Research studies have implied that an increased consonance between students' actual and preferred environments could enhance student performance outcomes (Fraser, 1994; Fraser & Fisher, 1983b).

Teachers that compare the results of the actual environment to the preferred environment are provided with an opportunity to modify the classroom environment so that the actual and preferred environments are in alignment. Research studies continue to explore the association between the learning environment and student performance (Moriarty, Douglas, Punch, & Hattie, 1995).

The OICEQ was developed and validated in order to provide a statistical comparison between student's written results from the ICEQ and oral results from the OICEQ. The OICEQ and ICEQ will act as mediating variables between the instruments used for academic predictors and performances in the chemistry classroom. Statistical comparisons will be drawn between the OICEQ and ICEQ, predictors of academic achievement, and academic performance.

3.2.4 Teacher-Developed Tests (Academic Performance)

Two teacher-developed tests were administered during the course of this research study; a pretest and posttest and a final written examination. These instruments have been specifically designed for evaluation of chemistry academic performance.

Teacher-developed tests, the most widely used tests for measurement of learning in the classroom, and possibly the most valid, will be the instruments used to measure chemistry achievement. Pretest-posttest gain scores have been found to be consistently and strongly associated with cognitive learning outcomes (Fraser & Fisher, 1994). Final examinations and performance on academic achievement tests, have also been utilized in association with learning environments (Henderson, Fisher, & Fraser, 1994).

The pretest (50 items), posttest (50 items), and final written examination (80 items) used in this study consist of multiple-choice questions designed to evaluate course syllabus objectives and emulate questions (in content and context) placed on the nationally standardized achievement tests. Grades 11-12 students are required to take nationally standardized achievement tests for entrance into American universities. The questions on each of the tests are also designed to test students' knowledge of key facts and their ability to access, research, analyze and make predictions (A.R.A.P.) in order to solve problems. The chemistry pretest and posttest and the final examination used in this study are modeled after the SAT (Scholastic Aptitude Test) and the ACT (American College Test) in basic structure and content. These instruments have been developed, tested, and retested in chemistry educational settings since 1985 and used in this action researcher's chemistry classroom since 1986. Sample questions from the pretest, posttest, and final written examination are found in Appendix C of this thesis.

3.3 Methodology

Because of the importance of predictors of learning, perceptions of learning environments, and subsequent student achievement, a continuing investigation of the three forms of assessment was conducted over three years in the chemistry classroom.

The organizational scheme for this study involved administering the three forms of assessment (predictors, perceptions, and performances) to each class of students each year.

Action research was the method for evaluating a constructivist chemistry classroom and the chaos of assessment. The research methodology of this study utilized a constructivist chemistry teacher as the primary researcher to design, collect, and analyze the data from three types of science educational assessments; predictors, perceptions, and performance. Two instruments were used for each type of assessment.

3.3.1 Sample

This study focuses on students in secondary chemistry classes in Maize, Kansas, USA. The sample consisted of students studying Chemistry in the secondary grades, 11 and 12, in 21 Chemistry classes, with one teacher, in one public education school in the United States. The sample consisted of one sample of students in both Chemistry I and Chemistry II classes each year for a three-year period of time in which the curriculum and the tests remained the same. The sample contained 473 students; 249 females and 224 males.

The secondary chemistry courses are one year in duration with a total teaching time of approximately 190 hours. Students in the state of Kansas are required to take two years of science; one year of physical science and one year of life science. Chemistry is generally an elective class for most students. Chemistry I (introductory chemistry) and Chemistry II (advanced placement chemistry) are two offerings in the physical science category.

3.3.2 Procedure

The researcher administered the instruments to 21 classes of Chemistry students each year for a three year time period (three school years). The instruments used for predicting achievement (TOLT and True Colors) were administered at the start of each school year for three school years beginning in September of 1993. The classroom environment questionnaires and the instruments used for measuring achievement performance were administered at the conclusion of each of the three school years (May of 1994 - 1996). The data collected over the three-year period were analyzed as one set of data. All data were collected from chemistry classes in one instructor's class -- this action researcher's constructivist chemistry classroom.

Approximately one hour was required to administer both the ICEQ and the OICEQ forms. The OICEQ was administered privately and individually three days after the ICEQ. The OICEQ process involved a reader, recorder, reporter (scale translator). Students scheduled appointments during scheduled class time to complete the OICEQ. The remaining forms (TOLT, True Colors, Pretest, Post-test, and Final exam) were part of the traditional class format (as listed in the class syllabus) and were not considered invasive or disruptive.

3.3.3 Data Collection and Analysis

All test instruments were hand-scored by a battery of paraprofessionals, with periodic checks for errors. Upon completion of the scoring, all data were compiled and calculated by professional statisticians at Wichita State University utilizing the SPSS, Version 4.1.

The types of statistical measures used to analyze the results of the study were:

1. To validate the structure of the OICEQ (<u>objective #1</u>), as reported in Chapter 4:
    a. alpha reliability for internal consistency,
    b. mean correlation as discriminant validity,
    c. correlation between OICEQ and ICEQ.
2. Regression analysis and correlations were used to investigate the relationship between chemistry students' perceptions of the classroom environment and the prediction and measurement of chemistry performance. (<u>objective #2</u>)

The chemistry classroom as perceived by students was measured using the short form of the actual and preferred versions of the Individualised Classroom Environment Questionnaire (ICEQ) designed by Fraser (1990). The modified version of the short form ICEQ, the Oral

Individualized Classroom Environment Questionnaire (OICEQ), was also utilized. Transcripts of the oral interviews conducted for the OICEQ were compiled. The data reported used both the individual and the class mean as the unit of analysis.

The Test of Logical Thinking (TOLT) and the professionally developed adaptation of Myers-Briggs Type Indicator, True Colors personality profiles, were used as predictors of chemistry achievement. The data reported used the individual as the unit of analysis.

A previously validated pretest and posttest along with a final exam were utilized to measure student outcomes. The data reported used the individual as the unit of analysis. The pretest and posttest were norm-referenced and criterion-referenced tests. The tests were validated through the administration, and subsequent item analysis, of the test to both university and high school students over a three-year period of time. The sample population consisted of 739 chemistry students.

The statistical analyses conducted in the action research study assisted in providing answers to the two research questions:

1. Are chaos and constructivism allies or adversaries to assessment? (objective #3)
2. Is action research a valid process of evaluating a constructivist chemistry classroom? (objective #4)

3.4 Summary

Because this study centers on chemistry students in Maize, Kansas, USA, this chapter describes the situation in which nearly all of the students taking chemistry courses offered from 1994-96 participated in the study. Almost all students in the sample completed actual and preferred versions of the ICEQ and OICEQ, the TOLT, True Colors, a pretest, posttest and final examination.

This chapter identifies the importance of a holistic/triangulation approach to instrumentation and methodology for this research study. This can be accomplished by employing instrumentation and methodology that measure student predictors, perceptions, and performances. It is appropriate to obtain information about a learning environment from those who are actively involved in constructing, sustaining, and changing it; classroom teachers and their students. This is achieved through action research (Kuh, 1995). Data utilized in profiling or portraying the socio-psychological processes and operating norms which comprise the learning environments of schools is obtained from on-site school professionals, support personnel, and students (The 21st Century School Improvement Program, 1995). Professional and support personnel provide data through which overall school climate dimensions are constructed. Students provide data through which class climate dimensions, as well as perceptions of themselves as learners, are profiled. Classroom climates are not properties of the school itself, but result from the interactions of those who participate in the social processes occurring within the organizational contexts of schools (The 21st Century School Improvement Program, 1995). This type of research instrumentation and methodology adheres and applies to this particular view and perception.

The self-evaluation aspect of action-research is congruent with the philosophies contained in Total Quality Education and Outcomes Based Education (National Research Council, 1994). Chemistry teachers need to view the totality of the classroom, not a fragment, in order to make valid decisions regarding the learning environment. Personality profiles of students, student perceptions of the classroom environment (laboratory, demonstrations, projects, activities, testing, portfolios, etc.), and teacher-developed evaluation instruments (test, portfolios, etc.) are variables that impact learning and the learning process. Learning is a process of infinite, sometimes identifiable variables and utilizing only one of those variables for research can be misleading and unreliable.

From an action researcher's standpoint, the use of a holistic approach to assessment (the use of predictors, perceptions, and performance) is valid and reliable. The use of pretests and posttests and a final examination as indicators of chemistry academic performance, along with predictors of performance and students' perceptions of the classroom environment contribute to make this study an unrivaled science education research investigation.

Chapter 4

Data Collection: Validation and Descriptive Information For Predictors, Perceptions, and Performances

4.1 Introduction

One objective of this study was to describe the senior chemistry students' perceptions of their actual classroom environments and to compare these perceptions with students' ideal or preferred learning environments using the ICEQ short form and the OICEQ short form.

As mentioned in Chapter Three of this thesis, previous research has indicated differences in students' perceptions of their actual and their ideal or preferred environment (e.g. Fraser 1991; Hofstein & Lazarowitz, 1986; Levy, Creton & Wubbles, 1993; Raviv, Raviv, & Reisel, 1990; Wong & Fraser, 1994). Generally, it has been found that students prefer a more positive learning environment than they perceive to be present (Fraser, 1994).

In this chapter, descriptive statistics are used to address the reliability and validity of the ICEQ and the OICEQ (perceptions) and the internal consistency of the TOLT (predictor), pretest-posttest (performance), and the final examination (performance). Students' responses to the ICEQ and OICEQ are used to compare students' perceptions of the actual learning environments with the learning environments they prefer.

4.2 Reliability and Validity of Instruments

4.2.1 The ICEQ (Perceptions)

Table 4.1 reports two sets of reliability, validity, and ANOVA statistics for the 25-item version of the ICEQ short form used with the present sample of 473 students in 21 chemistry classes. Cronbach's (1951) alpha coefficient was used as an index of internal consistency (the extent to which items in the same scale measure the same dimension), the mean correlation of a scale with the other scales was used to measure the discriminant validity and the *eta*^{2} statistic represents the proportion explained by class membership. Consistent with previous research, statistics are reported for two units of analysis, namely, the student's score and the class mean score. As expected, reliabilities for class means are higher than those where the individual is used as the unit of analysis.

Table 4.1 shows that the alpha reliability for different scales of the actual form of the ICEQ range from 0.56 to 0.83 when the individual student is used as the unit of analysis, and from 0.59 to 0.94 when the class mean is used as the unit of analysis. These figures for the 25-item short form version of the ICEQ are similar to those obtained by Fraser & Fisher (1983c) where scale ranges were from 0.63 to 0.85 for the individual and 0.68 to 0.87 for the class mean. Table 4.1 shows that, for the preferred version of the ICEQ, alpha reliability figures for the different scales range from 0.42 to 0.75 when the individual student is used as the unit of analysis, and from 0.47 to 0.88 when the class mean is used as the unit of analysis. The low results, 0.42 and 0.47, come from the Differentiation scale which needs to be interpreted with care as this scale has proved to be problematic in previous research studies.

The mean correlation of a scale with other scales was used as a convenient measure of the discriminant validity of the ICEQ. For the actual version, the mean correlation ranged from 0.15 to 0.34 with the individual as the unit of analysis and from 0.28 to 0.42 for class means. For the preferred version, figures range from 0.13 to 0.36 with the student as the unit of analysis and from 0.27 to 0.49 when class means are used. These figures indicate that the ICEQ measures distinct (although somewhat overlapping) aspects of the classroom learning environment. Reliability figures obtained in this study are similar to those reported by Fraser (1993) when the individual is used as the unit of analysis, 0.67 to 0.92 and 0.86 to 0.92 when class means are used.

Another desirable characteristic of any instrument like the ICEQ is that it is capable of differentiating between the perceptions of students in different classrooms (Fraser, McRobbie, & Giddings, 1993). That is, students within the same class should have similar perceptions while the class mean should vary from class to class. This characteristic was investigated for each scale of the ICEQ using one-way ANOVA, with class membership as the main effect. Table 4.1 indicates that each ICEQ scale differentiated significantly ($p<0.001$) between classes and that the eta^2 statistic, representing the proportion of variance explained by class membership, ranged from 0.12 to 0.34 for different scales.

Table 4.1 Internal Consistency (Cronbach Alpha Coefficient), Discriminant Validity (Mean Correlation with Other Scales) and Ability to Differentiate Between Classrooms for the ICEQ Short Form

Scale	Unit of Analysis	Alpha Reliability		Mean Correlation with Other Scales		ANOVA Results (eta^2)
		Actual	Preferred	Actual	Preferred	
Personalization	Individual	0.83	0.73	0.30	0.35	0.34*
	Class Mean	0.94	0.81	0.30	0.27	
Participation	Individual	0.73	0.70	0.29	0.36	0.20*
	Class Mean	0.83	0.88	0.37	0.35	
Independence	Individual	0.70	0.75	0.15	0.20	0.30*
	Class Mean	0.72	0.82	0.28	0.36	
Investigation	Individual	0.69	0.63	0.25	0.13	0.24*
	Class Mean	0.84	0.72	0.36	0.49	
Differentiation	Individual	0.56	0.42	0.34	0.28	0.12*
	Class Mean	0.59	0.47	0.42	0.36	

n = 473 The sample consisted of 473 secondary chemistry students in 21classes.
*$p < .001$

Table 4.2 shows that the alpha reliability for different scales in the actual form of the OICEQ range from 0.60 to 0.81 when the individual student is used as the unit of analysis, and from 0.71 to 0.92 when the class mean is used as the unit of analysis. These figures for the OICEQ short form are representative of those obtained from Fisher (1992). Table 4.2 shows that, for the preferred version of the OICEQ, alpha reliability figures for the different scales range from 0.61 to 0.85 when the individual student is used as the unit of analysis, and from 0.69 to 0.94 when the class mean is used as the unit of analysis.

The mean correlation of a scale with other scales was used as a convenient measure of the discriminant validity of the OICEQ. For the actual version, mean correlation ranged from 0.17 to 0.34 with the individual as the unit of analysis and from 0.22 to 0.43 for class means. For the preferred version, figures range from 0.21 to 0.35 with the student as the unit of analysis and from 0.31 to 0.42 when class means are used.

Using the one-way ANOVA, with class membership as the main effect, Table 4.2 indicates that each OICEQ scale differentiated significantly ($p<0.001$) between classes and that the eta^2 statistic, representing the proportion of variance explained by class membership, ranged from 0.23 to 0.43 for different scales.

This is the first reported use of the statistical data (alpha reliability, mean correlation, and ANOVA) with the 25-item short form version of the OICEQ.

The correlations between the ICEQ and the OICEQ, particularly, the low correlations, will be addressed in Chapter 5.

Table 4.2 Internal Consistency (Cronbach Alpha Coefficient), Discriminant Validity (Mean Correlation with Other Scales) and Ability to Differentiate Between Classrooms for the OICEQ Short Form

Scale	Unit of Analysis	Alpha Reliability		Mean Correlation with Other Scales		ANOVA Results (eta^2)
		Actual	Preferred	Actual	Preferred	
Personalization	Individual	0.81	0.71	0.17	0.21	0.43*
	Class Mean	0.92	0.94	0.22	0.36	
Participation	Individual	0.60	0.61	0.24	0.33	0.28*
	Class Mean	0.71	0.69	0.33	0.40	
Independence	Individual	0.73	0.85	0.22	0.24	0.37*
	Class Mean	0.75	0.80	0.28	0.31	
Investigation	Individual	0.72	0.77	0.32	0.35	0.41*
	Class Mean	0.88	0.78	0.43	0.42	
Differentiation	Individual	0.69	0.74	0.34	0.28	0.23*
	Class Mean	0.72	0.86	0.38	0.34	

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes.
*$p < 0.001$

4.2.2 *The OICEQ (Perceptions)*

Table 4.3 contains information about the validation data for the OICEQ short form. The table contains statistical correlations, alpha reliabilities, and mean correlations with other scales and comparisons with the ICEQ. The figures presented in Table 4.3 show correlations between the ICEQ short form and the OICEQ short form for each scale which range from 0.54 to 0.81. The alpha reliability coefficients range from 0.60 to 0.85 in the OICEQ short form. Mean interscale correlations are low enough (0.17-0.35) to confirm the discriminant validity of the OICEQ and indicate that each of the scales measure distinct (although somewhat overlapping) aspects of the classroom environment.

Table 4.3 Validation of OICEQ Short Form: Correlation between Short Form ICEQ and Short Form OICEQ and Alpha Reliability (Internal Consistency), Mean Correlation with Other Scales (Discriminant Validity)

Scale	Correl. between ICEQ & OICEQ Short Form	Form	Alpha Reliability ICEQ Short Form	Alpha Reliability OICEQ Short Form	Mean Correl. with Other Scales ICEQ Short Form	Mean Correl. with Other Scales OICEQ Short Form
ICEQ & OICEQ						
Personalization	0.81	Actual	0.83	0.81	0.30	0.17
	0.79	Preferred	0.73	0.71	0.35	0.21
Participation	0.67	Actual	0.73	0.60	0.29	0.24
	0.68	Preferred	0.70	0.61	0.36	0.33
Independence	0.57	Actual	0.70	0.73	0.15	0.22
	0.60	Preferred	0.70	0.85	0.20	0.24
Investigation	0.61	Actual	0.69	0.72	0.34	0.32
	0.62	Preferred	0.63	0.77	0.36	0.35
Differentiation	0.57	Actual	0.56	0.69	0.25	0.34
	0.54	Preferred	0.42	0.74	0.13	0.28

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes.

4.2.3 TOLT (Predictor), Pretest-Posttest(Performance), Final Examination (Performance)

This study used a predictor of performance entitled *Test of Logical Thinking* (TOLT) as described in Section 3.3.1. For the present sample, the 10-item TOLT was found to have an alpha reliability of 0.79 with the individual student as the unit of analysis and 0.81 when class means were used.

As mentioned in Section 3.3.4, instruments used for academic performance, pretest, posttest, and final written examination, have been developed and tested and re-tested in chemistry educational settings since 1985. These instruments have been used in this action researcher's chemistry classroom since 1986. For this study, the 50-item pretest-posttest is found to have an alpha reliability of 0.69 with the individual student as the unit of analysis and 0.70 when class means were used. The statistical information for the final examination consists of an alpha reliability of 0.72 with the student as the unit of analysis and 0.76 when class means are used. These figures indicate that both instruments have acceptable internal consistency.

4.3 Student Perceptions of the Classroom Environment: The ICEQ

As mentioned previously, each of the 25 items of the ICEQ is allocated to one of 5 scales, with each scale having 5 items. To enable comparison between students' actual and preferred perceptions of the classroom environment, mean scores for each scale have been calculated. Because students responded to each item on a five-point scale (from 1-5) and each scale has five items, the maximum score for each scale is 25. These scores, calculated separately for the individual student and the class mean as the units of analyses, are presented in Table 4.4.

Table 4.4 Scale Means and Standard Deviations for Actual and Preferred Versions of the ICEQ Short Form

Scale	Unit of Analysis	Actual Scale Mean (25 possible)	Actual Standard Deviation	Preferred Scale Mean (25 possible)	Preferred Standard Deviation	Mean Difference (Preferred-Actual)
Personalization	Individual	16.23	3.45	18.11	3.12	1.88*
	Class Mean	16.14	2.34	18.19	1.76	2.05*
Participation	Individual	17.37	4.38	17.64	2.58	0.27
	Class Mean	17.44	2.93	17.70	1.49	0.26
Independence	Individual	13.59	3.21	11.23	3.02	-2.36*
	Class Mean	13.64	1.25	11.28	1.24	-2.36*
Investigation	Individual	13.24	3.69	14.45	3.76	1.21*
	Class Mean	13.02	2.10	14.34	1.75	1.32*
Differentiation	Individual	19.59	3.71	19.32	2.59	-0.27
	Class Mean	19.52	1.79	19.26	0.90	-0.26

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes.
*$p<0.05$

The data indicate that, relative to the actual environment currently present, students prefer a classroom environment that is more personalized and provides for less independence among students. Students also prefer teachers that provide experiences that are investigative in nature.

4.4 Student Perceptions of Classroom Environment: The OICEQ

As mentioned in Chapter 3, the modification of the instrument involved administering the ICEQ orally, rather than with pencil and paper. This required a reader, a recorder, and a reporter. Other than an oral administration of the test, OICEQ is the same instrument. Test items and scales are identical to the ICEQ short form (five scales with five items in each scale). To enable comparison between students' actual and preferred perceptions of the classroom environment, mean scores for each scale have been calculated. Because students responded to each item on a five-point scale (from 1-5) and each scale has five items, the maximum score for each scale is 25. These scores, calculated separately for the individual student and the class mean as the units of analyses, are presented in Table 4.5.

Table 4.5 Scale Means and Standard Deviations for Actual and Preferred Versions of the OICEQ Short Form

Scale	Unit of Analysis	Actual Scale Mean (25 possible)	Actual Standard Deviation	Preferred Scale Mean (25 possible)	Preferred Standard Deviation	Mean Difference (Preferred-Actual)
Personalization	Individual	19.93	3.80	20.02	2.53	0.09
	Class Mean	19.95	1.71	20.21	0.86	0.26
Participation	Individual	19.45	3.62	19.10	2.47	-0.35
	Class Mean	19.51	2.04	19.16	1.02	-0.35
Independence	Individual	15.11	3.13	16.39	3.30	1.28*
	Class Mean	15.20	1.44	16.42	1.28	1.22*
Investigation	Individual	17.28	4.28	17.89	4.04	0.61*
	Class Mean	17.39	2.44	17.97	2.32	0.58*
Differentiation	Individual	18.36	4.52	16.36	3.90	-2.00*
	Class Mean	18.39	2.31	16.21	1.25	-2.18*

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes.
*$p<0.05$

The data indicate that, relative to the actual environment currently present, students prefer a classroom environment that is more independent and allows more investigation in the classroom setting. Utilizing the data collected from the OICEQ, students also appear to prefer less differentiation than their actual perceptions. These results are discussed further in Chapter 5.

4.5 Correlations Between the Predictors, Perceptions, and Performances

Table 4.6 reports the correlation coefficients between data collected for the predictors (TOLT & True Colors), perceptions (ICEQ & OICEQ), and performances (Pretest-Posttest & Final Exam) collected in this study. The sample consisted of 473 students in 21 chemistry classes. The individual is the unit of analysis for the table.

Table 4.6 is a 9x13 matrix composed of data collected for each instrument or category utilized in this study. The results for both the actual and preferred versions of the ICEQ and OICEQ are included, along with the collection of data for the four categories of personalities found in the True Colors test.

The results for Table 4.6 reveal a total of fifty-six significant correlations at the significance levels of $p<0.005$ and $p<0.001$. Thirty-eight of the correlations are significant at $p<0.05$. Eighteen of the correlations are significant at $p<0.001$.

The short form ICEQ and OICEQ are used in this study. The five scales (Personalization, Participation, Independence, Investigation, and Differentiation) have not been individually totaled. Rather, the five scales have been totaled. The total of the five item scores for each of the five scales have been added together to produce the total. A total score of 115 is possible (25 items multiplied times 5 points for each item). Data for these calculations will be discussed in Chapter 5.

Table 4.6 Correlation Coefficients Table: Predictors, Perceptions and Performances

Test Instr.	TOLT Test Predictor	True Colors Group 1 Predictor	True Colors Group 2 Predictor	True Colors Group 3 Predictor	True Colors Group 4 Predictor	ICEQ (Actual) Percep.	ICEQ (Pref.) Percep.	OICEQ (Actual) Percep.	OICEQ (Pref.) Percep.	Final Exam Perform.	Pretest Perform.	Posttest Perform.	Gain Score Perform.
TOLT Test	1.00	0.43**	0.22*	-0.03	0.50*	0.06	0.15*	0.39*	0.27	0.32*	0.18	0.42**	0.49**
ICEQ (Actual)	0.06	0.36	-0.47**	0.21	0.43**	1.00	0.19	0.49*	0.31	0.18	0.27*	0.04	0.35
ICEQ (Pref.)	0.15	0.26	0.05	0.47*	0.04	0.19	1.00	0.23	0.19	-0.07	-0.06	0.08	0.18
OICEQ (Actual)	0.39*	0.50*	0.32	0.20	0.43**	0.49*	0.23	1.00	0.73**	0.47*	-0.13	0.37*	0.49*
OICEQ (Pref.)	0.29	0.36*	0.30*	0.05	0.51**	0.31	0.19	0.73**	1.00	0.39*	0.51*	0.48*	0.40*
Final Exam	0.32*	0.50**	0.24	0.25	0.35*	0.06	-0.07	0.47*	0.39*	1.00	0.18	0.50**	0.39*
Pretest	0.18	0.33	-0.08	0.36*	0.18	0.27*	-0.06	-0.13	0.51*	0.18	1.00	0.41**	-0.53**
Posttest	0.42**	0.25	-0.34	0.21	-0.44*	0.04	0.08	0.37*	0.48*	0.50**	0.41**	1.00	0.48**
Gain Score	0.50**	0.50*	0.32	0.38*	0.41**	0.35*	019	0.49*	0.40*	0.39*	-0.53**	0.47**	1.00

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes. The individual is the unit of analysis.
$^*p < 0.05$, $^{**}p < 0.01$

Group 1 = Green (Intuitive-Thinking)
Group 2 = Gold (Sensing-Judgment)
Group 3 = Blue (Intuitive-Feeling)
Group 4 = Orange (Sensing-Perception)

4.6 Summary

This chapter reports data collection and the descriptive and validation statistics used to test the reliability and validity of the instruments used for measuring perceptions (ICEQ and OICEQ), predictions (TOLT and True Colors), and performances (pretest-posttest and final written examination). The statistics and descriptions presented justify the future use of the six instruments in secondary chemistry classes.

One purpose of this chapter was to report descriptive information about secondary chemistry students' perceptions of their classroom environment as measured by the OICEQ. This information has been used to validate the OICEQ for chemistry classroom settings in the USA secondary school. The reliability and validity of both the actual and preferred forms of the OICEQ have been shown to differentiate between students in different chemistry classes. The data presented also confirm the internal consistency and reliability of the OICEQ when used in secondary chemistry classes.

An additional objective of this chapter was to investigate associations between three types of assessments; (1) predictors of student achievement; (2) student perceptions of the learning environment; and (3) academic performance of students in a chemistry classroom. Six instruments were used for the collection of data to determine the statistical associations between the three types of assessments.

In general, previous research has been replicated as students were found to prefer a more positive learning environment than they perceived to be present. More specifically, the findings from this study are broadly similar to those from previous research involving the ICEQ. Most of the obvious discrepancies between students' actual and preferred learning environments apply to similar scales in the ICEQ. When interpreting data for the ICEQ results, the Differentiation and Participation scales provide data that is the most diversified and inconsistent. In this study, students' perceptions of Participation and Differentiation closely resembled the preferred perceptions. When interpreting data for the OICEQ results, Differentiation appears to be a lesser preference to students than their actual perception of the classroom environment. These results differ from the ICEQ and will be discussed further in Chapter 5. The statistical values fluctuate from the ICEQ to the OICEQ when making an overall comparison between the data for each of the five scales. The first four scales on Table 4.4 (Personalization, Participation, Independence, and Investigation) have lower mean scales as compared to the first four scales on Table 4.5. Table 4.4 contains data for the ICEQ short form and Table 4.5 contains data for the OICEQ short form. A potential explanation for the differences between the ICEQ results and the OICEQ results is chaos, changes in initial conditions create differences in final outcomes. The initial conditions in this study involved the ICEQ (a pencil and paper test) and conditions changed when the OICEQ (an oral test) was administered.

This chapter reports that there are significant correlations between the three types of assessment incorporated into this study. Correlations exist between predictors of chemistry students' achievement and their academic performance outcomes. Correlations are also present between predictors and students' perceptions of the chemistry classroom environment. Additionally, correlations exist between student perceptions of the classroom environment and academic performance of students in the chemistry classroom.

This study describes the first use of the OICEQ with a single sample population. Another distinctive feature of this study is that it focuses on three forms of assessment administered to students in grades 11-12 in chemistry classes in the USA. Most research studies involving the ICEQ have employed sample populations of students from middle school, general science, and in countries outside of the USA.

Chapter 5

Analysis and Reflection

5.1 Introduction

Two of the objectives of this study were to investigate the association of chaos to assessment in a constructivist chemistry classroom (Objective #3) and to provide a self-reflection on the validity of an action research process examining associations between chaos and constructivism in a constructivist chemistry classroom environment (Objective #4). In the first section of this chapter, results of statistical analyses of these associations are examined.

As previously mentioned, this study is the first to use both the OICEQ and the ICEQ with a single sample population. The use of the OICEQ will be justified in future research if it is found to have unique statistical significance with student academic performance outcomes (as measured by pretest-posttest and final examination) and student predictor outcomes. Therefore, simple and multiple correlations were used to determine significant associations between the OICEQ and ICEQ scales with performance outcomes and student predictors (as measured by the TOLT and True Colors). The results of these analyses are presented in this chapter.

This chapter is divided into three sections. The first section is an analysis of statistical associations between student perceptions of the classroom environment, as measured by the ICEQ, and student outcomes (predictors and performances). The second section is an analysis of statistical associations between student perceptions of the classroom environment, as measured by the OICEQ, and student predictor and performance outcomes. The third section is a descriptive reflection on the relevancy of the action research process as related to constructivism, chaos, and assessment of student predictors, perceptions, and performances.

5.2 Associations between the Individualized Classroom Environment Questionnaire (ICEQ) and Student Predictors and Performances

The 25-item actual form of the ICEQ was used to measure students' perceptions of the chemistry classroom environment. Students' academic predictors were measured by the TOLT and True Colors tests as described in Chapter 3 of this thesis. Academic outcome performances were measured by students' performance on pre and posttests and a final examination at the end of the course. Details of these methods of assessment are provided in Chapter 3 of this thesis.

In order to investigate associations between students' perceptions of the classroom environment and student outcomes (predictors and performances), the data were analyzed using both simple and multiple correlations. The results of these analyses are reported in Table 5.1 and Table 5.2, where the simple correlation (r) describes bivariate associations between student predictors and performances and an ICEQ scale and the standardized regression weight (β), the result of a more conservative test, denotes the association between an outcome on a particular ICEQ scale when all other ICEQ dimensions are controlled.

An examination of the simple correlation (r) figures in Table 5.1 and Table 5.2 indicates that there were 21 significant relationships ($p<0.05$), out of 45 possible, between students' perceptions (ICEQ) of the classroom environment and student outcome variables; this is nearly 7 times that expected by chance alone. An examination of the beta weights reveals 12 out 45 significant relationships ($p<0.05$), which is approximately 5 times that expected by chance. All multiple correlations (R) of the set of ICEQ scales with an outcome measure were significant.

Table 5.1 Associations between Perceptions (ICEQ Short Form Scales) and Predictors in Terms of Simple (r), and Multiple (R) Correlations

Scale	(predictor) TOLT		(predictor) True Colors Group #1		(predictor) True Colors Group #2		(predictor) True Colors Group #3		(predictor) True Colors Group #4	
	r	β	r	β	r	β	r	β	r	β
Personalization	0.23**	0.13*	0.47**	0.27**	0.36*	0.15	0.39**	0.39*	0.52**	0.33*
Participation	0.20	0.08	0.14	0.23*	0.19	0.14	0.11	0.02	0.15	0.19
Independence	0.19*	0.06	0.22	0.17	0.16	0.28	0.31*	0.13	0.12	0.22
Investigation	0.35*	0.14*	0.38*	0.18	-0.13	-0.09	-0.04	-0.10	0.14	0.10
Differentiation	0.08	0.12	0.12	0.09	0.05	0.14	0.17	0.02	0.14	0.16
Multiple Correlation, R	0.35**		0.41**		0.23**		0.20		0.42**	
R^2	0.12		0.17		0.05		0.04		0.18	

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes. The individual is the unit of analysis.

r = simple correlation

β = standardized regression coefficient for multiple regression analysis

R = multiple correlation

$*p < 0.05$, $**p < 0.01$

Group 1 = Green (Intuitive-Thinking)
Group 2 = Gold (Sensing-Judgment)
Group 3 = Blue (Intuitive-Feeling)
Group 4 = Orange (Sensing-Perception)

5.2.1 Predictor Outcomes

The multiple correlation (R) data reported in Tables 5.1 and 5.2 indicate that four associations were significant (one TOLT and three True Colors) between the ICEQ scales and both of the predictor outcomes. Associations were strongest between True Colors Groups #1 and #2. Simple correlation (r) figures indicate statistically significant associations between students' predictor outcomes and all ICEQ scales except Differentiation. In particular, students' TOLT scores (Table 5.1) were significant in instances where students perceived greater Personalization, Independence, and Investigation.

No statistical significance existed between the four personality group categories and Participation and Differentiation. All four groups (Green, Gold, Blue, & Orange) perceived the class to have a high degree of Personalization. However, the Green group (Intuitive-Thinking) was the only group to have a significant association with Investigation, and the Blue group (Intuitive-Feeling) the only group to have a significant association with Independence.

Standardized regression weights (β) were used to identify which of the five scales contributed to the variance in student predictor outcomes when the other environment scales were mutually controlled. The beta weights presented in Table 5.1 suggest that TOLT scores were significant with the Personalization and Investigation scales and not significant with the scales involving Participation, Independence, and Differentiation.

Standard regression weights (β) for the True Colors (Table 5.1) groups revealed that the Green, Blue, and Orange groups showed levels of significance with Personalization. In addition, the Green group displayed significance with the Participation scale.

There are no comparable studies that have investigated associations between students' perceptions of the classroom environment and students' predictor outcomes, namely the TOLT test and the True Colors personality profile test.

Table 5.2 Associations between Perceptions (ICEQ Short Form Scales) and Performance Outcomes in Terms of Simple (r), and Multiple (R) Correlations

Scale	(performance) Final Exam		(performance) Pretest Score		(performance) Posttest Score		(performance) Gain	
	r	β	r	β	r	β	r	β
Personalization	0.25*	0.19*	0.35	0.11	0.14*	0.09*	0.42*	0.15*
Participation	0.26*	0.14	0.29	0.24*	0.33*	0.17	0.10	0.12*
Independence	0.28	0.18*	0.21	0.12	0.42**	0.20	0.17	0.04
Investigation	0.22	0.13	0.08	0.09	0.17	0.10	0.26**	0.16
Differentiation	-0.19*	-0.04	0.15	0.03	0.19	0.05	0.05	0.10
Multiple Correlation, R	0.37**		0.28**		0.42**		0.33**	
R^2	0.14		0.08		0.18		0.11	

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes. The individual is the unit of analysis.
r = simple correlation
β = standardized regression coefficient for multiple regression analysis
R = multiple correlation

*$p < 0.05$, ** $p < 0.01$

5.2.2 Performance Outcomes

The data presented in Table 5.2 indicate associations between student perceptions and performance outcomes are similar to those between student perceptions and predictor outcomes. Cognitive achievement (Table 5.2) was higher where students had a perception that the classroom environment had a high degree of personalization, participation, independence, and investigation-related chemistry activities. An example of this is the positive significant correlation that exists between a student's perception of the amount of Personalization present in the classroom and final exam scores, posttest scores, and gain scores (the difference between the pretest score and posttest score). This indicates there is a strong association between the amount of personal contact a student receives from the teacher and a student's cognitive performance.

However, examination of Table 5.2 and the simple correlation (r) and the standard regression weights (β), does not reveal any particular pattern regarding the four other scales on the ICEQ and performance outcomes. The final examination has five significant correlations (one which is negative), the pretest has one, the posttest has four, and the gain score category has four. The one negative significant correlation that is present is between the final exam score and the Differentiation scale, the only correlation present for Differentiation on Table 5.2. Differentiation is the degree of individualization and diversity that students perceive to be in the classroom; different students do different work, use different textbooks, and are allowed to work at different rates. The negative correlation would suggest that the final exam score would increase as Differentiation decreases.

Other research studies utilizing the ICEQ have explored whether students achieve better when there is higher similarity between the actual and preferred environment. Such research is referred to as person-environment research (Hunt, 1975). In one such study (Rentoul & Fraser, 1980), 285 students in 15 classes were the sample population in which a comparison of the actual to the preferred form was administered and then correlated to achievement among studies. Findings showed that higher levels of actual Individualization seemed to impede achievement among students with lower preference for

Individualization. This is somewhat similar to the negative correlation identified in this study between the Differentiation scale and the final exam score. However, when reviewing other research studies involving the ICEQ, the Differentiation scale appears to be the most problematic and inconsistent scale on the ICEQ.

5.3 Associations Between the Oral Individualized Classroom Environment Questionnaire (OICEQ) and Student Predictors and Performances

The 25-item "actual" form of the OICEQ was used to measure the students' perceptions of the chemistry classroom learning environment. The assessment of students' perceptions (using ICEQ), student outcomes predictors, and student performance outcomes and the statistical methods used to investigate associations between student perceptions and outcomes were described in Section 5.2. Tables 5.3 and 5.4 will present the results of analysis of associations between students' perceptions (using OICEQ) of the classroom learning environment and students' predictor and performance outcomes.

An examination of the simple correlation (r) figures in Tables 5.3 and 5.4 indicates that there were 29 significant relationships ($p<0.05$), out of 45 possible, between students' perceptions (OICEQ) of the classroom environment and student outcome variables; this is over 10 times that expected by chance alone. An examination of the beta weights reveals 20 out 45 significant relationships ($p<0.05$), which is approximately 5 times that expected by chance. All of the five multiple correlations of the set of OICEQ scales with an outcome measure were significant.

Table 5.3 Associations between Perceptions (OICEQ Short Form Scales) and Predictors in Terms of Simple (r) and Multiple (R) Correlations

Scale	(predictor) TOLT		(predictor) True Colors Group #1		(predictor) True Colors Group #2		(predictor) True Colors Group #3		(predictor) True Colors Group #4	
	r	β	r	β	r	β	r	β	r	β
Personalization	0.58**	0.33**	0.18	0.06	0.34*	0.22*	0.47**	0.35*	0.26*	0.13
Participation	0.36*	0.12	0.37*	0.14	0.56**	0.38**	0.48**	0.24*	0.16	0.19
Independence	0.11	0.02	0.49**	0.31**	0.33*	0.21*	-0.24*	0.10	0.10	0.11
Investigation	0.47**	0.35**	0.45**	0.29*	0.13	0.09	0.15	0.03	0.27*	0.12
Differentiation	0.44**	0.23*	-0.34*	-0.26*	0.11	0.03	0.22*	0.15*	0.06	0.05
Multiple Correlation, R	0.53**		0.46**		0.48**		0.39**		0.21	
R^2	0.28		0.21		0.23		0.15		0.04	

n = 473 The sample consisted of 473 secondary chemistry students in 21classes. The individual is the unit of analysis.

r = simple correlation
β = standardized regression coefficient for multiple regression analysis
R = multiple correlation

*$p< 0.05$, ** $p< 0.01$

Group 1 = Green (Concrete-Sequential)
Group 2 = Gold (Concrete-Random)
Group 3 = Blue (Abstract-Sequential)
Group 4 = Orange (Abstract-Random)

Table 5.4 Associations between Perceptions (OICEQ Short Form Scales) and Performance Outcomes in Terms of Simple (r) and Multiple (R) Correlations

Scale	(performance) Final Exam Score		(performance) Pretest		(performance) Posttest		(performance) Gain Score	
	r	β	r	β	r	β	r	β
Personalization	0.41**	0.29*	0.32	0.21*	0.44*	0.29*	0.48*	0.31*
Participation	0.24*	0.26*	0.13	0.04	0.39**	0.28*	0.30*	0.14
Independence	0.48**	0.31*	0.31*	0.09	0.22	0.19	0.15	0.10
Investigation	0.20**	0.11*	0.30**	0.22**	0.28*	0.15	0.34**	0.21*
Differentiation	-0.18	-0.06	0.12	0.09	0.14	0.03	0.21*	0.08
Multiple Correlation, R	0.47**		0.36**		0.41**		0.40**	
R^2	0.22		0.13		0.17		0.16	

n = 473 The sample consisted of 473 secondary chemistry students in 21 classes. The individual is the unit of analysis.

r = simple correlation
β = standardized regression coefficient for multiple regression analysis
R = multiple correlation

*p< 0.05, ** p< 0.01

5.3.1 Predictor Outcomes

The multiple correlation (R) data reported in Tables 5.3 and 5.4 indicate that all five associations were significant (one TOLT & three True Colors) between students' perceptions of the classroom environment and both of the predictor outcomes (TOLT & True Colors). Associations were strongest between the TOLT and True Colors Groups #1 and #2 (Table 5.3). Simple correlation (r) figures indicate statistically significant associations between students' predictor outcomes and all OICEQ scales. In particular, students' TOLT scores (Table 5.3) were significant at p<0.01 in instances where students perceived greater Personalization, Investigation, and Differentiation

(Participation scale significant at $p<0.05$). Students' TOLT scores were not significantly associated with the Independence scale.

Significant associations existed between the True Colors (Table 5.3) groups and all five of the scales on the OICEQ. Statistical significance existed between Group #1 (Green) and the Participation, Independence, Investigation, and Differentiation scales; Groups #2 and #3 were significant with Personalization, Participation, and Independence; Group #4 with Personalization and Investigation. Group #1 had a negative correlation with the Differentiation scale, while Group #3 a negative correlation with the Independence scale.

The more conservative multiple regression analysis using beta weights indicates that some of the OICEQ scales contributed uniquely to the variance in student outcomes when all other OICEQ scales were mutually controlled. The beta weights presented in Table 5.3 suggest that TOLT scores were significant with the Personalization, Investigation, and Differentiation scales and not significant with the scales involving Participation and Independence.

Standard regression weights (β) for the True Colors (Table 5.3) groups revealed that the Green group (Group #1) showed levels of significance with Independence, Investigation, and Differentiation; the Gold group (Group #2) significance with Personalization, Participation, and Independence; and the Blue group (Group #3) significance with Personalization, Participation and Differentiation. The Orange group

(Group #4) did not have any significant correlations with any of the five OICEQ scales.

There are no comparable studies that have investigated associations between students' perceptions of the classroom environment using the OICEQ and student predictor outcomes, namely the TOLT test and the True Colors personality profile test.

5.3.2 Performance Outcomes

The data presented in Table 5.4 indicate associations between student perceptions and performance outcomes are similar to those between student perceptions and predictor outcomes. The four categories of performance outcomes (final exam, pretest, posttest, and gain score) had levels of significance with all five scales on the OICEQ. Cognitive achievement was highest ($p<0.01$) where students had a perception that the classroom environment had a high degree of Personalization, Participation, Independence, and Investigation-related chemistry activities. Correlation was also strong ($p<0.05$) between Differentiation and gain score. All of the correlations that were significant were positive correlations. The Investigation scale had the highest number of correlations -- four. Similar to the findings on Table 5.2 of the ICEQ data, the Differentiation scale had the fewest number of significant associations, one. This indicates there is a strong association between the frequency of classroom and laboratory investigations, as measured by the OICEQ, and a student's cognitive performance.

This is the first reported use of the OICEQ; therefore, there are no comparable studies that have investigated associations between students' perceptions of the classroom environment using the OICEQ and student performance outcomes.

5.4 Reflection

This section encompasses a self-reflection of the validity of an action research process in a chemistry classroom examining associations between chaos, constructivism, and assessment. The self-reflection constitutes not only the analysis of data collected for this particular study, but also the analysis and cognitive conflict involved in 16 years of teaching chemistry at the secondary level. This section is from a constructivist perspective of the classroom environment based on three principles of constructivism: 1) knowledge is gained through experience, 2) the replacement of absolute truth with concept viability, and 3) knowledge construction is a social and cultural process mediated by language (Milne & Taylor, 1994).

The chemistry courses utilized in this study are constructivist in nature due to the fashion in which the classroom learning environment is established and maintained. Teaching strategies and activities used in the chemistry courses focus on the premise that knowledge is constructed by the learner based upon personal experiences, beliefs, and pre-existing mental structures. The primary approach to learning is project-oriented and discovery-based with emphasis on the solving of chemistry-related problems. Over forty percent of the course involves laboratory and field experiences. Emphasis is placed on students learning to access, research, analyze, and predict chemical information. The chemistry courses in this study, like constructivism, promote the thought that learners construct knowledge through their experiences. Action research is the precedence, validation, and premise for the following reflections.

As a result of the action research-constructivist (reflection) approach to this study, the following impression has been derived: chaos is to learning as entropy is to assessment. Chaos impacts (Baeyer, 1995 & Rockler, 1991) how students learn while entropy impacts the assessment of how much a student learns. Chaos is a personal constructivist (phenomenonologist) phenomenon and entropy is social constructivist (ethnomethodologist) phenomenon.

As mentioned in Section 2.4.1, the term "chaos" refers to the condition of disorder and the term "entropy" refers to the measurement of disorder (Dresden, 1992). Chaos is the search for patterns in complex systems (Ruelle, 1991). Entropy is concerned with dynamics, a field of study that deals with motion, change, and equilibrium of systems under the action of forces usually outside the system. Entropy also refers to the amount of information (Rothwell, 1994) in a system and how crucial it is to social decision-making, a form of assessment. The predisposition of thought is that chaos is omnipresent and has effects (Baeyer, 1995) on our surroundings. Entropy is concerned with the measure of statistical character of constructing messages -- a process of assessment.

Entropy has also been described as a measure of the amount of disorder (chaos) in a physical system, but it is now clear that a more precise statement is that entropy measures lack of information (Bazarov, 1964) about the structure of the system. This lack of information is associated with the possibility of a great variety of microscopically distinct structures which, in educational research, cannot be distinguished from one another. Since any one of these microscopic structures, such as knowledge constructs, can occur at any given time, lack of information corresponds to actual disorder at that level and increase of entropy corresponds to progressive loss of information. Information is vital to the study of a particular system in that it reduces uncertainty. As mentioned in Chapter Two, section 2.4.2, a gain in entropy means loss of information. The increase in entropy is directly proportional to the loss of information. As the disorder of a system increases, so does the loss of information.

Since the development of information theory, it has come to be realized that the statistical concept of entropy can be detached from thermodynamics and associated with any probability distribution whatsoever. In particular, it can be applied to a study of the statistical structure of language (Marshall, 1995), and this has led to interesting results in the statistical characterization of literary vocabularies (Zumdahl, 1993). Entropy is concerned with the quantity of information (Bazarov, 1964). Assessment lends meaning to the quantity of information collected that takes place in complex, dynamical systems.

The dynamic, complex, system in this study is the classroom environment, which can be considered a cybernetic system that is impacted (Von Baeyer, 1995; Rockler, 1991) to varying degrees by chaos. Entropy shares many common characteristics with cybernetics (discussed in Chapter Two). Both entropy and cybernetics have been associated with studies that examine patterns of complex systems, quantity of information, dynamics, communication, and control.

Cybernetics can be considered a form of entropy. Entropy is concerned with the quantity, and sometimes quality of information whereas cybernetics is concerned with only the quantity of information. The theory of entropy is one of the landmarks of modern science and notions of negentropy (as defined in Chapter 2) are landmarks of post-modern science. From its origins in thermodynamics, theories of entropy and negentropy have migrated, most notably to biological sciences, educational research, and to communication and cybernetics (Best, 1991). It has long been held for example, that biological forms defy entropy, but the realization that some complex systems, such as learning, might also be said to defy entropy, by creating order out of disorder, makes negentropy a notion with very broad applications. If complex systems are as common as now thought, the second law of thermodynamics may well be regarded as more like a local council ordinance than a law of the universe. Students' cognition may also be regarded as a negentropic system which creates order (internal constructs, personal constructivism, personal assessment) from disorder (external constructs, social constructivism, social assessment). The negentropic view is that students can't stop making sense, and that information is, therefore, created in the classroom rather than lost or simply conserved. Just as theories of entropy informed research in biology, communications and cybernetics, an assertion of negentropy and a denial of entropy is a perspective which might illuminate facets of learning. In particular, a reaching of negentropic constructionism (Arnold, 1993) brings together the powerful educational theories of Piaget, Vygotski, Minski, and others, with the communications and cybernetic theories of Wiener, Shannon, and Weaver.

Because of similarities shared between entropy and cybernetics, the term cybernetics will be used interchangeably (with entropy) for the remainder of this study. Cybernetics is a more contemporary version of entropy and has a unique and specific way of explaining human behavior and motivation, focusing on feedback and environment (Keaten, 1995). Since behavior (i.e. learning) is something that is continually constructed in successions of self-correcting adjustments to changing life conditions, cybernetics provides the framework for analyzing behavior and many complex systems (i.e. learning environments) (Hobbs, 1993).

As in entropy, the quantity of information is central to cybernetics. Cybernetics, however, does not examine the meaning of information, instead it examines the amount of information in the system at a given time, a testament to Heisenberg's uncertainty principle. The quantity of information is unrelated to the meaning of the information, its significance, or its truth. The function of information within a system is to reduce uncertainty (chaos). Information allows the system to reduce the number of ways in which a goal may be obtained. The quality of information is central to entropy. Assessment gives meaning to the information. (Keaten, 1995).

Cybernetic theory can be considered an extension of general systems theory and, therefore, includes the concepts of structure, function, and evolution. The structure of a cybernetic system refers to the "means by which it is enabled to receive, to store, to process, and to recall information" (Rapoport, 1968). The evolution of a cybernetic system refers to the way in which both structure and function change over time.

Cybernetics is the study of control within a self-governing system. Feedback is the vehicle by which control is exerted. Feedback can signal the system to either deviate (positive feedback) or return to a previous state (negative feedback). Information is vital to the study of cybernetics in that it reduces uncertainty. To manage information effectively, cybernetic systems develop, maintain, and revise rules relevant to processing of information. To manage information effectively, cybernetic systems, such as a classroom, develop, maintain, and revise rules relevant to the processing of information.

As there appear to be similarities between entropy and cybernetics, there also appears to be an association between chaos and cybernetics. Both the cybernetic theory and chaos theory were constructed using the constructs of general systems theory. Therefore, both theories focus on constructs such as structure, function, and evolution. Both theories subscribe to the general systems principle, such as nonsummativity and wholeness and both theories have been used to examine patterns of behavior present in complex adaptive systems. Due to the aforementioned similarities, a theoretical integration of cybernetics and chaos theory will be utilized, thus interjecting the term "cyberchaos" (Keaten, 1995). Cyberchaos theory is intended to provide researchers with specific salient variables and a method for detecting complex patterns. Cyberchaos is a holistic, triangulation procedure for educational research: predictors, perceptions, and performances.

Cyberchaos serves as an interconnecting medium between entropy, cybernetics, and chaos. The following table illustrates two categories of features that are present within a system.

Type I	Type II
1. Positive feedback-iterations (cybernetics)	1. Negative feedback-iterations (cybernetics)
2. Positive entropy (entropy)	2. Negentropy (entropy)
3. Stretching (chaos)	3. Folding (cybernetics)
4. Divergence-bifurcation (chaos)	4. Convergence-attractors (chaos)

Cyberchaos theory provides an alternative framework for educational researchers (dynamicists). Traditionally, researchers approach dynamics quantitatively, systems are given numerical values, and the job of the dynamicist is to calculate how those numbers change over time. Today, however, the approach to dynamics has become qualitative. Researchers are saying things about the general features of the system rather than the specifics (Haynes, Blaine, & Meyer, 1995). Cyberchaos theory is an integrative, hybrid approach to both quantitative and qualitative research. The action research, a constructivist methodology, conducted in this study acknowledges the relevance of researchers being active parts of the whole process, and being cognizant of the impact of cyberchaos on the predictions, perceptions, and performances when assessing the chemistry learning environment.

The fashion in which cyberchaotic systems behave is highly dependent on initial conditions. Sensitivity to initial conditions suggests that each input "evolves into an overwhelming difference in output" (Morris, 1992). The concept of sensitivity to initial conditions presents an argument against and a solution to the problem of quantification necessary for empirical research. Empiricism assumes that all human behavior can be approximately quantified and eventually predicted.

Cyberchaos theory's supposition is that when initial conditions are changed by even the slightest degree, differences increase over and over again with each moment and eventually lead to two drastically different pictures of the same process. In the case of student learning, initial conditions may be intellectual competence (predictors), and final conditions may be intellectual performance (performances). Learning environment surveys such as the ICEQ and OICEQ may be the mediation (perceptions) between prediction and performance. Research that incorporates constructivism and cyberchaos is a holistic, triangulation, process of research--action research. The action researcher is an active, evolving participant in the process, not a passive observer.

Cyberchaos theory postulates that the very act of measuring an object changes it (Kuh, 1995, Marshall, 1995, Bobner; et al., 1989). Successive measures of the same object may produce different answers. Every situation is unique and emphasis is placed on describing a situation for its own sake. Researchers that adhere to the Heisenberg uncertainty principle will concede that it is not possible to observe and measure simultaneously the classroom environment. The nature of observation affects the results (Kuh, 1995, Marshall, 1995, Bobner; et al., 1989); changes in initial conditions create extensive differences in the final outcome. Therefore, a holistic approach to assessment of the learning environment has been taken; predictors, perceptions, and performances in order to reduce uncertainty and to describe general features of the systems rather than specifics.

As mentioned previously, attractors (convergence), bifurcations (divergence), feedback, stretching, folding, and outliers are all part of cyberchaos theory. How one deals with the "constrained randomness" of cyberchaos, as applied to educational research depends on one's philosophical perspective. A quantitative researcher believes the studied behavior is not truly random, and would strive to adequately quantify all of the system's variables so that accurate prediction is possible. The quantitative researcher works to explain by applying numerical values to the system and therefore, eliminate randomness. A qualitative researcher, however, would consider the "randomness" of the system as a part of the data in order to say general things about the system, a manifestation of the system that should be worked into theory rather than eliminated (Bobner, 1989). Seemingly random behavior in a system can be looked at another way. This randomness could be considered analogous to the concept of outliers in so-called linear systems. Depending on one's point of view, the outlier is treated differently. From a quantitative perspective, the outlier is considered an anomaly and is thrown out of the statistical analysis. From a qualitative perspective, the outlier is considered a meaningful part of the data and is retained in whatever methodologies are applied. Cyberchaos takes both approaches into account and attempts to calculate how the numbers evolve over time.

When assessing a constructivist classroom via action research, it is important to recognize the existence of a strange attractor, a feature of cyberchaotic systems (Stewart, 1993). Underlying the apparent lack of order in a chaotic system is bounded pattern. That which attracts the system is a bounded pattern. That which attracts the system toward this pattern is called the strange attractor (Dresden, 1992).

The reason for the development of this bounded chaotic pattern is the iteration or feedback involving the continual reabsorption or unfolding of what has come before . . . a constructivist event. Data points affected by the position of the point that came before it can be considered a constructivist event. However, small changes in the initial position of that point can create feedback loops that produce exponential differences as the point moves through time (Keaten; et al., 1994). The presence of such a feedback loop is another characteristic of cyberchaotic processes, constructivist processes, and action research.

Learning can be strongly nonlinear, and small fluctuations in assessment data are not smoothed out as iteration proceeds. Rather, they are magnified through cascading series of bifurcations. Within the chaotic bounded pattern, the same patterns continuously reiterate as in a kaleidoscope. Hence, the obscure, often minute dissimilarities between initial conditions of seemingly similar systems are magnified over time by iteration and cause the chaotic pattern for each system to be unique. According to Keaten (1995), "... nonlinear solutions tend to be stubbornly individual and peculiar."

The action research process identifies attractors, which may be considered statistical levels of significance, by plotting a great many data points which represent the behavior of the system, the learning environment. This pattern is not apparent when only a few points are plotted. It depends on the inclusion of all the states that the system assumes over time. Accordingly, an underlying pattern of behavior in a "human" system may not manifest because too few examples are being studied. Cyberchaos theory would suggest that the outlier is also part of the system and is connected to it by some underlying construct.

Prior knowledge is recognized as worthwhile and important, even though the knowledge may not be consistent with accepted knowledge in a discipline. However, knowledge is always the result of a constructive activity, therefore, it cannot be transferred to a passive receiver. It has to be built up by every single knower (Von Glasersfeld, 1992), a "constructivist event." The metaphor, learning as construction, entails the building of new knowledge on the foundation of prior knowledge, a posteriori. Assessment of such an event is made possible by an action research approach to cyberchaos: predictors, perceptions, and performances -- triangulation research and assessment.

Viewing the statistics compiled during the course of this research study provides insight, reflection, into some of the anomalies that appear when analyzing the data. Following are some examples of statistical outliers/anomalies present in the data collected:

1. The low correlation between the OICEQ short form and the ICEQ short form for each scale ranged from 0.54 to 0.81.

2. Chapter 4 table 4-2 shows the alpha reliability coefficient for the ICEQ range from 0.42 to 0.83. Differentiation scale is problematic in virtually all of the statistical data compiled. The Differentiation scale deviates more statistically (low correlation, reliability, etc.) than any other scale.
3. Use of the Total Scale points for ICEQ and OICEQ (equals 115) versus the use of individualized scales.

A holistic, rather than parts assessment of the data will be used to respond to the three outliers/anomalies, a constructivist-action research, cyberchaos perspective. The uncertainty of any of the data is due, in large part, to sensitivity to initial conditions wherein the divergence property of cyberchaotic attractors ensures extensive differences in outcomes. These attractors, nevertheless, provide a method for identifying some order out of what might initially appear to be total bifurcation in the behavior of the system. Constructivism (ethnomethodology & phenomenology), the concept that learners construct knowledge through experiences, an "a posteriori" approach, verifies the belief that initial conditions change during knowledge construct formation. Due to the complexity of the initial conditions of measuring learning constructs, the ability to quantify all of the initial conditions is not possible. Personal constructivism (phenomenology) and social constructivism (ethnomethodology) seek to understand the elusive variables in educational research by retrospective methodologies – action research and reflective practice. Both methods acknowledge that all variables which influence the outcome cannot be known under initial circumstances, but can be deduced after the outcome has been discovered.

Following are responses to the three outliers/anomalies mentioned above:

1. Statistically significant data identified in this study can be considered to be attractors and outliers can be considered to be bifurcation points. The low correlation between the ICEQ short form and OICEQ short form could be considered an outlier. Based on the methodology (action research-constructivism) and perspective of this study (cyberchaos), all data, attractors and outliers, will remain as part of the general systems approach to assessment of data. The relatively low correlation, an outlier, between the ICEQ an OICEQ is due in part to the relationship of cyberchaos, written communication versus verbal communication. Language is a social event, high cyberchaos, divergent data. The ICEQ is more of a personal constructivist instrument while the OICEQ is more of a social constructivist instrument (Fraser, McRobbie & Giddings, 1993). This explains the differences between the answers given on the OICEQ and the ICEQ. Written communication (ICEQ) is more of a personal construct, while oral communication (OICEQ) is more of a social construct (person asking questions, student responding).

2. The variance found in the Differentiation scale can be due to the fact that students' opinions about other students is a social

assessment question, high entropy results, which is not predictable. The Personalization scale, however, is a form of personal assessment that provides lower entropy results. The Differentiation scale requires students to assess features external to their own reality, while the Personalization scale requires students to assess features internal to their own reality.

3. Due to the embracement of cyberchaos theory and action research, Tables 4.6 and 4.7 in Section 4.5 use the Total Scale points for the ICEQ and the OICEQ which equals 115 total points rather than each scale. This is a holistic perspective rather than a parts perspective. Differences in the results because of the Total versus the Parts is a general systems, precision approach rather than a quantitative, accuracy approach.

Also, as advocated by the cyberchaos theory, a holistic, general systems approach is utilized. Complex systems, such as the classroom learning environment, are to be viewed as wholes, not as isolated parts. The whole is greater than the sum of its parts (Peca, 1992). Unlike empirical research, which seeks to isolate the parts of a system in order to understand the whole, cyberchaos theory seeks to understand the whole system as a whole. In order to know how the whole looks as it moves and changes, action research with a cyberchaos perspective regarding assessment is required.

Constructivism (personal and social; phenomenology and ethnomethodology) and cyberchaos theory emphasize a holistic view of the assessment of learning and the learning environment (complex system), action research. Both constructivism and cyberchaos theory posit the whole as being greater than the sum of its parts as being intrinsic to understanding -- assessment.

Linear models work well when the goal is to study a system's behavior under controlled conditions. However, the learning environment in the chemistry classroom is a nonlinear model (Jones & Beeth, 1995), with limited controlled conditions, a constructivist-action research model impacted by cyberchaos. Thus, when the goal is to describe a system's behavior in its natural environment, such as a chemistry classroom, the outcome could be difficult to assess.

5.5 Summary

This chapter reported associations between senior chemistry (grades 11-12) students' perceptions of aspects of their classroom environment and predictor (TOLT and True Colors) and academic performance (pre-posttest & final exam) outcomes. Students' perceptions of their learning environment were found to be similarly associated with both predictor and performance outcomes at varying statistical degrees.

No previous studies have been conducted incorporating the OICEQ. However, for a basis of reference, a comparison of Tables 5.1 and 5.2

(ICEQ) and Tables 5.3 and 5.4 (OICEQ) provides data that is worthy of comparison regarding associations between student perceptions and predictors, with complementary and contradictory information existing between the ICEQ and the OICEQ. Also, the number of statistical correlations between perceptions and predictors present in Table 5.1 and is noticeably less (13) than in Table 5.3 (21). In addition, the total number of beta weight measurements vary in each table. Table 5.1 shows six correlations and Table 5.3 reports 12 correlations.

In both studies, the Personalization and Investigation scales have similar numbers of statistical correlations on the TOLT (complementary data) although the values for each statistical correlation found in Table 5.1 and 5.3 vary considerably. The TOLT information for the ICEQ on Table 5.1 has five significant correlations (one at $p<0.01$), whereas the TOLT information for the OICEQ on Table 5.3 has seven correlations (five at $p<0.01$). Additionally, the four True Colors groups on Table 5.1 have only ten significant associations (four at $p<0.01$) and Table 5.3 has 22 significant associations (seven at $p<0.01$). The ICEQ data shows no correlations between the differentiation scale and personality profile (True Colors) predictors while the OICEQ shows four correlations (contradictory data), two positive and two negative correlations. The conservative beta weight statistic shows four significant associations on the ICEQ -- True Colors table and nine significant associations on the OICEQ -- True Colors table.

A comparison of student perceptions found on Table 5.2 (ICEQ) and student performances located on Table 5.4 (OICEQ) also provides data worthy of analysis. In both studies the Personalization and Differentiation scales have similar numbers of statistical correlations (complementary data) although the values for each statistical correlation found in Table 5.2 and 5.4 vary considerably. Also, the number of statistical correlations between perceptions and performances present in Table 5.2 is noticeably less (14) than in Table 5.4 (23). Table 5.2 shows two statistical correlations that are significant at $p<0.01$ while Table 5.4 shows seven significant associations at $p<0.01$. In addition, the beta weight measurements vary in each table. Table 5.2 shows six correlations and Table 5.4 reports ten.

The action research approach to the analysis and interpretation of the data in this study has entrenched the premise that constructivism, cyberchaos, and assessment are interrelated, intertwined, and integrated. For teachers as researchers, action research can be considered a form of constructivism. The researcher is the practitioner and the research involves an investigation into his or her own practice and that of colleagues. Both action research and constructivism share a common belief that knowledge is gained through a posteriori experience.

Cyberchaos is a conceptual framework for action research. Both cyberchaos and action research are natural components of dynamic systems, including the educational classroom. They are integrated with the classroom environment. Cyberchaos is a unifying concept that addresses constructivism, chaos-entropy, and assessment.

Action research involves teachers in becoming researchers in their own classrooms and addressing problems of immediate practical significance (McNiff, 1993). Action research provides the practitioner the opportunity to be considered a viable, valid, and rigorous researcher within the science education community. They are often experts at manipulation and management of research data within the classroom. Due to personal constructs that action researchers develop, a form of convergent chaos (Stewart, 1993), a form of personal assessment. Assessment instruments, such as predictors (TOLT & True Colors), perceptions (ICEQ & OICEQ), and performances (pretest-posttest & final examination), a form of divergent chaos, become reliable and valid on the merit of expertise of the action researcher, not solely on the statistical validity of the research instrument.

Cyberchaos is a state function, which is dependent only on the initial and final states of the research variables not on the path between them. Similarly, the manner in which knowledge constructs are formed may be of no consequence. The initial and final state of the information is the item of importance. No spontaneous change will occur when the cyberchaos is at a maximum, that is, when no increase in cyberchaos can occur without changing the conditions of the system. At this point, the system will then be in a state of cyberchaotic equilibrium.

The constructivist perspective holds that meaningful learning is constructed in the internal world of the learner and understandings tend to resist change, due to disequilibration (Saunders, 1992). Meaning is constructed by the cognitive apparatus of the learner. Consequently, it is not communicated by the teacher to the student (Resnick, 1983). Constructivism emphasizes individual cognitive (reduced chaos) activity, but acknowledges negotiations (increased chaos) with others as a means of determining the viability of knowledge (Taylor, Dawson, & Fraser, 1995a).

Action research is like personal constructivism, one can communicate (social constructivism) a system but never its results (personal constructivism). The ICEQ is a system for action research. It can be communicated but the results of a teacher doing action research cannot be communicated. As we communicate, cyberchaos increases and information decreases.

Action research is a unifying concept for constructivism, cyberchaos, and assessment. Action research in this study utilizes a holistic, triangulation method of research -- predictors, perceptions, and performances. Entropy, the measurement of disorder, and cybernetics, the science of control of information, are also taken into consideration -- cyberchaos. Action research is a form of constructivism and follows the premise of cybernetics. Acknowledging constructivism, action research, and cyberchaos is a triangulation approach to assessment of the chemistry classroom.

The challenge of educational researchers is to view the classroom as a complex, non-linear, dynamic system that is not structured in a serial or linear way, where chains of input/output, instruction/outcome, cause/effect can be isolated and explicated. Rather, it is constructed as a system in which elements are in a state of dynamic interplay at every scale. To attend to such a system is to attend to notions of learning in terms used to describe complex dynamic systems, terms which perhaps signify novel concepts to educational researchers. Constituents such as feedback loops, modes of disequilibrium, self-regulation, strange attractors, and bifurcation points might be used to represent aspects of learning or precursors to learning. The use of these terms is not to express old ideas in new ways, but to signify different concepts and to generate different perspectives. For example, when writing of complex systems Gleick notes that "Non-linearity supposes that both the rules and the variables (the two are inseparable) change as the system changes." (Gleick, 1987).

The perspective offered by the non-linear classroom is therefore a perspective that rejects models that are dependent upon unchanged states, which is to reject the methodological structure of much educational research. If observers are caught in a change loop, contributing to change, and subject to change, and treatments are caught in a change loop, and controls are caught in a change loop, methodologies which attend only to pre-treatment/post-treatment change in the subjects will tell a different story to that told by research which attends to change in process and to reflexive change in all inhabitants of the space (action research).

An example of educational research that attends to change as an inherent dimension space within which the learning occurs, is to be found in the work of Lave and Wengner (1991). Lave and Wengner assert that learning is not simply a change situated in the mind of the learner, but assert learning, and therefore change, is distributed among co-participants in situated action. In the course of learning (or legitimate peripheral participation) the apprentice changes, the teacher changes, and the skills being mastered change. Within a frame which attends to reciprocal and distributed change, learning outcomes are, therefore, not accounted for the mechanistic teleology of modern science, in which the learning outcomes are determined by a one-way flow of cause and effect emanating from the properties of space at the beginning. To attend to dynamic reciprocal relations and suggested theories of complex systems is to attend to the problem.

Construction of knowledge is considered an open system, and entropy of an open system may not be possible to determine. Therefore, if entropy is not determinable in open systems due to the magnitude of variables, then assessment of those systems is not possible and educational researchers will have substantial difficulty assessing the information (knowledge constructs) within the system. Entropy measures the lack of information about the structure of the system. This lack of information is associated with the possibility of a great variety of microscopically distinct structures which, in practice we cannot distinguish from one another. Since any one of these microscopic structures can occur at any given time, lack of information corresponds to actual disorder at that level and increase of entropy corresponds to progressive loss of information (Encyclopedia of Philosophy, 1967). Social assessments measure the amount of information in a system and are certainly sensitive dependent on the entropy of a system. In many cases social assessment measures mental information storage rather than knowledge construction. For some systems a change in a single variable can cause a transition to the chaotic states. If the entropy of an open system is not determinable then neither are social assessments. Chaos and learning are observable features of nature, but may not be measurable.

No degree of meticulous observation, even in theory, can provide an account of the state of relevant variables at any given time, Heisenberg's Uncertainty Principle. The classroom is, therefore, unsimulatable by any representation with fewer elements than itself. The corollary of this is that, in the terms of their own discourse, the reliability of studies which take place in a clinical or experimental setting is compromised, if not in the transfer of results from experimental setting to experimental setting, at least in the transfer of results from experimental setting to a natural setting. Indeed, chaos theory also casts doubts upon the replicability of results as a scientific principle, through attending to the extreme sensitivity of systems to initial conditions, although reproducible results are to be expected in stable systems close to equilibrium — thermodynamic death.

The Heisenberg Uncertainty Principle validates that we cannot assess two variables simultaneously, only one variable at a time. It is also impossible to observe and measure simultaneously the academic performance of a student because the nature of observation affects the results (Kuh, 1995; Bobner; et al., 1989). The very act of measurement of a system affects the outcomes of the results. Successive measurements of the same system may produce different answers. This validates the significance of action research. We can assess the learning environment, but cyberchaos affects communication of the results. We can predict, but we can't measure the learning environment. This provides value to triangulation research and assessment.

The two general categories of methodologies and paradigms in research are qualitative and quantitative in nature. Quantitative research involves assigning numbers to objects and using this data in a predictive sense. It is a philosophy of research that assumes that the environment is predictable if enough information is available -- entropy related. Emphasis is placed on reliability and validity.

Constructivist teaching and researching requires three principles:

1. The first principle maintains that learning involves mental construction of knowledge by individuals, rather than absorption from external sources. This principle implies that

we learn by interpreting new experiences in relation to our extant knowledge, a process that leads to changes in knowledge including additions, replacements and alterations (Cobern, 1993a), and is characteristic of dynamic systems.

2. The second principle of constructivism requires the replacement of the concept of absolute truth with the concept of viability. According to this principle, it is not reasonable to claim that our experiences of the world mirror exactly the reality of the world. We have no means of determining the match between our knowledge of the world and the world as it really is. As a result, it is generally accepted that there is no justification for claiming scientific knowledge and educational research have absolutely authoritative foundations (Taylor, 1994a). The viability criterion entails a tentative view of the nature of scientific knowledge and an ethical option for teachers of not presenting current constructions of the world as the only acceptable ones.
3. The third principle of constructivism is that knowledge construction is a social and cultural process mediated by language. A position adopted by Tobin (1993), argues that the individual and social components of the learning process are equally important and occur concurrently. In one way or another, therefore, we make sense of our new experiences by assigning language to our ideas and communicating them to others whose responses enable us to determine the viability of, and to readjust (changes in initial conditions), newly adjusted

knowledge. Together, these three principles of constructivism constitute a framework for human knowledge as having a genesis (dynamics) within our own socially situated thinking and a status whose certainty is culturally and historically dependent.

Cyberchaos theory assumes the uniqueness of apparently similar systems due to the initial conditions, which, in complex systems, are rarely equal in affecting system behavior. Because of this uniqueness, generalization is difficult, if not possible, but understanding can be gained through reflective practice -- action research. However, because of imperfection of measurement, predicting final outcomes of any cyberchaotic pattern in the chemistry classroom is virtually impossible, simply because measuring initial conditions with infinite precision is impossible.

Cyberchaos theory seeks to explain the influence of the innumerable uncontrolled variables that determine an experimental result. The results of the experiments with chaotic systems may appear random because we often observe only a single realization of the dynamical process evolving from a specific initial condition. Thus, cyberchaos theory does not posit reality as chaotic and unpredictable, but as unpredictable due to researcher's inability to precisely measure all initial conditions and due to reality being inherently ordered despite appearances to the contrary.

Cyberchaos theory confirms the inability of empiricism to isolate all the variables in a complex system because of the system's sensitivity to initial conditions.

Perhaps cyberchaos theory has become so fascinating and compelling because it does present an alternative way to study reality and also confirms and explains why empiricism is unable to quantify, predict, and generalize about complex systems. Cyberchaos theory provides an expansion of means by which reality can be known and perhaps, will allow greater tolerance for alternative paradigms in educational research. Cyberchaos theory approach to research is action research -- constructivist assessment to data.

The concept of sensitivity to initial conditions presents an argument against and a solution to the problem of quantification necessary for empirical research. Empiricism assumes that all human behavior can be approximately quantified and eventually predicted. Chaos theory's supposition is that when initial conditions are changed by even the slightest degree, differences increase over and over again with each moment and eventually lead to two drastically different pictures of the same process.

Cyberchaos theory can increase our understanding of the constantly evolving learning process. Cyberchaos presents a reason for triangulation-action research, the researcher is a part of the rotating and evolving system when assessing the learning process. A triangulation formula for action research involves measurement and assessment of predictors, perceptions, and performances utilizing constructivism, cyberchaos, and action research. Dynamical systems theory and cyberchaos theory focus attention on critical junctures in the learning process as beliefs, perceptions, and knowledge spontaneously reform to create predictable order out of disorder.

Personal assessment, personal constructivism, is a negentropy, folding, convergent, negative feedback, is an organized means of personal assessment. It is an adversary to cyberchaos. Personal constructivism is an adversary to social assessment, an ally to personal assessment -- highly organized.

Social assessment, social constructivism is a positive entropy, stretching, divergent, positive feedback, is a highly disorganized means of personal and social assessment. It is an ally of cyberchaos. Social constructivism is an adversary to social assessment and personal assessment -- highly disorganized.

Action research, being a form of constructivist practice, addresses chaos-entropy. Action research, constructivism, and chaos-entropy are holistic, general systems approaches to educational assessment. Action research, constructivism, and cyberchaos promote the thought that knowledge constructs are in a constant state of flux. Additionally, constructivism, and chaos-entropy are nonlinear, dynamic, complex, initial-condition dependent entities that impact the final outcomes of action research. As mentioned in Chapter Two, this is the first study to explore the impact of chaos (Von Baeyer, 1995; Rockler, 1991) and constructivism on the learning environment, and the formulation of subsequent predictions (Gustin & Corazza, 1994; Peca, 1992; Bobner, 1989) about student achievement. However, this study espouses the belief that a constructivist practice and the cyberchaos phenomenon skew the collection, reflection, analysis, and interpretation of assessment data.

When you cannot measure it, when you cannot express it in numbers, your knowledge is of a very meager and unsatisfactory kind.

When you can measure it, when you can express it in numbers, your knowledge is still of a meager and unsatisfactory kind.

Not everything that is counted counts, and not everything that counts is counted.

Chapter 6

Conclusion

6.1 Introduction

In the past 25 years much attention has been given to the development and use of instruments to assess the qualities of the science classroom environment from the perspective of the student (Fraser, 1986b, 1994; Fraser & Fisher, 1994), and the associations between learning environment variables and student outcomes has provided a particular rationale and focus for the use of such instruments.

Although numerous past studies have examined associations between student perceptions of the learning environment in science classes and student outcomes (Fraser, 1986, 1994), this study is unique in that it: (1) developed the OICEQ (Oral Individualized Classroom Environment Questionnaire to assess student perceptions of the chemistry learning environment, (2) examined associations between three types of assessment: predictors, perceptions, and performance of students in a chemistry classroom, (3) investigated the relationship between constructivism, chaos, and assessment in a constructivist chemistry classroom, (4) provided a self-reflection on the validity of an action research process utilized in examining constructivism, chaos, and assessment, and (5) used the MBTI adaptation, True Colors, to identify student personality profiles in the classroom.

Furthermore, this study is distinctive in that it centered on students in secondary chemistry classes, whereas previous research on the science classroom has centered largely on students in physics and integrated science classes.

6.2 Overview of the study

This thesis presents the results of an investigation of associations between chaos and constructivism, while determining the relationship of chaos to assessment in a constructivist chemistry classroom environment in the USA. Predictors of performance, perceptions of the classroom environment, and performance outcomes are the assessment instruments utilized in this research study. Associations between the variables assessed by these instruments are the focus of this study, along with the relationship of chaos to assessment of learning in this constructivist classroom. Action research was the method of research adopted for this particular study and the chemistry classroom teacher was the primary researcher. Because this is the first study to use the Oral Individualized Classroom Environment Questionnaire (OICEQ) with a single sample of students, statistical validation was achieved through the use of alpha reliability (internal consistency) and mean correlation with other scales (discriminant validity) between the OICEQ and the ICEQ instruments.

Chapter Two contains a review of some of the literature related to past research on learning environments in science education. In order to put this study into context, particular attention was devoted to the topics of constructivism, chaos, and assessment.

In Chapter Three, the instrumentation and methodology were discussed. The OICEQ was developed specifically for this study. Chapter Three describes the development and validation of the OICEQ and reviews previous research studies involving the use of the ICEQ and other learning environment instruments. Additionally, studies involving the TOLT, True Colors, pretest and posttest, and final examination were reviewed and discussed.

Descriptive statistics are used in Chapter Four to address the reliability and validity of the ICEQ and the OICEQ (perceptions) and the internal consistency of the TOLT (predictor), pretest-posttest (performance), and the final examination (performance). Students' responses to the actual and preferred versions of the ICEQ and OICEQ are used to compare students' perceptions of the learning environment with the learning environment they prefer. Chapter Four is a presentation of the validation, reliability, and descriptive information regarding the data collected in the study.

Associations between students' perceptions of the classroom environment, predictors of student performance, and student performance outcomes are reported in Chapter Five. The quantitative data presented is supplemented by a descriptive reflection on the relevancy of the action research process as related to constructivism, chaos, and assessment of student predictors, perceptions, and performances. An examination of the associations revealed 21 significant associations between the five ICEQ scales and predictor and performance outcomes. (In contrast, there were 29 significant associations between the five OICEQ scales and predictor and performance outcomes.) However, the types of associations with predictors and performances varied between the scales on the ICEQ and scales on the OICEQ. The Personalization scale was the most consistent and the Differentiation scale was the most inconsistent on both the ICEQ and OICEQ. Statistical analysis reveals associations between predictors, perceptions, and performances to varying levels of significance and correlations.

6.3 Major Findings of the study

The first research question proposed for this study was:

> Are chaos and constructivism allies or adversaries to assessments (predictors, perceptions, and performance)?

Chaos is an adversary to social assessment (external assessment). Social constructivism (ethnomethodology), a form of chaos, is also an adversary to social assessment. Personal constructivism (phenomenology) is an ally to personal assessment (internal assessment).

The development of personal constructs, personal constructivism, appears to be a product of personal assessment. As students assess information, personal or social, they ultimately develop personal constructs. Social assessment, a form of "noise" (outside interference) produces numeric values that are open to interpretation by persons evaluating another person's personal constructs. The social assessment of personally constructed knowledge produces obscure, conglomerate, and confusing conceptual contradictions that lead to internally inconsistent results (Von Glasersfeld, 1992). Constructivists and chaos theorists embrace approaches to assessment that do not trivialize educational questions into oblivion by reducing data to only that which is measurable or suitable only to specific forms of assessment.

The formation of personal constructs is a form of work input in a system which results in a more orderly form of information which is low entropy (as mentioned in section 2.4.1, entropy measures the amount of disorder, the measure of statistical character of constructing messages). The formation of social constructs is a form of work output in a system which results in a disorderly form of information, spontaneous change, high entropy. Students' cognition may also be regarded as a "negentropic" system (Arnold, 1993) which creates order (internal constructs) from disorder (noise, the environment, social interaction).

Personal assessment is possibly the only assessment that merits value. Internalization is a low entropy function and knowledge construction --

personal assessment. It may be a negentropic activity that produces value and meaning to only the learner because it organizes information into meaningful knowledge constructs. Due to chaos, there is a minimum of common knowledge collection, interpretation, and assessment of educational data. Extrospection is a high entropy function -- social assessment. Social assessments that attempt to validate common realities may merely bring about more confusion on the social level when presented as a recipe for educational success.

A paradox of both social constructivism and chaos is the ability of learning systems to act orderly within the unpredictable chaotic conditions -- personal constructivism. Disorder and random events continually wage a tug-of-war against learning organization. Chaos is a part of our learning, but it is also an adversary to the social assessment of our learning.

Constructivism and chaos theory share similar characteristics in that both have holistic approaches to complex systems, both are sensitive to initial conditions, both are evolving and dynamical, nonlinear, share perceptions of reality, and both refer to the quantity and quality of information in a system. The majority of these characteristics are adversaries to social assessment.

Following is a summary of comparable views of chaos theory and constructivism in complex systems (Peca, 1992):

1. Isolation and quantification of all variables which affect a system is impossible but can be known through retrospective methodologies and reflective practice.
2. The goal of research is understanding complex patterns.
3. The whole of the system is greater than the sum of its parts. The parts are merely variables that comprise the whole.
4. Apparently similar systems are found to be unique. Generalizations are avoided due to the uniqueness of variables within each instance of reality.
5. Existence of objective reality can be known only in a subjective manner.
6. Reality is in a constant state of flux that can only be ordered through individual interpretation involving societal events.
7. The presence of noise (outside interference), bifurcation points, and attractors are all variables that exist as part of complex systems.

In this study, statistical data is a form of social assessment, which provides results that are chaotic and high entropic in nature. Discrepancies between results on the ICEQ and OICEQ, varying correlations between predictors, perceptions, and performances, and fluctuating levels of significance throughout are some of the examples of statistical anomalies.

The following are specific examples and possible interpretations revealed in this study:

1. Difference between ICEQ and OICEQ is the chaos factor -- written versus oral, which is a change in initial conditions. Low correlations on Table 4.2 due to the ICEQ being a written instrument and the OICEQ a verbal instrument.
2. The most problematic scale on the ICEQ and OICEQ is the Differentiation scale, which is a more socialized item (different students do different work). Whereas, the Personalization scale is a more personalized item (the teacher takes a personal interest in each student) and is the least problematic scale. Social assessment is highly chaotic and unpredictable.
3. Differences between Scale Mean and Standard Deviation on Tables 4.4 and 4.5 are due to changes in initial conditions.
4. Correlation coefficients in Tables 4.6 and 4.7. Varying correlations and varying degrees of correlations are due to chaos and constructivist principles. Empirical investigation seeks to determine how the parts (five scales) affect the whole pattern. Chaos theory endeavors to understand the whole pattern (total score of short form ICEQ & OICEQ equals 115), which is composed of ever-changing parts. Complex systems must be viewed as a whole because all parts and iterations, however apparently insignificant, interact with all other parts

and iterations (Peca, 1992). This is a form of holistic scoring that supports the constructivism and chaos theory.

The evaluation, interpretation, and analysis of data, due to chaos and constructivism, produce potentially inaccurate assessments and predictions regarding learning. The constructivist model, a process of extrospection and apperception, promotes personal constructs as a means of knowledge formation, which would be considered a method of manipulating chaos. Personal assessment, a form of personal constructivism, contributes to lowered chaotic conditions. Social assessment, a form of social constructivism, contributes to increased chaotic conditions. Personal constructivism appears to aid in minimizing internal chaos while social constructivism appears to increase external chaos. Personal constructivism and personal assessment provide work input for learning (internalized learning). Social constructivism and social assessment are more chaotic because of the complexities of the variables and the measurement of the variables. Predictability of patterns is more involved. Learning is a negative entropy (personal constructs) phenomenon while social assessment is a positive entropy (social constructs) phenomenon.

Chaos theory and constructivism maintain that precise measurement of social assessment and learning which is personal assessment, is lacking due to mathematical limitations – a position that phenomenonologists (constructivists) have long held (Peca, 1992). One can communicate the system used in the study, never its results . . . a chaos-constructivist perspective.

Assessment is the means by which we attempt to bring order and predictability to the data that are collected and analyzed. From these data we strive to find patterns that can give rise to generalizations involving learning. Human mental processes are not linear and additive, thus attempts to model human mental processes that assume linearity and additivity take us astray. Test theorist Lee Cronbach (1988) observes that human mental processes can be described by models that are nonlinear and multiplicative. Chaos theory provides models that replace input-output determinism with the study of patterns. Educational assessment attempts to identify these patterns and make predictions applicable to educational learning. To a constructivist and chaos theorist, objective reality is not defined by correspondence but by the interaction of the individual person's experience and that individual's ability to reason. Measurement and assessment of those experiences can only be known in a generalized, subjective manner.

Although social constructivism and chaos are adversaries to assessment of learning, personal constructivism acts as an ally to the process of learning. There may not be a technical solution to the problematic scenario of the impact of chaos and constructivism on the assessment of learning. The force of chaos does not make exceptions; it is pushing all things into dissolution and disorder. Chaos and social constructivism may continue to exist as perpetual adversaries to the social assessment of learning.

In the context of assessment, it is possible that what we observe is not nature itself, but nature exposed to our method of questioning. Therefore, when assessing students in a constructivist teaching paradigm that is impacted by chaos, students may have the right answers and we, as assessors, have the wrong questions.

The second research question proposed for this study was:

> Is action research a valid process of evaluating a constructivist chemistry classroom (examining associations between chaos and constructivism)?

Action research, in this research study, has proven to be a valid and valuable process for evaluating a constructivist chemistry classroom. The validity of action research is tested by evaluating the impact of these action steps in a continuous process of data collection, reflection, analysis, interpretation, action, and evaluation (Altricheter & Posch, 1993). At a later stage it can be further validated through the process of communicating a range of outcomes to other practitioners who will make implicit comparisons with their own repertoire of experience and judge the work to be worthwhile or not on this basis. Whitehead (1989) describes a particular approach to this kind of validation . . . action research, a precision approach, rather than accuracy approach, presents a higher probability for common conceptual domain among practitioners.

Action research is in compliance with the Heisenberg Uncertainty Principle: observation of a class from an outside observer affects the outcomes of the results. Action research places the researcher in a participation role, a member of the system rather than an observer, which further validates the significance of action research and further reduces inaccuracies in measurement.

The principles of action research, constructivism, and chaos have contributed to the triangulation process of assessment utilized in this study, and subsequent conviction in the validity of correlations identified between predictors, perceptions, and performances.

The statistical correlations substantiate the wide variety of factors that are related to academic measurements: Proportional reasoning ability, personality profiles (intellectual competence), perceptions of the classroom environment, and performance results on pretests, posttests, and final exams (intellectual performance). Through the assessment process utilized in this study, and cyberchaos research perspective, action research should be considered a valid process of evaluating a constructivist chemistry classroom.

Action research varies considerably with different cultural settings. Action research concerns itself primarily with processes of development and change in social situations, and these can never be amenable to the demand for certainty. Like personal constructivism, action research with a cyberchaos perspective, adheres to the notion that one can but communicate (social constructivism) a system, never its results (personal constructivism). The process for a teacher doing action research can be communicated but not the statistical results. There are some kinds of human action which can only be described from a phenomenological (personal constructivist) perspective (Baird, 1989); assessment of learning is one of those human actions.

Action research has a highly constructivist orientation. The primary purpose is to relay the findings directly back into educational practice with the intent of initiating personal, intrinsic change -- personal constructivism approach.

The researcher is the practitioner and the research involves an investigation into his or her own practice and that of colleagues. It is impossible to carry out analysis and interpretation of the data without doing so in the light of prior knowledge (Somekh, 1995), a constructivist perspective. In the case of this particular study, the predictors, perceptions, and performance evaluations administered are for the purpose of research and are a regular aspect of the classroom environment. The data collected for this study is data that is, and has been, collected for several years in the classroom. Therefore, the tests administered to students and the data collected were a normal part of the classroom environment. It was not viewed by students or teachers as an external or extraneous part (observers affect the outcome of the results) of the classroom environment as in cases where professional researchers are involved. It was a vital and reliable intrinsic (personal constructivist) method of research. Additionally, the analysis and interpretation of the data is a long-term, continuous process that is viewed from a constructivist teacher's frame of reference.

The action research undertaken in this study has entrenched the premise that constructivism, chaos, and assessment, are interrelated, intertwined, and interactive. They are natural components of dynamic systems, including the educational classroom. They are integrated with the classroom environment. The constructivist teaching paradigm and chaos impact the assessment of classroom learning.

Action research is a unifying concept for constructivism, chaos, and assessment. Action research in this study utilizes a holistic, triangulation method of assessment . . . predictors, perceptions, and performances. A holistic orientation allows adequate account to be taken of the multiple factors that act to influence the thoughts and actions of individuals being studied. Intellectual competence and intellectual performance (Baird, 1989) are two such factors, and in this study, predictors emulate intellectual competence, perceptions are an added factor, and performances emulate intellectual performance.

Action research embodies the concepts of constructivism, chaos, and assessment. Action research is the practice of constructivism, both personal and social. Social constructivism typifies chaos in that it creates difficulty in assessment in a chemistry classroom. Entropy, the measurement of disorder, and cybernetics, the science of control of information, are variables taken into account during this action research process -- cyberchaos theory. The action research utilized in this study, a form of constructivism, follows the premise of cyberchaos theory . . . a triangulation approach to research of a chemistry classroom (action research, constructivism, chaos), a holistic approach.

Cyberchaos theory is a research perspective/paradigm that assists in interpretation and analysis of a constructivist-action research process. A premise of cyberchaos theory is that the function of information is to reduce uncertainty. Of particular interest to cyberchaos theory are the changes in the quantity of information over time. Also, communication (social assessment) serves a regulative function in that it signals the system to either increase information (positive feedback – divergence – entropy) or to decrease information (negative feedback – convergence – negative entropy). Cyberchaos theory promotes the belief that small changes in information quantity escalate into exponentially large differences between initial conditions and final outcomes, which make system behavior unpredictable. Short-term prediction of a system is accurate to a certain degree, but the accuracy of prediction is an inverse function of elapsed time. Cyberchaos theory maintains the conviction that observation of a system by an outside observer affects the outcomes of the measurement of the system (Heisenberg Uncertainty Principle). Whole entities, as fundamental and determining components of reality, have an existence other than as the mere sum of their parts. Thus, complex systems must be viewed as a whole because all parts and iterations, however apparently insignificant, interact with all other parts and iterations -- complexity cannot be reduced to a simpler form.

Holism requires a general systems approach to nonlinearity within chaotic systems and requires numerous measurements and analyses of the system. Action research is a holistic, general systems approach to educational environments. The use of predictors, perceptions, and performances is a holistic method of assessment of educational environments (Guess & Sailor, 1993).

Linear models work well when the goal is to study a system's behavior under controlled conditions. However, when the goal is to describe a system's linear and/or nonlinear behavior in its natural environment, the outcome is much less satisfactory. This is the reason for action research with a cyberchaos research perspective.

We are in and of the moment that we are attempting to analyze, in and of the structures we employ to analyze it (Connor, 1989). Action researchers, through a constructivist and chaos perspective, realize that assessment is a continuous and evolving process. Assessment is dependent upon the methods employed for the analysis and interpretation of data.

6.4 Implications for Chemistry Teachers

This study reports the first use of the Oral Individualized Classroom Environment Questionnaire and the True Colors personality profile test in senior secondary chemistry classes. The instruments were found to be economical to use and reliable and valid. These widely applicable, convenient, and useful instruments, can now be used with confidence by teachers to assess, evaluate and improve aspects of the chemistry classroom environment.

This study provides evidence of associations between the actual environment and students' preferred environment. The data indicates that, relative to the actual environment currently present, students prefer a classroom environment that is personalized, allows participation, independence, and investigation in the classroom setting. Utilizing the data collected from the OICEQ, Differentiation appears to be a lesser preference to students than their actual perception of the classroom. Students' perceptions of the actual classroom environment and the preferred classroom environment are closely matched in the scales involving Personalization, Participation, Independence, and Investigation.

Regarding personality profiles, the results of this study imply that Group 1 personalities (concrete-sequential) prefer a classroom environment that allows personalization, independence, investigation, and differentiation. Group 2 personalities (concrete-random) prefer personalization, participation, and independence. Group 3 personalities (abstract-sequential) prefer personalization, participation, independence, and differentiation. Group 4 personalities (abstract-random) prefer personalization and investigation.

This study also confirms that a constructivist teaching paradigm and chaos have an impact on the assessment of a constructivist chemistry classroom. Teachers should understand that there is a wide variety of variables involved in student learning, such as constructivism and chaos, in the social assessment of student learning.

Social assessment is merely a means of assisting teachers in making a personal assessment decision, an internalized decision made with a constructivist approach to teaching and learning. Social assessment is a high cyberchaos endeavor. "Learning is not knowledge written on, or transplanted, to a person's mind as if it were a blank slate waiting to be written on or a gallery waiting to be filled" (Cobern, 1991). A constructivist teacher works at the interface of curriculum and student to bring them together in a way that is meaningful for the learner. Teaching is a mediation between the unpredictable and the predictable. Thus, constructivism is about understanding the fundamental, culturally-based beliefs that students and teachers bring to class -- a sometimes ominous task.

Action research is a valid means of research that takes place in the chemistry classroom; both quantitatively and qualitatively, objectively and subjectively, numerically and nonnumerically. Action research is a cyberchaos form of research in that it uses a holistic, general systems, information approach to assessment -- predictors, perceptions, and performance measurements. Cyberchaos theory is a perception teachers should take into account when assessing their classrooms. Cyberchaos theory will assist teachers in realizing that there are no blueprints for teaching, learning, or social assessment of learning due to chaos (a force) and constructivism (a practice).

Cyberchaos theory affirms an approach to research methodology that is sensitive to initial conditions, acknowledges that reality is in a constant state of flux, and promotes the belief that the whole of the system is greater than the parts -- an action research impetus.

Perhaps the single term "complexity" can be utilized to represent all the factors in research studies and their tendency to increase the cyberchaos or disorder of a dynamic system. The term "redundancy" can be employed to the same factors when they tend to lower the cyberchaos or establish a higher degree of order. It becomes possible then to represent all the factors in a simple equation identifying how the factors work to lower or raise cyberchaos:

$$\text{Cyberchaos equals} = \frac{\text{meaningful complexity and noise (unexplained variance)}}{\text{meaningful redundancy}}$$

(Marder, 1974)

Although such an equation can be designed, the application of numerical values would be disastrous. Cyberchaos is a tendency and its value in rhetorical systems at best would be felt, not calculated -- testament for an action research-constructivist approach to assessment of learning. Complex systems, such as a chemistry classroom, must be viewed as a whole because all parts and iterations, however apparently insignificant, interact with all other parts and iterations. Complexity cannot be reduced to a simpler form. Therefore, chemistry teachers should socially assess the classroom with a constructivist, cyberchaos perspective realizing the complexity of variables involved in social assessment. In this way, teachers will be able to make the necessary changes to their classrooms which will help create a more supportive environment for learning, which will in turn help students improve their own learning.

To believe a single quantitative measure can possibly reveal all of the gifts of which the human mind is capable puts unnecessary limitations on our concept of human development.

6.5 Limitations of the Study

The fact that only students in a certain school and university participated in the study means that the sample was not strictly random. Furthermore, the study involved students in only one state of the United States, so caution should be observed in generalizing from the results of this study.

The classroom environment instruments used in this study, the ICEQ and OICEQ, were found to be reliable and valid instruments. Additionally, the ICEQ has been known from previous research to be reliable and valid. However, certain limitations were evident in the assessment of student predictors, perceptions, and performances.

The first limitation exists in the ability to accurately measure and maintain initial conditions involving learning. The chemistry classroom is not a closed system, thus initial conditions were not monitored or controlled. While the TOLT and True Colors instruments were designed as predictors of academic performance in this study, they are not reliable measurements of initial conditions (intellectual competence).

Despite the achievements of past learning environment research (perceptions), Fraser and Tobin (1991) point out that there is potentially a major problem with nearly all of the existing classroom environment instruments, thus another limitation subsists. Identifying differences between subgroups (e.g. males and females) or in the construction of case studies of individual students is an enigma when using one of the environment instruments for research studies. The problem is that items are worded in such a way that they elicit an individual student's perceptions of the class as a whole (social constructivist feature -- highly chaotic), as distinct from that student's perceptions of his/her own role within the classroom (personal constructivist feature -- reduced amount of chaos).

The third limitation lies in the measurement of students' academic performance. The students comprising the sample were enrolled in one of two chemistry courses offered. Although the courses had similar content and skills objectives, they had different final examinations. While the final examinations for the two courses varied slightly and were similar in the style and content of the questions, it is possible that some of the variance in students' achievement performance was due to variance in the final examinations. The use of standardized *z* scores in the analysis of data would have reduced this effect.

The final limitation to the study is not considering time and noise as variables. Each assessment instrument was a single episode event, not ongoing. As mentioned in Section 6.2, the ICEQs were taken three times during the course of the year and produced different results each time, particularly individual student's scores.

6.6 Suggestions for Future Research

Action research, when incorporating the concepts of constructivism, cyberchaos theory, and assessment, provides a new research paradigm that is part of a scientific movement to understand complexity and move away from reductionism (Keaten, 1994). The new discipline of cyberchaotic dynamics is an analytical approach to the array of real-world cybernetic (communication and control) systems (Waldrop, 1992) that are random, irregular, aperiodic, and unpredictable. Learning and learning environments can be considered to be complex cyberchaotic systems. Social assessment, a version of communication, is a real-world dynamic and cyberchaotic system that has been researched from a comparatively static perspective by researchers. A close inspection of cyberchaos concepts may aid researchers' future efforts to explain cyberchaotic (dynamical communication) processes. For the person who is considering applying cyberchaos theory to research, it may be more functional to focus on the possible range of applications and to be aware of his or her own biases and the biases of the authors he/she is reviewing.

Since both quantitative and qualitative paradigms inadequately address complex systems, this educational research project is studying the evolution of the whole; it is an action research-constructivist process with a cyberchaotic perspective. This research study leads to an understanding of a complex system (the learning environment) by using a holistic, triangulation method of assessment: predictors, perceptions, and performances.

Theories of complex, non-linear, dynamic systems are able to suggest to education researchers the consideration of different sets of metaphors, signifiers, and signalfields, constructions of relations and of fields. The scientific, cultural and social ideas, which intersect in a post modern era, are able to inform education research, and are ideas in which disorder, complexity, uncertainty, non-linearity, noise, language, the observer, scale, reproducibility, causality, subjects, objects, and laws are reconstituted and charged with different roles than those assigned to research in the empiricist era. Viewed as a complex dynamical system, the classroom takes on a variety of properties and dimensions. The character and the dynamics associated with the classroom and cyberchaos may well form the basis of a reform for educational research.

Parallels exist between cyberchaos theory and traditional research methodologies. The strange attractor can be thought of as representing an underlying construct (constructivism) of a system and as such can be equated conceptually with a factor. Factor analysis is done to produce factors that are assumed to measure or represent underlying constructs in the behavior being studied. Factors are derived by running a series of correlations to determine the structure of the data. Based on the factor loadings, the researcher can interpret the structure by naming the construct which the data seem to represent. Similarly, a strange attractor is produced by plotting what can be considered a series of correlation points, or the relationship between variables at a given moment in time. The shape that results is one that can be replicated in further studies of the same system -- iteration.

Educational research has the task of making order out of disorder -- social assessment. (The concept that social assessment can accurately predict the personal constructs of knowledge is misleading.)

Generalizations about educational data may be possible, but taking specific, microscopic data and applying them as a recipe for success in the extraordinary educational settings is unrealistic and unproductive. Small events are absolutely unpredictable even though the overall process operates within large limits or constraints that are identifiable (Erickson, 1992). Cyberchaos theory, being ubiquitous, casts doubts upon the replicability of results as a scientific principle due to the extreme sensitivity of systems to initial conditions. If initial conditions of systems are sensitive dependent then the final conditions (results) of social assessment of learning lacks credibility and predictability. Initial conditions are seldom, if ever, maintained when using social assessment. It is a virtual impossibility to maintain initial conditions of the measured variables let alone initial conditions of the unmeasured, uncontrolled, and unidentified variables that exist and change during the course of assessment. Small errors in initial conditions produce large errors over periods of time.

The clinical trial method of educational research may not work because of cyberchaos, sensitive dependence of initial conditions, and the complexities of nonlinear systems. No degree of meticulous observation, even in theory, can provide an account of the state of relevant variables at any given time. The classroom is, therefore, nonsimulatable by any representation of models that use fewer elements than are present within itself (Arnold, 1993). The consequence of this is that the reliability of studies which take place in a clinical or experimental setting is compromised, if not in the transfer of results from experimental setting to experimental setting, at least in the transfer of results from an experimental setting to a natural setting -- social assessment. As the two laws of nature exude the ideas that things in nature move toward highest entropy lowest energy, so does information exchange -- social assessment.

Complex systems, such as the chemistry classroom, are ultimately unanalyzable (Pecca, 1992) and irreducible into parts, because the parts are constantly being folded into each other by iterations and feedback. Therefore, it is an illusion to speak of isolating a single interaction between two particles and to claim that this interaction can go backward in time. Any interaction takes place in the larger system and the system as a whole is constantly changing, bifurcating, and iterating. So the system and all of its parts have a direction in time.

One of the major characteristics of the cyberchaos theory of research is that it promotes a general systems approach to looking at the totality of the data and derives its theory from the data. Interpretation, explanation, and reflection (insight) emerge from the data. Cyberchaos researchers follow this methodology. They study a system in order to see what emerges from it. Quite often, previously held theories about the system fail to accurately predict its behavior. A concrete example of cyberchaos modeling in research is utilizing reliability and validity data as strange attractors (points of convergence). Assessment in a constructivist-chaos pedagogically, philosophically, and epistemologically-based classroom is an action research methodology directed at identifying strange attractors. Cyberchaos theory is compelling because it presents an alternative way to study reality and also confirms and explains why empiricism is unable to quantify, predict, and generalize about complex systems. Cyberchaos theory provides an expansion of means by which reality can be known and perhaps, will allow greater tolerance for alternative paradigms in educational research.

To connect educational research with research in the natural sciences, and to assert that one affects the other, requires that the two exist in a shared cultural field. For just as research is immersed in a culture and is empowered and constrained by that culture, so the culture is conditioned by the assumptions which have guided the constitution of knowledge in the scientific paradigms of the day. Therefore, it benefits the educational researchers to attend to these influences, to be sensitive to them and to be conscious of their capacity to contribute to analysis and interpretation -- assessment.

To date, most research has been designed to measure psycho-social characteristics of classroom learning environments using paper and pencil measures. Possible avenues of future research might be oral versions of other learning environment instruments, such as the CLES, SLEI, etc. Additionally, future research might be directed toward the identification of aspects of the classroom and/or laboratory learning environment that are associated with student achievement outcomes. Finally, this research study consisted primarily of quantitative data collection and analysis. It might be desirable for future research studies to have larger qualitative components.

Much of our assessment is like the story of the person looking for a lost quarter under the street light because it was too dark to look in the alley where the coin was dropped.

6.7 Final Comments

The purpose of this thesis is to report a comprehensive study of assessing predictors, perceptions, and performances of students in a constructivist chemistry classroom. The results of this study indicate predominant associations between predictors-perceptions, perceptions-performances, and predictors-performances. Such findings have important practical implications in that they provide teachers with information that could help chemistry teachers teach more efficiently and effectively, provide them with a valuable tool for assessing (using predictors, perceptions, and performances) their classroom environments, while promoting improved student learning.

Through an action research-constructivist process and a cyberchaos research perspective, this study espouses the belief that chaos and constructivism skew the collection, reflection, analysis, and interpretation of assessment data.

Whoever undertakes to set himself up as a judge in the field of truth and knowledge is shipwrecked by the laughter of the gods (attributable to Einstein).

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Appendix A

Test of Logical Thinking (TOLT)

&

True Colors Personality Profile Test

Note: For copyright reasons Appendix A (pp208-214 of this thesis) has not been reproduced.

(Co-ordinator, ADT Project (Retrospective), Curtin University of Technology, 13.1.03)

Appendix B

Individualised Classroom Environment Questionnaire (ICEQ)
Preferred Version

&

Indivualised Classroom Environment Questionnaire (ICEQ)
Actual Version

Note: For copyright reasons Appendix B (pp216-19 of this thesis) has not been reproduced.

Co-orrdinator, ADT Project (Retrospective), Curtin University of Technology, 13.1.03)

Appendix C

Pretest and Posttest

&

Final Examination

Pretest and Posttest

1. The recommended adult dose of Elixophyllin, a drug used to treat asthma, is 6.0 mg per kg of body weight. Calculate the dose, in milligrams, for a 170-pound person.

   (1) 3.5×10^{-2} mg (3) 1020 mg
   (2) 460 mg (4) 2250 mg

2. Expressed to the appropriate number of significant figures, the result of the calculation

   $$\frac{(5.031 - 4.96)(2.38)}{3.91} \text{ is}$$

   (1) 0.04 (2) 0.043 (3) 0.0432 (4) 0.04322

3. Using the cathode-ray tube, J.J. Thomson was able to determine

   (1) the charge of an electron.
   (2) the charge-to-mass ratio of an electron.
   (3) the charge-to-mass ratio of a proton.
   (4) that the nucleus of an atom is very small but contains most of the mass.

4. The partial symbol for a particular ion is $^{24}Mg^{2+}$. The number of electrons contained in one of these ions is

   (1) 2 (2) 10 (3) 12 (4) 22

5. The mass percent of carbon in methanol, CH_3OH, is

   (1) 12.0 % (2) 12.5 % (3) 16.7 % (4) 37.5 %

6. The correct molecular formula of a compound that has an empirical formula C_3H_4O and a molecular mass of 168 grams/mole is

   (1) C_3H_4O (3) $C_8H_8O_4$
   (2) $C_6H_8O_2$ (4) $C_9H_{12}O_3$

7. A gas sample is contained in a flask connected to a U-shaped manometer. Measured from the bottom of the U-tube, the height of the mercury on the side connected to the flask is 62 mm. The height of the mercury on the side open to the atmosphere is 182 mm. The atmospheric pressure is measured with a barometer to be 759 mm Hg. The pressure of the gas in the container is

   (1) 120 mm Hg (3) 821 mm Hg
   (2) 639 mm Hg (4) 879 mm Hg

8. A sample of a gas with a volume of 800 mL and pressure of 1.0 atm is transfered to a second container which has a volume of 250 mL and is at the same temperature. The pressure of the gas in the new container is

   (1) 0.31 atm (2) 1.0 atm (3) 1.5 atm (4) 3.2 atm

9. A 1.22 gram sample of an unknown volatile substance is vaporized at 100°C into an evacuated 205 mL flask. The pressure of the vapor at 100°C is 0.993 atm. The molecular weight of the substance is

   (1) 49.2 g/mol (3) 183 g/mol
   (2) 122 g/mol (4) 308 g/mol

10. Iron (III) Oxide can be reduced with carbon monoxide to form metallic iron as described by the unbalanced chemical equation

    $$Fe_2O_3 + CO \rightarrow Fe + CO_2.$$

    The number of moles of CO required to form one mole of Fe from its oxide is

    (1) 1 (2) 1.5 (3) 2 (4) 3

11. A product of the reaction of silver nitrate, $AgNO_3$, with calcium chromate, $CaCrO_4$, in aqueous solution is

    (1) $CaNO_3$ (2) Ag_2NO_3 (3) $AgCrO_4$ (4) Ag_2CrO_4

12. Sodium nitrate, heated in the presence of an excess of hydrogen, forms water according to the two-step process

    $$2\,NaNO_3 \rightarrow 2\,NaNO_2 + O_2$$
    $$2\,H_2 + O_2 \rightarrow 2\,H_2O.$$

    How many grams of sodium nitrate are required to form 9 grams of water?

    (1) 21.3 (2) 42.5 (3) 69.0 (4) 85.0

13. Which quantity of nickel has the largest mass?

    (1) one mole
    (2) 6.02×10^{23} atoms
    (3) 58.7 grams
    (4) 22.4 moles

14. Which element should have properties most like those of phosphorus?

    (1) Si (2) S (3) As (4) Sb

Final Examination

33. The normal boiling point of a liquid is defined as:

(1) the pressure at which a liquid vaporizes.
(2) the temperature at which a liquid vaporizes.
(3) the temperature at which the vapor pressure of a liquid equals 1 atm.
(4) the temperature at which the vapor pressure of a liquid equals the barometric pressure.

34. In the reaction $SO_2 + 2\,H_2S \rightarrow 3\,S + 2\,H_2O$

(1) sulfur is oxidized and hydrogen is reduced.
(2) sulfur is reduced and there is no oxidation.
(3) sulfur is reduced and hydrogen is oxidized.
(4) sulfur is both reduced and oxidized.

35. Which group among the representative (main-group) elements contains the most powerful oxidizing agent?

(1) group I (2) group III (3) group VI (4) group VII

36. The following standard electrode (reduction) potentials refer to aqueous solutions at 25°C.

$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$ $E^o = -0.25$ V
$Cu^{2+}(aq) + 2e^- \rightleftharpoons Cu(s)$ $E^o = +0.34$ V
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$ $E^o = +0.77$ V

What is the standard potential for the reaction

$$Cu^{2+}(aq) + Ni(s) \rightleftharpoons Cu(s) + Ni^{2+}(aq) \ ?$$

(1) 0.09 V (2) 0.59 V (3) 0.86 V (4) 1.02 V

37. Which ion, in aqueous solution, can be oxidized by appropriate chemical means but also can be reduced by a different chemical reaction?

(1) Fe^{2+} (2) F^- (3) CO_3^{2-} (4) NO_3^-

38. Choose the pair of salts whose aqueous solutions would form a precipitate upon mixing.

(1) $NaNO_3$ and $MgBr_2$ (3) $BaCl_2$ and K_2CO_3
(2) KNO_3 and $(NH_4)_2CO_3$ (4) Na_2SO_4 and $(NH_4)_2S$

39. Which statement describing chemical equilibrium is NOT correct?

(1) A system at chemical equilibrium has a constant mass.
(2) A system in chemical equilibrium acts so as to oppose slight disturbances.
(3) Forward and reverse reactions proceed at the same rate in a system at chemical equilibrium.
(4) Reactant and product concentrations vary with time in a system at chemical equilibrium.

40. The equilibrium constant for the process

$$Ag_2S(s) + H_2O(l) \rightleftharpoons 2\,Ag^+(aq) + S^{2-}(aq)$$

has a very small numerical value. This implies that

(1) silver sulfide reacts extensively with water.
(2) the solubility of silver sulfide in water is very small.
(3) solutions can be prepared containing large concentrations of silver ions and sulfide ions.
(4) the process described by the equation is not affected by temperature.

41. The rate of a chemical reaction between substances A and B is found to follow the rate equation

$$\text{rate} = k\,[A]^2\,[B]$$

where k is a constant. If the concentration of A is halved, what should be done to the concentration of B to make the reaction go at the same rate as before?

(1) The concentration of B should be kept constant.
(2) The concentration of B should be doubled.
(3) The concentration of B should be halved.
(4) The concentration of B should be quadrupled.

42. If the average velocity of SO_2 molecules at 25°C is 0.2 mile/sec., what is the average velocity of CH_4 molecules in miles/sec. at the same temperature?

(1) 0.1 (2) 0.2 (3) 0.4 (4) 0.8

43. Cesium-137 decays spontaneously to emit beta particles and form Barium-137. Its half-life is 30 years. Approximately what length of time will have elapsed before 97 % of the Cs-137 in a particular sample will have decomposed?

(1) 30 years (2) 60 years (3) 150 years (4) 2900 years