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RELATIONSHIPS AMONG EPISTEMOLOGICAL BELIEFS, IMPLEMENTATION OF INSTRUCTION, AND APPROACHES TO LEARNING IN COLLEGE CHEMISTRY

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RELATIONSHIPS AMONG EPISTEMOLOGICAL BELIEFS, IMPLEMENTATION OF INSTRUCTION, AND APPROACHES TO LEARNING IN COLLEGE CHEMISTRY

A Dissertation APPROVED FOR THE DEPARTMENT OF INSTRUCTIONAL LEADERSHIP AND ACADEMIC CURRICULUM

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Dedication

To my mother, Louise Saunders

Your love, support and confidence have made this possible.

To my father, Kilton Saunders

For encouraging a young girl to explore her interests and potential.

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Abstract

This study investigated possible relationships among students' epistemological beliefs and approaches to learning, and examined the possible influence of teachers' implemented instruction on students' beliefs and learning approaches. The sample consisted of five chemistry laboratory teachers and 232 students. Relationships were investigated through observations of the teachers' instruction and using two student questionnaires. Instruction was characterized as either "more inquiry" or "less inquiry" based upon observational data. Scores from the questionnaires represented students' epistemological beliefs and learning orientations.

Students became a source of scientific knowledge when they were allowed to be and encouraged to do so. When the teacher presented himself as an authoritative source of knowledge, students accepted him as such. The justification for knowing in the chemistry laboratory appeared to depend upon the perceived source of knowledge. Agreement of a source of authority was the justification for knowing in less inquiry classrooms. Results of experimentation and logical reasoning were the justification for knowing in more inquiry classrooms. The epistemological assumptions of the instruction differed due to the ways teachers implemented the curriculum. Students' perceptions of

instruction may have been influenced to a greater extent by the laboratory manual or their prior experiences than by their instructor.

The epistemological messages inherent in the two types of instruction did not appear in students' responses to the Science Knowledge Questionnaire. Some students showed strong beliefs in received knowledge; no students held strong beliefs in reasoned knowledge; and most students showed mid-range beliefs. In contrast, many students reported that they generated personal scientific knowledge during the chemistry laboratories. Perhaps these students had developed parallel ways of knowing about science.

Results of the Learning Approach Questionnaire indicated that meaningful and rote learning approaches are unrelated approaches to learning. Type of instruction was not correlated with learning approach. However, the open-ended responses suggest that students' perceptions of classroom tasks influenced choice of learning strategies.

Rote learning approach was predicted by belief in reception of knowledge from authorities. Students who believed that knowledge comes from an external authority were more likely to attempt to memorize information than to "make sense" of the information for themselves.

Chapter I: The Problem

Introduction

An elementary education student was asked his opinion of science. "I despise science," was his immediate response. When asked to elaborate on his response, the student described science as consisting of reading thick textbooks, listening to lectures, and memorizing disconnected facts and theories. As the discussion continued, it became clear that the student's conceptions of science and learning in science classes were inseparable and identical. The student could not explain how the facts and theories in the textbooks originated; he stated, " I never thought about the information coming from anywhere." This senior had completed several university-level science courses, yet he believed that existing science knowledge was unchanging and that scientific researchers simply discovered new facts that were added to the existing facts. The student had expressed his personal beliefs about knowledge in science. Beliefs about the origin of knowledge, the formation of knowledge and the characteristics of knowledge are called *epistemological beliefs.*

Review of theory and research concerning epistemological beliefs across disciplinary boundaries led to the definition of epistemological beliefs as beliefs about the *processes of knowing* and the *nature of knowledge* (Hofer & Pintrich, 1997). Hofer and Pintrich define the processes of knowing as personal theories about the source of knowledge and the process of justification for knowing (including the evaluation of evidence and the opinion of experts). For example, a person may believe that knowledge originates in external authority and may simply accept the opinions of experts without question. In contrast, a person may believe that she has the ability to construct knowledge herself and may choose to evaluate the opinions of experts for herself through examination of the evidence. The nature of knowledge has been defined as consisting of personal theories about the certainty and simplicity of knowledge (e.g., Hofer & Pintrich, 1997). For example, a person may believe that knowledge is absolute, certain truth or that knowledge is tentative and evolving. Knowledge may be thought of as an accumulation of discrete facts or as highly interrelated concepts.

Epistemological beliefs about the origin and formation of knowledge (processes of knowing) in science can be described in the form of the following question, "<u>How</u> do scientists <u>know</u>?" Understanding the processes of knowing in science leads to certain understandings about the characteristics of science knowledge (nature of knowledge), as described by Ryan and Aikenhead (1992):

> Scientists engaged in consensus making draw upon empirical evidence, assumptions, and their values to reach a conclusion on the 'truth' of a conceptual invention (or the adequacy of an experimental procedure). Their conclusions constitute scientific knowledge. This knowledge is probabilistic, tentative, and paradigm bound. (p. 575)

The epistemological question (How do scientists know?) is not often examined in courses that study the disciplines of science (Munby & Russell, 1987). Science instruction in the disciplines generally communicates the products of scientific investigation with little emphasis placed upon the other facets of the nature of science (Yager & Yager, 1985). Many science textbooks present the products of science with insufficient mention of the process by which the knowledge was generated (Gallagher, 1991). In these textbooks, the process of knowledge formation is portrayed as the accumulation of a set of confirmed hypotheses rather than as a process driven by theoretical considerations (Carey & Smith, 1993). From reading these textbooks, students may develop personal theories of the process of knowledge formation in science that are not reflective of inquiry in science.

Since science classes can be expected to teach students only a fraction of the information that science has generated, it is important for science education to prepare students to be able to think critically about issues related to science (Carey & Smith, 1993). The ability to critically examine the results of scientific investigations rather than simply accept the interpretations of 'experts' requires an understanding of the formation of knowledge in science. Science education should prepare students to value "the kind of knowledge that is acquired through a process of careful experimentation and argument" (Carey &

Smith, 1993, p. 235). However, studies show that despite taking science courses, students do not understand that science knowledge is constructed through theoretical interpretations of evidence (Ryan & Aikenhead, 1992).

Furthermore, a person's beliefs about the processes of knowing and the nature of knowledge in science may influence the way in which the person approaches the task of learning in science. For example, if a student believes that science knowledge consists of factual information, the student may believe that recalling the information constitutes <u>knowing</u>. Thus, the student may believe that learning science knowledge consists of memorizing information. In contrast, if a student believes that science knowledge is complex, resulting from interpretation of evidence in light of theories, then the student may believe that learning requires mental effort to understand the interrelationships and complexities of the knowledge (Roth & Roychoudhury, 1994; Schommer & Walker, 1995).

The ways in which students approach learning tasks have been the subject of several studies (Bretz, 1995; Cavallo & Schafer, 1994; Entwistle & Ramsden, 1983). A student's choice of using memorization as a mode of learning has been described as reflective of a surface or rote learning orientation (Cavallo & Schafer, 1994; Entwistle & Ramsden, 1983). When a student chooses to deal with a learning task by trying to understand the relationships among new information and other information, the student's learning orientation has been described as deep or meaningful (Cavallo & Schafer, 1994; Entwistle & Ramsden, 1983).

Bretz (1995) explored the possibility of a link between students' learning orientation and personal theories about knowledge. The study revealed a relationship between college students' learning orientation and the way in which they described learning to be scientifically literate (Bretz, 1995). Students who had rote learning orientations described learning and scientific literacy in terms of receiving knowledge and the amount of knowledge they possessed. In contrast, students with meaningful learning orientations described making connections between prior knowledge and knowledge they wanted to learn, as well as making connections between domains of knowledge in anticipation of using the knowledge for problem solving.

Other researchers have also speculated about possible relationships between learning and epistemology. Hofer and Pintrich (1997) suggested that ideas about learning may be developmental precursors to ideas about epistemology. Perry (1981) hypothesized that as a person's epistemology changes, the person's mode of learning and studying may also change. However, this hypothesis has not been tested.

Cavallo, Miller, and Blackburn's (1996) investigation of high school students' meaningful learning in laboratory-based science instruction indicated that classroom environment and teachers' instructional behaviors may enable students to learn concepts meaningfully regardless of the students' orientation to learn meaningfully or by rote. These findings suggest that a student's choice of using a meaningful or rote learning approach may be influenced by the context of the learning situation.

Thus, students' experiences in science laboratory classes may influence their beliefs about the processes of knowing in science (the source and justification of the knowledge) and the process of learning. The setting of a laboratory science class may provide opportunities for students to participate in the process of scientific inquiry and the formation of knowledge. Laboratory experiences can be structured in very different ways. The laboratory experience may require students to verify the knowledge that has already been presented to them by an authority source (verification or non-inquiry laboratory). In contrast, the laboratory experience may engage students in active inquiry and involve students in the construction of knowledge (inquiry laboratory).

Authors of laboratory science curricula may intend for lessons to be implemented as either verification or inquiry. However, the behaviors of the classroom teacher may result in the implementation of curricula in a manner that differs from what the authors intended. For example, Methven (1986) found that two teachers implemented the learning cycle (a guided inquiry, laboratory-based science curriculum) incorrectly in their classrooms following participation in a science teaching inservice workshop. Although all the teachers in the study used the same written materials to guide the laboratory investigations, the two teachers errantly "informed the students of the concept and did not use the students' data in the conceptual invention" (Methven, 1986, p. 43). This finding suggests that the type of instruction that students' experience in laboratory science classes may vary depending upon the ways in which the teacher implements the written curricula materials.

Instruction is guided by certain epistemological assumptions that may influence students' epistemological beliefs (Hofer & Pintrich, 1997). The epistemological assumptions of non-inquiry (verification) laboratory instruction include the premise that the source and justification for knowing stem from expert authorities since the objective is to replicate the findings of others. In contrast, inquiry teaching and learning are based on the epistemological assumptions that the source of knowledge is within the learner, not in an authority, and the justification for knowing comes from examination of evidence and interpretation of the evidence by the learner. The question that persists is, "How might students be influenced by the epistemological assumptions of the type of instruction they experience?"

Previous research concerning students' epistemological beliefs has been conducted with college students and the results of these studies indicate that students' epistemological beliefs can change during the college years (Baxter Magolda, 1992; Perry, 1981). There is ongoing speculation that educational experiences may serve as an impetus for change in epistemological beliefs, but little research has been conducted to support or refute the idea (Hofer & Pintrich, 1997). In a recent study, Hofer (1994, as cited in Hofer & Pintrich, 1997) compared the epistemological beliefs of college students who experienced calculus instruction that emphasized active learning, cooperative group learning, and problem solving with the beliefs of students who experienced instruction as lectures and demonstrations of problem sets. Results indicated significant differences in the epistemological beliefs of the two groups of students. However, interpretations of these results are limited because beliefs were not assessed prior to instruction. It remains unclear whether the different types of instruction have an affect on students' beliefs.

College students' epistemological beliefs may be in a state of change, which makes this age group interesting to study. At the college level, there is often a requirement for students in all majors to enroll in introductory science courses, therefore the students in introductory courses may represent a wide variety of background experiences and beliefs. Since laboratory-based science classes provide opportunities for students to be actively involved in the construction of knowledge in science, the influence of students' beliefs about the processes of knowing and the nature of knowledge in science on their learning orientation may be observable in the activity that takes place in the laboratory setting.

Statement of the Problem

Relationships may exist among implementation of laboratory instruction, students' epistemological beliefs about science and students' approaches to learning science. However, the nature and extent of these relationships have not yet been documented. This study is designed to contribute to current understandings of students' epistemological beliefs about science by investigating the possible relationships among instructional experiences, epistemological beliefs and approaches to learning in science laboratory classes. Therefore, the research problem of this study is to investigate the ways in teachers implement a laboratory curriculum, and examine the possible relationships among students' instructional experiences, epistemological beliefs and approaches to learning in science laboratory classes. The specific purposes of the study are:

1. To describe teachers' implementation of an inquiry chemistry laboratory curriculum as either consistent or inconsistent with the curriculum design.

2. To describe the students' approaches to learning and their epistemological beliefs about science.

3. To explore possible relationships among students' epistemological beliefs, the type of instruction and approaches to learning in chemistry laboratory classes; and to determine if these variables are predictors of learning approach.

Significance of the Study

The findings of this study will be important to science educators for several reasons. It would be important for science educators to know if certain types of classroom science instruction contribute to understanding epistemology in science more than other types of science instruction because "...if we are not teaching the true nature of the discipline, we are [not] teaching science" (Renner, 1982, p. 709). Experiencing inquiry processes during science investigations may enhance a student's understanding of the nature of science (Lawson, Abraham, & Renner, 1989; Lazarowitz & Tamir, 1993; Roth & Roychoudhury, 1994). The findings of two investigations pointed to classroom variables that were related to the development of more "acceptable" views about science knowledge in students: active participation of students, frequent teacher-student interactions, expectations that students would think analytically about the subject matter, little emphasis on rote memorization and a classroom climate described as "discovery" (Haukoos & Penick, 1983; Lederman & Druger, 1985). The description of the laboratory-based chemistry classes in this study will reveal if the classroom variables described were present in the lessons observed. It is expected that the classroom variables described may be more likely found in inquiry laboratory instruction than in non-inquiry laboratory instruction. The findings of this study could be used by educators who desire to modify their science instruction to nurture understanding of the processes of knowing and the nature of knowledge in science.

The findings of the study may also reveal if experiencing inquiry or non-inquiry laboratory instruction is related to changes in students' approaches to learning. Students may adopt a rote approach to learning in a class if the valued knowledge is that information provided by an authority, and if their success in class depends upon recall of this information (characteristic of non-inquiry laboratory instruction). Students may adopt a meaningful approach to learning if the valued knowledge is that which is constructed from their own experiences (characteristics of inquiry laboratory instruction). If laboratory science instruction is to encourage students to strive for meaningful understandings of science, teachers need to know if students' approaches to learning in their classes may be influenced by the knowledge that is valued in class and the type of laboratory instruction implemented.

Chapter II : Review of the Literature

Introduction

The purposes of this study are to investigate the possible relationships among students' epistemological beliefs and their approaches to learning, and to examine the possible influence of teachers' implemented instruction and students' epistemological beliefs on their approaches to learning. Although no study has been conducted which addresses these precise questions, several related studies have been conducted that indicate that understanding of these topics is incomplete. The literature review focuses on several differing areas of theory and research relevant to this study: epistemological beliefs, students' epistemological beliefs about science, approaches to learning, characteristics of two types of science instruction, and laboratory science instruction.

Epistemological Beliefs

Definition of Epistemological Beliefs

Tobin, Kahle and Fraser (1990) drew on descriptions from the social sciences and philosophy in forming their definition of a belief as "... a proposition, or statement of relation among things, accepted as true" (p. 36). Educational researchers have become interested in the effect that beliefs have upon the processes and outcomes of teaching and learning. In this study, the beliefs of interest are the beliefs a student holds about the formation of knowledge in science and the characteristics of the knowledge (i.e., epistemological beliefs).

Epistemological beliefs have been the focus of numerous studies, but various authors have often used differing definitions of 'epistemological beliefs' (Hofer & Pintrich, 1997). The comparison that follows utilizes Hofer and Pintrich's descriptive labels of each authors' definitions. Perry's (1968) definition of epistemological beliefs consists of beliefs about the certainty of knowledge and the source of knowledge. Baxter Magolda (1992) extended Perry's definition to include beliefs about the justification for knowing and beliefs about learning (role of the learner, role of the instructor). Schommer (1990) utilized Perry's definition, added beliefs about learning and intelligence, but did not include beliefs about the justification for knowing. Kuhn (1991) identified beliefs about the certainty of knowledge, the source of knowledge, and the justification for knowing as the components of epistemological beliefs. King and Kitchener (1994) added beliefs about the simplicity of knowledge to Kuhn's definition. This brief listing of the different interpretations of epistemological beliefs indicates the need for a clarification of the construct. Examination of each author's definitions of the components of beliefs revealed that many of the components have overlapping definitions. Based upon a review of research, Hofer and Pintrich (1997) proposed that the definition of epistemological beliefs "...be limited to individuals' beliefs about knowledge as well as reasoning and justification processes regarding knowledge" (p. 116).

For the purposes of this study, epistemological beliefs will be defined as beliefs about the processes of knowing and the nature of knowledge, consistent with the recommendation of Hofer and Pintrich (1997). The dimensions, processes of knowing and nature of knowledge, will also be defined according to Hofer and Pintrich (see Table 1):

1. Beliefs about the processes of knowing are defined as beliefs about the source of knowledge and the justification for knowing. Beliefs about the source of knowledge may range from an acceptance of receiving knowledge from an authority source to an understanding that knowledge is constructed by the knower. Beliefs about the justification for knowing may vary from the idea that knowledge requires no justification and one just receives the knowledge that others provide, to an understanding that knowledge is constructed through critical examination of the opinions of experts and the examination of evidence.

2. Beliefs about the nature of knowledge are defined as beliefs about the certainty and simplicity of knowledge. Beliefs about the certainty of knowledge may vary from the idea that knowledge is absolute and undisputed to the

understanding that knowledge is tentative, evolving and contextual. Beliefs about the simplicity of knowledge may range from the idea that knowledge is composed of isolated bits of information (simple) to the understanding that knowledge consists of interrelated concepts (complex).

Individuals will be described as believing that knowledge is *received* or *reasoned* on the dimensions of processes of knowing and nature of knowledge. The dimensions of epistemological beliefs and descriptions of contrasting views for each component are presented in Table 1.

Table 1

The dimensions of epistemological beliefs and descriptions of contrasting views for each component (Hofer & Pintrich, 1997).

Dimension of epistemology	component of dimension	Received view	Reasoned view
Processes of knowing	source of knowledge	authorities are the source of knowledge	knowledge is constructed by the knower
	justification for knowing	knowledge requires no justification, one receives knowledge from others	critical examination of evidence and critical the opinions of experts
Nature of knowledge	certainty of knowledge	knowledge is absolute and undisputed	knowledge is tentative, evolving and contextual
	simplicity of knowledge	knowledge is simple, composed of isolated pieces of information	knowledge is complex, composed of interrelated concepts

Research about Epistemological Beliefs

Perry's (1968) investigation of college undergraduate students' epistemological beliefs showed that entering students believe knowledge is provided by an authority and that knowledge is certain. In contrast, college seniors believed that knowledge was derived through reason and that knowledge is complex and tentative. Thus, the college freshmen had beliefs in received knowledge, whereas the seniors believed in reasoned knowledge. King and Kitchener (1990) identified a developmental progression of college students' epistemological beliefs that supports Perry's (1968) findings. The results of these studies indicate that the epistemological beliefs of college students may be in flux or be susceptible to change, however the agents of change have not been identified.

Building upon the work of Perry, Schommer (1990) proposed that a person's epistemological beliefs could be composed of a system of somewhat independent beliefs. The system of beliefs consisted of four aspects of personal epistemology: simple knowledge, certain knowledge, learning and intelligence (Schommer, 1993). Since the beliefs were considered independently, it was possible for a person to hold more mature beliefs (reasoned knowledge) about some aspects of knowledge and learning while also holding more naive beliefs (received knowledge) about other aspects. Schommer's finding of independence of beliefs may indicate that her definition of epistemological beliefs is too broad. Although Schommer included beliefs about learning in her definition of epistemological beliefs, in this study, students' ideas about learning will be conceptualized as separate from, but possibly related to, epistemological beliefs about science knowledge. It remains unclear whether the dimensions of epistemological beliefs that will be used in this study are interdependent or if individuals can hold beliefs about received knowledge in one dimension while holding beliefs about reasoned knowledge in another dimension.

In addition to evidence that a person's epistemological beliefs change with maturity (King & Kitchener, 1990; Perry, 1968; Schommer, 1993), the development of epistemological beliefs must also be affected by the experiences a person has with knowledge and learning (Davidson, 1992; Nicholls & Thorkildsen, 1989). Epistemological beliefs of college students were found to vary across different levels of education and in different academic fields in a study by Jehng (1991). Using an instrument based upon Schommer (1990), Jehng found that undergraduate students and engineering students believed that learning involves assimilating certain knowledge provided by authorities (teachers). In contrast, graduate students and social science students tended to believe in learning as a process of formation of ideas. Jehng suggests that an individual's epistemological beliefs may be shaped by the culture of the discipline that the person is studying.

Students' Epistemological Beliefs about Science

Processes of Knowing and Nature of Knowledge in Science

Classroom research has shown that many students have limited understandings of the epistemology of knowledge in science. In a study of eighth grade students' views of science, Songer and Linn (1991) found that 21% of students believed that science knowledge is essentially static and unchanging, 15% of students reported a dynamic view of science knowledge and 63% of students exhibited mixed beliefs. Ryan and Aikenhead (1992) concluded that eleventh and twelfth grade students across Canada had not acquired a uniform view of science knowledge. Results from the students' responses on the instrument, *Views on Science-Technology-Society*, indicated that most students did not understand that science knowledge is constructed through the interpretation of evidence. Many students agreed that science knowledge is the reflection of things as they really are (e. g., a position consistent with logical positivism). Approximately half of the students were not aware that scientific knowledge is based upon a consensus of opinions. Only one-third of students understood that science knowledge is tentative because facts may be interpreted through different theories. In their investigation of the epistemological views of male, college-bound physics students, Roth and Roychoudhury (1994) concluded that "two thirds of the students were committed to the view that scientific knowledge is exact, not tentative, and that it is independent of conceptualization" (p. 27). Solomon (1991) reported findings similar to Roth and Roychoudhury (1994), but Lederman and O'Malley (1990) reported that all the students they interviewed believed in the tentativeness of science. Assuming that the results of the research studies are comparable, and thus, that students do hold differing views of knowledge in science, the question raised is, "Why do students have differing views of knowledge in science?"

Some research has addressed this question by examining the possible influence of classroom factors on students' beliefs (Haukoos & Penick, 1983; Lederman & Druger, 1985). Lederman and Druger (1985) identified classroom variables that were associated with changes in students' conceptions of science. Their results indicated that the teacher's expressed beliefs about the nature of science were not significantly related to changes in students' beliefs. The greatest changes in students' conceptions of science occurred in classrooms where inquiry oriented questioning was frequent, problem-solving and teacher-student interactions were common, students were active participants in the lessons, students were expected to think analytically about the science subject matter, and there was little emphasis on rote memorization and recall. In their quasi-experimental study of community college students, Haukoos and Penick (1983) showed that changes in students' understanding of science knowledge were related to the "discovery classroom climate" of the treatment classroom. Forawi (1996) found that an inquiry teaching approach statistically enhanced tenth grade students' understanding of science knowledge as constructed more than a traditional (non-inquiry) teaching approach. The results of these studies suggest that students' understandings and beliefs about science knowledge may be influenced by many aspects of their experiences in science classrooms.

Epistemological Beliefs about Science as related to Learning Science

The students in Roth and Roychoudhury's (1994) study used a variety of metaphors to describe their knowledge and learning in a high school physics class taught in an inquiry manner. The main ideas expressed by the students included: "(a) knowledge as a material that can be transferred, (b) the mind as a container of knowledge, (c) knowledge as territory, (d) the brain as a muscle, and (e) knowledge and learning as constructed" (p. 16). Most of the students' metaphors were consistent with an implicit objectivist epistemology about knowledge and learning. Only a few students gave descriptions of learning that were consistent with constructivist epistemology. However, many students used contradictory metaphors during the course of the interviews, indicating that students' epistemological commitments may be situationally dependent or be in flux. For example, some students described learning in terms that implied that they viewed learning as both transmission of knowledge and as individual construction of knowledge. These results suggest that students' epistemological beliefs may be influenced by experience in an inquiry class.

Songer and Linn (1991) investigated eighth grade students' strategies for learning science in conjunction with their study of students' views about science. They reported that students who held static beliefs about the nature of science approached the learning of science through memorization, while students who held dynamic beliefs about science approached learning through efforts to create meaningful understandings. The authors suggest that students' classroom experiences may have impacted their beliefs in the static nature of science. They also propose that students' uses of cognitive integration (i.e., meaningful) learning strategies are influenced by their beliefs about the nature of science: "Students may not integrate material presented in science classes if they believe that science consists of isolated principles. In addition, students may not develop a view of science consistent with historical evidence if science is presented as a collection of fairly unrelated facts and ideas" (Songer & Linn, 1991, p. 781).

These findings suggest that the students' views of science and the type of instruction experienced in this class may have influenced their approaches to learning.

Approaches to Learning

Ausubel's (1968) theory of meaningful verbal learning posits that learners engaged in the meaningful learning actively attempt to relate new concepts to prior knowledge and use their new conceptual understanding to explain new experiences they encounter. The theory states that for students to meaningfully learn new concepts, first they must be given *meaningful learning tasks*, that is, the instructional material must have the potential to be meaningfully learned. A concept has the potential to be meaningfully learned if non-arbitrary relationships can be made between the new concept and other concepts and ideas. Strings of words that have no connection to one another do not have the potential to be meaningfully learned. Second, in order to learn the concept meaningfully, learners must form relationships between newly learned concepts and prior knowledge. Therefore, the learner's possession of *relevant prior knowledge* is important for meaningful learning. Third, to learn concepts meaningfully, learners must actively attempt to form connections between newly learned concepts and prior knowledge. Ausubel refers to this active formation of relationships by learners as the *meaningful learning set*. Research suggests that learners may tend to manifest the meaningful learning set to different extents (Cavallo & Schafer, 1994; Edmonson, 1989; Entwistle & Ramsden, 1983). The extent to which students use meaningful or rote approaches to learning new ideas is called their "learning orientation".

Cavallo and Schafer (1994) investigated students' learning orientation relative to the the conceptual understandings they attained. They determined that students' tendencies to learn meaningfully or by rote predicted their attainment of meaningful understanding of certain biology concepts. An important finding of this study was that learning orientation (meaningful, rote) is a variable of learning that is distinct from aptitude and achievement motivation.

Edmondson (1989) related college students' approaches to learning to their conceptions of scientific knowledge in an introductory level biology course. Findings indicated that students who used rote learning strategies held beliefs in logical-positivist epistemology (knowledge is unchanging and discovered). Students who tended to use meaningful learning strategies held beliefs in constructivist epistemology (knowledge is created and changing). These findings prompted Edmondson to conclude "...that a student's learning strategy is the outward manifestation of epistemological commitments" (p.194). Edmondson speculated that students' epistemological positions would also be influenced by curriculum and teaching methods, however, this was not addressed in her study.

The current study extends the findings of Edmondson (1989) and Cavallo and Schafer (1994) by exploring factors that may influence a students' learning orientation. The hypothesized relationships among epistemological beliefs and learning orientations are illustrated in Figure 1.

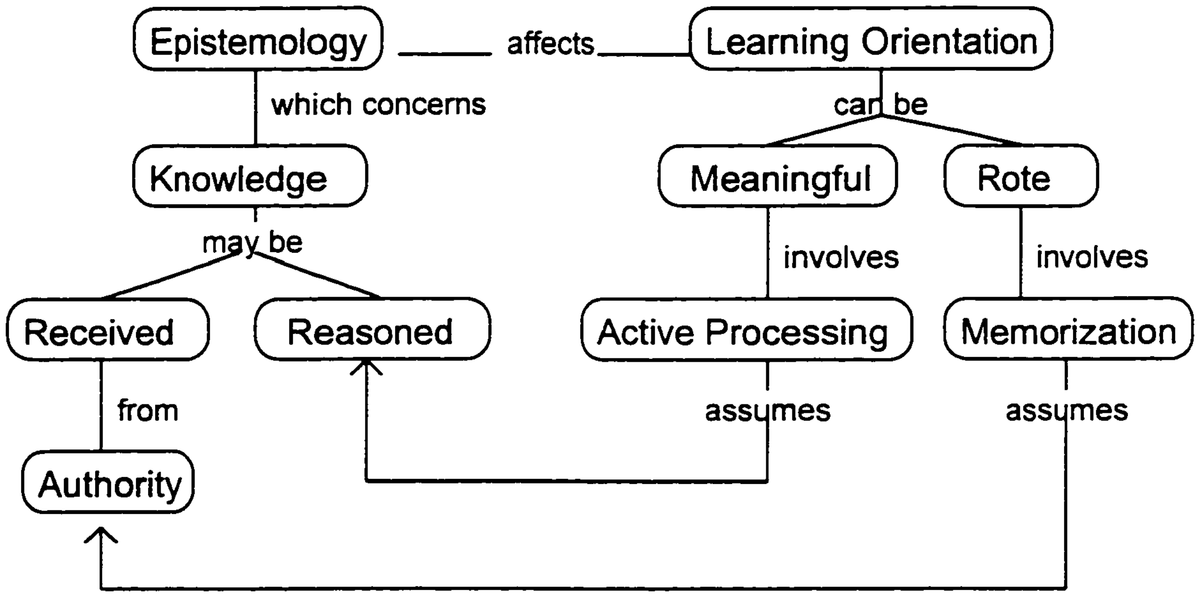

Figure 1. Hypothesized relationships among epistemological beliefs and learning orientations.

Characteristics of Two Types of Science Instruction

Traditional Science Instruction

Tobin, Tippins and Gallard (1993) formed a description of "traditional" science classrooms based upon classroom observations. In these classrooms, a student's role was primarily to learn, by rote memorization, the content presented by the teacher and the textbook. The content could include both factual information and procedures to follow when solving problems. Since instruction in solving problems consisted of practice in applying formulas and algorithms, "solving" a problem was a matter of recognizing the type of problem and recalling which algorithm to use to find the correct answer. The teachers' curriculum planning placed heavy emphasis on covering a list of topics in order to prepare students for tests and examinations. The implemented curriculum placed little emphasis on developing students' understanding of the science topics. The focus in laboratory activities was on following procedures in order to get the correct data. Students rarely participated in planning investigations or interpreting of results.

In the classrooms described above, science was taught in a way that emphasized the acquisition of science content from an authority source (e.g., a textbook, teacher, or laboratory guide) and students attempted to accurately remember the information that was presented. The goal of laboratory experiences was for the students to verify the information given by the teacher. Instruction often included opportunities for students to practice recalling information. In traditional science classrooms, certain epistemological assumptions are implicit in the instruction: the source of knowledge is an authority and the justification for knowing is the expertise of authorities rather than the interpretation of evidence. During traditional science lessons students have few opportunities to engage in inquiry, therefore lessons of this type will be referred to as *non-inquiry lessons*.

Inquiry Science Instruction

When science is taught and learned as inquiry, the curriculum, role of the teacher, role of the students, and goals of instruction may differ greatly from the roles, curriculum and goals of non-inquiry science instruction. In contrast to non-inquiry instruction, the epistemological assumptions in a class taught as inquiry include: (a) the source of knowledge is students' construction of that knowledge, and (b) the construction of knowledge occurs through students' analysis and interpretation of evidence.

The epistemological assumptions of inquiry instruction are consistent with the inquiry processes of scientific investigation. When scientists are engaged in scientific investigations, they are involved in the processes of gathering information through observations and/or experiments. The interpretations of the data are constructions of knowledge based on the theoretical perspective that the scientists adopt. The data may be interpreted differently by scientists with a different theoretical perspective. Scientific knowledge is tentative in nature since the possibility exists that new evidence may be found or different theories might be referenced that would lead to a different interpretation of evidence.

Science, taught as inquiry, actively engages students in thinking and reasoning as they work toward making sense of their experiences (Lawson, et al., 1989). Teachers typically assume the role of facilitator during inquiry-based instruction. In a study by Lazarowitz and Tamir (1993), the findings of unstructured observations in science laboratory classes indicated that

> ...students in inquiry-oriented laboratories are more active and initiate more ideas than in conventional laboratories. Teachers are less direct; processes of science receive more emphasis; there is more postlaboratory discussion, and teachers give less instruction in front of the class and move around more, checking, probing, and supporting. (p. 113)

A goal of inquiry instruction is for students to value finding "answers" through their own effort and abilities. Students should view the teacher as supporting and promoting their inquiry (Hammer, 1995). Thus, classes where science is taught and learned as inquiry are characterized by active student participation in exploring materials and ideas, interactions among the teacher and the students, and students' construction of the knowledge.

Unfortunately, using inquiry curriculum materials does not necessarily create an inquiry learning environment. If the teacher presents the materials and information such that authorities are the source of knowledge and only knowledge of memorized content is valued, the pedagogy may resemble non-inquiry instruction rather than inquiry instruction. If the teacher does not use the students' data or interpretations of the results, laboratory experiences resemble hands-on, non-inquiry activities rather than inquiry processes (Roychoudhury, 1994; Tobin, et al., 1993). Thus, whether a lesson is inquiry or non-inquiry may be dependent on the teacher's mode of implementing the curriculum in their classroom teaching.

Laboratory Science Instruction

Ausubel (1968) described a role of laboratory instruction: "In dividing the labor of scientific instruction, the laboratory typically carries the burden of conveying the method and the spirit of science whereas the textbook and the teachers assume the burden of transmitting subject matter content" (p. 346). Although science education research in the 1960s and 1970s included many studies of students' understandings of the nature of science, few of these studies examined the impact of laboratory experiences on these understandings (Lazarowitz & Tamir, 1993). When Yager, Englen, and Snider (1969) compared the effects of laboratory and demonstration biology instruction on student outcomes, their results indicated no impact of the type of instruction on the students' understanding of the nature of science. In Tamir's (1972) study of a biology course that placed heavy emphasis on students' laboratory work in comparison to courses that were less laboratory-oriented, the students in the laboratory-oriented classes had higher scores on the Science Process Inventory (SPI) than students in the other courses. Tamir concluded that students in the laboratory-oriented classes had more accurate understandings of the nature of science than students in the non-laboratory oriented classes.

The apparent contradictions in the research findings discussed above may be due to the lack of distinction made about the differing ways that laboratory instruction is implemented. Laboratory experiences that confirm ideas known prior to experimentation, have been referred to as "verification laboratories" (non-inquiry). Laboratory experiences are "inquiry" in nature when concepts are discovered by students through laboratory experiences and not revealed to them prior to the laboratory experiences (Lawson, et al., 1989).

Research comparing inquiry and non-inquiry laboratory instruction has indicated that student outcomes in achievement and affect may differ depending on the type of laboratory instruction experienced. Inquiry laboratory instruction may result in greater conceptual understanding than verification laboratory instruction (Campbell, 1977; Ivins, 1986; Raghubir, 1979; Shadburn, 1990). Other studies have reported that there were no differences in student achievement when comparing inquiry-based (learning cycle) instruction with verification instruction (Lewicki, 1993; Vermont, 1985). Raghubir (1979) determined that students who experienced inquiry laboratory instruction reported greater curiosity, openness, responsibility and satisfaction in science class compared to students who experienced verification laboratory instruction. Campbell (1977) and Shadburn (1990) reported better attitudes toward laboratory work among students who experienced inquiry laboratory instruction than students who experienced verification laboratory instruction. Lawson, et al. (1989), Lazarowitz and Tamir (1993) and Roth and Roychoudhury (1994) suggested that student participation in science investigations that include experiencing inquiry processes improves students' academic achievement and attitudes towards science, and postulated that it may enhance their understanding of the nature of science, described here as epistemological beliefs.

Summary

The preceding discussion suggests that relationships may exist among teachers' styles of implementing laboratory instruction (inquiry, non-inquiry), students' epistemological beliefs about science and students' approaches to learning science. However, the nature and extent of these relationships is unknown. This study is designed to contribute to current understandings of students' epistemological beliefs about science by investigating possible relationships among instructional experiences, epistemological beliefs and approaches to learning in science laboratory classes.

Chapter III: Methodology

Introduction

The relationships that may exist among students' instructional experiences, students' beliefs and their approaches to learning were investigated through observations of students' laboratory experiences and data collection using two student questionnaires. The students' laboratory experiences were characterized as either "more inquiry" or "less inquiry" based upon observational data. Scores were compiled from questionnaire instruments to represent each student's epistemological beliefs and learning orientation.

Sample and Setting

The sample consists of college students enrolled in an introductory chemistry laboratory course at a large Midwestern university. Specifically, the investigation took place in the laboratory sections of this general chemistry course. The chemistry course is offered for five semester hours credit and is the first of a two semester sequence in chemistry. The course has a prerequisite of mathematics, and high school chemistry is not required. The chemistry class is a core area (natural science) general education 'laboratory' course and is offered every semester. The students enrolled in this course may or may not be declared chemistry majors, however, most have an interest in science or engineering. Few of the students were expected to have experienced inquiry laboratory science instruction, as described earlier, prior to enrolling in this chemistry course.

Students who enroll in the chemistry class attend a lecture course which meets for two and one-half clock hours each week. Enrollment in the course requires students to meet twice a week with their laboratory instructor in addition to the lecture course meetings. One of those meetings is the chemistry laboratory experience, which runs for approximately three hours. The other meeting is an hour long recitation and problem-solving session that meets in a lecture room. Approximately thirty students are enrolled in each laboratory section and a laboratory instructor may teach one or two lab sections. There are between 800 and 1,000 students enrolled in the chemistry course during a typical fall semester. The sample consisted of nine laboratory sections (approximately one third of the laboratory sections taught in a semester). The initial N of the sample was 247 students. The final N was 232 since a number of students dropped the course before the end of the semester. The sample consisted of 129 male students and 97 female students.

Instruction

Curriculum

The written curricula used for the chemistry laboratory is Inquiries into Chemistry, Second Edition, (Abraham & Pavelich, 1991). The curricula consists of a laboratory manual for the students with a corresponding teacher's guide. The materials contain introductions that inform the teachers and students that there are several purposes for the experiments, including learning laboratory techniques, introduction to basic chemistry concepts, and providing students with experiences using the processes of scientific investigation. The teacher's manual provides guidelines for implementation of the laboratories, grading of the laboratory reports, and the role of the teacher during the experiments. The manual was designed to permit students to conduct experiments, collect data, analyze the data, interpret the evidence, and draw conclusions with minimal guidance by the instructor.

The laboratory manual contains two types of experiments, guided inquiry and open inquiry. The teacher and student manuals describe the different purposes of the guided inquiry and open inquiry experiments. In the student laboratory manual, guided inquiry experiments include specific instructions concerning how to conduct the experiments and questions to answer about the collected data. Students are encouraged to discuss data and answers with classmates. The manual states, "The 'right answer' is any one that follows logically from the data and that you are comfortable with" (Abraham & Pavelich, 1991, p. 3). Students are not expected to have any knowledge of the concepts prior to experiencing the guided inquiry experiments. The open inquiry experiments allow students to extend their understanding of concepts learned through guided inquiry experiments. Students may investigate any aspect of the previously learned concept. Each open inquiry laboratory contains a number of ideas for investigation, for example, "Investigate the relationship between the volume and temperature of a gas at constant pressure" (Abraham & Pavelich, 1991, p. 231). Students are responsible for the design and implementation of the experiments.

One epistemological assumption of the curriculum is that the justification for knowing is an interpretation of evidence, therefore students evaluate the experimental evidence for themselves. If the lessons are implemented as designed, the students should be able construct understandings of chemical concepts from experimentation, reasoning and judgement. Since the design of the laboratory curriculum enables students to engage in the processes of scientific inquiry, the students can be considered to be 'doing science'.

Teachers

Graduate teaching assistants who were chemistry majors were the instructors of the chemistry laboratory sections. Using graduate teaching assistants at the university means that the teachers had varying backgrounds in science and teaching. Instructors who were native English speakers composed the initial pool of potential participants. Teachers who did not speak English as a native language were not considered potential participants since the interactions between the teachers and their students were of primary interest in this study. During the first two weeks of the semester, the researcher attended laboratory sections taught by all the native English speaking instructors. Five different instructors were selected to be the focus of this study. All of the instructors appeared to be comfortable being observed. These instructors managed the laboratory sections with a minimum of difficulty and appeared to be knowledgeable in the subject matter. All five of the instructors were white males in their twenties. Three of the teachers had been laboratory instructors in previous semesters. Two of the teachers were in their first semester of graduate school and had no prior teaching experience. All the teachers had participated in a teaching workshop prior to their first semester as instructors in the chemistry laboratories. During their first semester of teaching, all teachers enrolled in a seminar designed to explore pedagogical issues associated with teaching chemistry laboratories.

Procedures

Observation of Instruction

The researcher observed four laboratory meetings of each section of the chemistry classes throughout the semester. Field notes included descriptions of the way the teacher began and ended each lesson, the interactions of the teacher with the students (as a group and individually), the ways in which the teacher appeared to use the curriculum materials, procedures of classroom and materials management, and the context of the classroom, including some detail on reactions of students to the teacher's actions. Written materials (such as laboratory guides and graded student laboratory reports) were collected in order to more completely describe the instruction. Teacher observations and comparisons of teaching procedures with published descriptions of inquiry and non-inquiry laboratory experiences (e.g., Abraham, 1982), provided information to classify the teachers according to the extent to which instruction more closely matched the inquiry model or the non-inquiry model.

During a pilot study, it was necessary for the observer to move around the room to be able to see and hear the teacher's interactions with students. Due to the physical arrangement of laboratory benches in the room and the noise produced by equipment and students, it was not be possible to use audio or videotaping to record the classroom instruction. Field notes of observations made during the pilot study were analyzed for words and actions that indicated whether instruction was implemented as inquiry or non-inquiry. The field notes were compared with the Laboratory Program Variables Inventory (LPVI) (Abraham, 1982), which consists of twenty-five items describing behaviors of students and teachers during laboratory instruction (Appendix A). The instrument was designed by the author of the inquiry curriculum materials and has been used to investigate students' perceptions of the laboratory instruction (Pavelich & Abraham, 1979). The observational notes were found to be effective for identifying the instruction as either *more inquiry* (consistent with the printed curriculum) or *less inquiry.* The characterization of laboratory instruction as less inquiry rather than non-inquiry was based upon observations that many students in the less inquiry classrooms engaged in some inquiry processes (analyzing data and explaining data) by following the directions in the laboratory manual. The use of observational notes provided additional support for the classification of instruction as more inquiry or less inquiry through quoting and paraphrasing of the instructor's remarks to the students.

Instrumentation

Near the beginning of the semester, the students who agreed to participate in the investigation completed a set of questionnaires during the second meeting of their laboratory section (pre-test). The questionnaires included the Learning Approach Questionnaire (LAQ) (Appendix B) and the Background Information Questionnaire (BIQ) (Appendix C). The students completed these two questionnaires again near the end of the semester (post-test). The students also completed the Science Knowledge Questionnaire (SKQ) (Appendix D) and an Open-ended response questionnaire near the end of the semester.

Learning Approach Questionnaire.

The Learning Approach Questionnaire (LAQ) is a 50-item Likert scale instrument used to measure students' learning orientations and their epistemological beliefs about science (Donn, 1989). Items that address students' approaches to learning as either meaningful or rote were used as measures of learning orientation. Twenty-eight items from the original LAQ were utilized as the measure of learning orientation for the pilot study. Students were instructed verbally and in writing to respond to the questionnaire on the basis of their experiences in only the laboratory portion of the course. On the basis of students' comments, several items were reworded in order to improve clarity and four questions were dropped from the questionnaire. Twenty-four items were retained to form the measure of learning orientation that will be used in the study. The learning orientation scale consists of two subscales: the Learning Approach Questionnaire--Rote (LAQR) measuring the degree of rote learning orientation, and the Learning Approach Questionnaire--Meaningful (LAQM) measuring the degree of meaningful learning orientation (Cavallo, et. al., 1996). The LAQR consists of 11 items and the LAQM consists of 13 items. Cronbach alpha internal consistency reliability coefficients for the subscales were calculated to be $\underline{r}$ =.80 for the LAQM subscale ($\underline{N}$ = 232) and $\underline{r}$ =.65 for the LAQR subscale ($\underline{N}$ = 230). Sample statements from the learning orientation scale include:

1. I go over important topics until I understand them completely.
2. I learn some things by rote, going over and over them until I know them by heart.

Students responded to each statement by indicating their agreement, ranging from A (always true) to D (never true). A response of 'always true' on statement

1 indicated a tendency toward meaningful learning, and a response of 'always true' on statement 2 indicated a tendency toward rote learning. A high score on the LAQR indicates a higher degree of rote learning and a high score on the LAQM indicates a higher degree of meaningful learning.

Science Knowledge Questionnaire.

A questionnaire was adapted from existing instruments to measure students' epistemological beliefs about science. The items on the questionnaire were compiled from several instruments used in science education research that contained items related to epistemology of science (Edmondson, 1989; Rubba, 1977; Ryan & Aikenhead, 1992). The Science Knowledge Questionnaire consisted of 32 Likert scale items. Review of the questionnaire by science educators indicated that four items on the SKQ could have multiple interpretations and could not be clearly identified as indicating a belief in received or constructed knowledge in science. Items 19, 22, 25 and 31 were removed from the analysis, the resulting SKQ was composed of 28 items. Chronbach alpha internal consistency reliability coefficient for the 28 item SKQ was r = .78 (N = 232).

Sample items from the SKQ include the following:

2. Scientists should make the decisions about things like types of energy to use because they know the facts best.

15. The truth of scientific knowledge is beyond doubt.

Students responded to each statement by indicating their agreement, ranging from A (strongly agree) to D (strongly disagree). A response of 'strongly agree' on statement 2 indicated a belief that authorities are the source of knowledge. A response of "strongly agree" on statement 15 indicated belief in the certainty of knowledge in science. The scoring of each item was determined by the way in which the item was interpreted by the authors of the source instruments. Some items were reverse scored so that a high score on the SKQ would represent a view of the epistemology of science that is *reasoned* [more "mature" according to Schommer (1990), or "worldly" according to Ryan and Aikenhead (1992)]. A low score on the SKQ would represent a view of epistemology of science that is *received* [more "naive" according to Schommer (1990) and Ryan and Aikenhead (1992)].

Open-ended Response Questionnaire.

Students were also asked to complete three open-ended questions concerning their perceptions of their teachers and their laboratory experiences at the end of the semester. The questions were adapted from Edmondson (1989):

1) What types of things are you supposed to leam from the laboratory portion of Chemistry 1315?

2) Do you think that what you do in this laboratory could be described as generating scientific knowledge? Why or why not?

3) If you just went into the lab and conducted experiments without a teacher present, would that count as generating scientific knowledge? Why or why not?.

Chapter IV: Results

Analyses of the observational notes, the questionnaire data and the open-ended student responses were performed to address the three research purposes. This chapter presents the results of these analyses and will be organized by research purposes 1-3.

Research Purpose 1

To describe teachers' implementation of an inquiry chemistry laboratory curriculum as either consistent or inconsistent with the curriculum design.

Characterization of students' instructional experiences was guided by two questions: How do the teachers implement the curriculum? Is the implementation consistent with the inquiry nature of the curriculum design? Observational field notes from the laboratory lessons were examined for evidence that the instructional experiences of the students were either more inquiry (showing high consistency with the curriculum design) or less inquiry (showing low consistency with the curriculum design). Field notes and classroom artifacts (e.g., graded student laboratory reports) were examined in order to create a description of the classroom instruction. Examination of the field notes revealed patterns concerning the manner in which instruction was implemented.

Themes and patterns that emerged from multiple readings of the observations and artifacts were the basis of a coding scheme. The coding scheme was used to classify the events described in the field notes and the artifacts. The coding scheme was revised as analyses of data progressed through the process of ongoing analytic induction (LeCompte & Preissle, 1993). The coding scheme was reviewed by auditors familiar with qualitative research and science education. The author and an auditor independently developed codes from the same data. The resulting codes were compared and inconsistencies were resolved through discussions.

After an agreed upon coding scheme was developed, the scheme was applied to other portions of the data. These data were independently coded by the auditors for comparison with the author's coding of the same data. Inconsistencies were resolved by discussion. Interrater reliability of at least 90% was reached before the entire set of field notes and artifacts was coded.

Similarities in instruction among the teachers

Analysis of each teacher's laboratory instruction revealed similarities in the use of the laboratory manual and the grading of the laboratory reports. All teachers participated in a weekly meeting to discuss implementation of the laboratory activities. Discussions were led by the laboratory coordinator and included opportunities for the experienced teachers to give advice to the novice teachers. Many of the questions in the students' laboratory manual required the students to write equations to represent the reactions they observed or to make a calculation of some kind. Accordingly, many of the teacher-student interactions observed during the laboratory concerned equation-writing and calculations. The teachers' evaluations of students' written work were examined through comparisons of a set of graded student laboratory reports from one guided inquiry laboratory section and one open inquiry laboratory section for each teacher. Comparisons indicated that the teachers evaluated the students' laboratory reports in a similar manner using the holistic grading system described in the teacher's manual for the curriculum. All teachers were trained to use the holistic grading system during their first semester as instructors.

Differences in instruction among the teachers

The differences in teacher behaviors noted in the field notes of the observations led to the categorization of each teachers' instruction as more inquiry or less inquiry. Three teachers implemented instruction in such a way that student inquiry was encouraged and supported (more inquiry, MI). Two teachers implemented instruction in such a way that active student inquiry was not supported (less inquiry, LI). The two groups included both new and experienced teachers (MI - two experienced, one new; LI - one experienced, one new). Patterns that distinguish more inquiry instruction from less inquiry instruction are presented below. Examples of each pattern are also presented. The more inquiry teachers are referred to as MI-1, MI-2, MI-3. The less inquiry teachers are referred to as LI-1 and LI-2.

More inquiry and less inquiry teachers used different types of directions to introduce the laboratory activities. During the laboratory activities, more inquiry and less inquiry teachers interacted with their students in different ways.

Giving directions.

The directions given by all teachers included the use of equipment and safety precautions. During guided inquiry laboratories, the directions given by the less inquiry teachers were detailed and sometimes included telling the students what the results of the experimentation should be.

LI-1

> Teacher: "Look at the manometer. Two columns of mercury are the same height. If I hook up longer hose to syringe, what is pushing down on this side [the open side]? The teacher pauses briefly then answers his own question: "Air pressure"
> Teacher: "What is pushing on this side [the closed side]?" Teacher answers the question: "The system with the syringe. Which is pushing harder?"
> A few students reply: "The air."

Teacher: "The atmospheric pressure is 760 millimeters of mercury. What is the pressure of the closed system?" The teacher refers to the writing on the board, 760 mm Hg - 26 mm Hg, to answer his own question. The teacher then demonstrates the closed system being higher pressure than air pressure. The teacher reminds the students to check their systems for leaks. The teacher gives safety directions: "Don't blow into hose. Mercury is toxic.". Teacher: "We are relating pressure to volume and temperature. The teacher explains how to calculate the volume of the system: "When I have this hooked up, I am talking about the volume in the syringe, hose, and on top of the mercury. Assume the hose is a 1 cm diameter cylinder." The teacher refers to equations on the board for the calculation of volume. Teacher: "You will have two graphs: pressure (y-axis) vs. volume (x-axis) and pressure (y-axis) vs. 1/volume (x-axis). The teacher gives directions for the second part of the experiment: "Make a hot water bath with a 250 ml Erlenmeyer flask with a stopper and glass tube. Once this is heated up, hook it up to the hose. Add ice to water bath. As it cools this down, what happens to the pressure?"
Some students respond.: "It goes down."
Teacher: "Pressure decreases. Does everyone understand what they are doing? This works well. This is one of the few labs that works well. Check out syringe from me."

LI-2

The teacher gives directions for section I-G of the laboratory experiment: "Write this down. Graph pressure vs. Volume; this will be a curve, not a line. Graph pressure vs. 1/volume; this will be a straight line. Tell me why. Refer to one of your labs." Teacher gives directions for section II: "Graph pressure vs. Temperature. Set up a system like this [teacher has one set-up with beaker on ring stand, above bunsen burner and a stoppered flask suspended in the water in the flask]. Use beaker and wooden drawer in common cabinet - don't put on top of the shelf. Use a syringe to pull water out. Make sure pressure changes at least 10-15 cm. Check for leaks."

In contrast, the more inquiry teachers gave general directions to focus students' attention on the concepts being investigated during guided inquiry laboratories.

MI-1

> The teacher comes in and quickly prepares materials. Teacher: "F-1 Lab, page 77. Read section I-1, it is a caution, everything you will use today can be harmful, especially the sodium and potassium. Don't pull it out with your hands. Also, you will need to read Section B as you go along for background information. You are going to gain some kind of concept about chemicals through empirical methods. You are going to drop metals into liquids, see reactions, and work backwards to the equation." The teacher demonstrates how to make the gas trap and explains: "Use a 400 or 600 ml beaker. Make sure there is no air. The goal is to see if there is gas produced." The teacher describes how to hold and position the foil-wrapped metal, then cautions the class to keep the test tube vertical before testing with the flame. The teacher directs students to put used metal in a particular beaker. The teacher comments on the laboratory experiment: "Pretty self-explanatory".

During open inquiry laboratories, the LI teachers' directions limited students' choices of systems to investigate and often told the students exactly how to investigate the reaction.

LI-1

> The teacher introduces the laboratory experiment, asks questions and answers his own questions: "System I is most concerned with the quantitative portion. What happens to ionic compound in water? It dissociates into ions, also called dissolving. The more ions put into solution, the more electricity will be conducted. How good of a conductor of electricity is water? Who thinks it is good? Who thinks it is bad? Water is a perfect insulator unless it contains ions." The teacher tells a story about changing light bulbs under water. The teacher then explains the anticipated results of the experiment: "Different amounts [of a chemical] go into solution, so different amounts dissolve. There is a quantitative and qualitative trend. We have apparatus to test this." The teacher demonstrates how to use the light bulb apparatus for the qualitative portion of the experiment. He reminds students that with no electricity, you have no light. He demonstrates how to use the power supplies. The teacher reminds the students: "Test the bulb so you know the bulb hasn't burned out." The teacher gives directions for investigating the quantitative portion of the experiment: "There are two different means of testing conductance or resistivity of the solution, you can report either. Conductance is how easily something conducts electricity. Resistance is how little

the solution conducts electricity. The unit of resistance is an ohm, the symbol is [points to board]." The teacher also shows a conductivity meter and explains: "The units of conductance are siemans. The other unit of conductance is [points to board]. You don't need to know how to convert one to another. Test each twice to get good data." Teacher: "For system 2, the results will be horrible. The experiment is investigating solubility of salts, how much dissolves in terms of grams/ml (a density). How do you know how much dissolves? Weigh, dissolve, filter, dry undissolved solutes, and weigh again. Do all of the substances and do this twice. There are theoretical values you would need to compare to, you can find them in Chem-Math Library."

All the students in this section chose to investigate System 1, although the laboratory manual presents a choice of four systems.

During open inquiry laboratories, the MI teachers told the students to design and implement experiments to answer their own questions.

MI-1

The teacher introduces the laboratory experiment: "Basically, you will decide what you're going to do. You decide first. I'll come around and ask what you're doing and how you're going to do it. Turn in labs on Thursday during recitation. Any questions before we start? [There are none] Be careful with thermometers. If you break them, you will pay for them.

MI-2

The teacher introduces the laboratory experiment: "You can do any lab but systems 8 or 9. Design the experiment yourself, first come up with a question, then design the experiment to answer your question. I'm not going to tell you how to set up your experiment. I'll check your setups and ask questions for you to think about."

MI-3

The teacher introduces the laboratory experiment: "This systems lab is like your lab final; the most important thing in the write up is the procedure. How many variables can you test at one time?"
Several students reply: "One".

> Teacher: "So you'll have to design experiments to test one variable. I know how you can do each one of these, but I'm not going to tell you how. Plan and I'll come around and listen to what you've planned. Think about using manometers and two-hole flasks. Get started."

Interacting with students.

The topics of discussion between a teacher and his students during the laboratories revealed differences between more inquiry and less inquiry teachers. Since the less inquiry teachers would often tell the students how to design and perform the experiment, there was little need for explicit discussion of issues related to experimenting. However, both less inquiry teachers were observed to discuss the need for repeated trials in data collection. During the laboratories, the less-inquiry teachers tended to give students answers rather than encouraging students to find answers on their own. Both teachers were observed informing the students about what the results of the experiment would (or should) be, and what the interpretation of the results should be.

LI-1

> While trying to interpret results, a student refers to the Periodic Table.
> The teacher points to Periodic Table and says : "The farther you go this way [down] and this way [left], the greater the reaction. So what if you put rubidium in water?"
> The student replies: "It would be a strong reaction."
> Teacher: "That's why we don't do it."
> Student: "What about magnesium?
> Teacher: "If you left it in water long enough, it would do something, not violent."
> Student: "So can we say it didn't do anything?"
> Teacher: "No, because you're going to have to rank them and relate it to the periodic trends."

LI-1

A group of students don't get the light bulb to light.
The teacher says that they haven't used enough solute.
The students ask if they need to redo the experiment with greater concentrations of solute.
The teacher tells them to explain that they didn't see conductance w/the amount of solute they used, but if they had used more solute, they would have seen conductance because they know that ions conduct electricity.
A student asks: "But how do we explain that when we don't see it in our data?"
The teacher reiterates that they know that ions conduct electricity then leaves the group.
Student talks to partner: "This systems lab is going to be weird. I don't know really how to relate this since it didn't work. Should we ask him real quick how to relate Part A to Part B?" They call to the teacher. He is busy. They discuss, then go to the teacher and ask: "How do we relate Part A to Part B? In Part A, all of them conducted electricity except for water [but they didn't see conductivity in Part B].
Teacher: "This is a systems lab. You're going to get a pat answer."

LI-2

Teacher gives directions to the class: "Be sure to rank chemicals in order, most reactive to less reactive. Be patient. Wait 10 minutes. I don't want to see any reports of "no reaction," because they all react.
Later the teacher talks to a group of students: "You guys are going to make big fire."
Student to his partner: "Put it in."
Teacher: "Oh, it didn't make fire, which one was it?"
Student: "Sodium."
Teacher: "Sodium doesn't make fire, potassium does."
Student to partner: "Get potassium, see the fire."
Teacher: "Yeah; isn't that sweet?"

LI-2

The teacher tells a group of students to measure the conductivity before and after, and then he tells them the reason the conductivity would go up before they did the experiment.

LI-2

> A group of students assembles experimental equipment and puts stopper in flask before heating. The teacher sees this and tells them to remove it. The teacher explains that: "It needs to be open while heating, so then when the air cools, it will contract and the pressure will decrease."

Interactions among the less-inquiry teachers and their students were dominated by the teacher providing information concerning experimental procedures and content that the students needed to learn.

In contrast, the more-inquiry teachers also provided information about experimental procedures and content for the students, the teachers' interactions with the students' included discussions about conducting investigations and discussions of content. During the laboratory activities, these teachers tended to respond to students' questions with encouragement for the students to try to find answers on their own through experimentation or reasoning.

MI-1

> Before doing an experiment, a student asks: "This stuff isn't going to react too much, is it?"
> The teacher responds: "Maybe. That's for you to find out."

MI-1

> Student: "We are supposed to determine acid/base properties. How do we do that?"
> The teacher doesn't respond immediately, then asks the students to explain what they think they should do.
> The students respond: "Do you mean the litmus paper and all that?"
> Teacher: "Yes."

MI-1

> A group of students ask: "How do we check for acids or bases?" The teacher waits. A student continues.: "With litmus paper?"
> Teacher: "Does that tell you if it is acid or base?"
> Student: "Yes." The group asks more questions about the next thing they have to test to discover if it has acid or base properties: "How do we do this?" Teacher: "What can you do?"
> Student: "We can test it for both acid and base reactions and see what happens."

MI-2

> The teacher's side of a discussion with a student about writing equations, student does respond, but I couldn't record all statements: "What does it give off? So write down what it gives off. What charge does it have? Does that balance? You have three hydrogens. How are you going to balance that out? That would work. Does that equation make sense to you?"
> Student: "Where did the sodium go?"
> Teacher: "Where do you think?"
> Student: "The hydrogen made a gas, the sodium just went away."
> The teacher explains that it can't just go away, reminds student about forming ions. They work out the equation. The student seems to understand.

MI-3

> Student talks about results: "Something happened that didn't happen before."
> Teacher: "What?"
> Student: "It turned yellow."
> Teacher: "Did you use the same chemicals? What was the temperature data like? Do it again and see what happens."

Particularly during the open-inquiry laboratories, the more-inquiry teachers asked the students to describe the question they were trying to answer and frequently discussed issues of experimentation (variables, control, replicability, error analysis).

MI-1

> The teacher checks with a group about their plan for the experiment: "Now you're on the right track. You should know this. Why are you doing the experiment? What are you going to obtain from it? Once you know that, you'll be better able to design the experiment."
> The students reply.
> The teacher gives hints. He reminds students about when they can tell that there is thermal equilibrium.
> Student: "Oh, yeah."
> Teacher: "Then, knowing that, what do you do next?"

MI-3

> The teacher questions students about their experimental design: "So how are you going to keep the pressure constant? How are you going to keep those two levels right there?" The teacher leaves the students to think about his questions.

MI-2

> The teacher returns to a group still working on calculations, arguing about which values to use.
> Teacher: "Where do you think error might happen in this experiment?" Students identify some sources of error [transfer of liquids etc.]
> Teacher: "Your numbers are pretty close in the end."
> A student finds a calculation error.
> Teacher: "Calculate it totally out again, compare it with the specific heat of aluminum in the book."
> The students check in book and their results are off.
> Teacher: "So you can see where the error comes in, but your experiment was set up perfectly."

Because the more-inquiry teachers required their students to design experiments and construct interpretations of data on their own, the teachers were continuously moving around the laboratory room in order to monitor students' progress. The more-inquiry teachers monitored by asking students to describe the experimental set-up, the data they had gathered or their interpretation of the results. These teachers also monitored silently, stopping near each group to be available to assist if needed. The students sometimes asked the teacher questions but other times they told the teacher that they didn't need any help.

Summary of observations.

The more inquiry teachers' implementation of the chemistry laboratory curriculum encouraged the students to engage in critical thinking and investigation of chemistry phenomena. In the more inquiry classrooms, the teacher or the textbook was not the sole source of knowledge. The students' observations and reasoning were valued. Some students in these classes remarked that the teacher was not the only source of knowledge:

> During an open inquiry laboratory, a student jokes with MI-3, "What exactly do you want us to do? (Laughing)".

> Following a discussion of the interpretation of experimental results, a student remarked: "You told the answer on this one [laughs]."
> MI-3 replied: "No, I didn't. It took some work, but you finally said the answer."

> At the beginning of an open-inquiry laboratory, a group of students is trying to plan their experiment. One student suggests that they wait for the teacher (MI-1) to help them. Another student answers, "He won't tell us what to do."

Laboratory partners are trying to interpret their data and ask MI-2 for help. The teacher asks questions about the experiment:

> Teacher: "Think about what you're doing."
> Student: "We're adding acids to bases.
> Teacher: "What happens with each drop?"
> Student asks the teacher the same question.
> The other student responds, "He's not going to tell you that. Don't trust me, but if you have an acid and base in there, you have a salt floating around."

The second student knew that MI-2 would not be the source of knowledge. This student also encouraged the partner to interpret the evidence for himself.

When the more inquiry teachers explicitly discussed issues of experimentation (control of variables, replicability of results etc.), the implicit message was that carefully gathered data could serve as the basis for answering a specific question. Thus, the justification for knowing the answer to a question in the more inquiry classrooms was based upon examination of experimental evidence.

The less inquiry teachers often presented the laboratory exercise in such a way that the emphasis was on <u>one</u> correct way to perform an experiment and <u>one</u> correct answer that the teacher already knew. The implicit message was that the teacher or the text was the source of knowledge. The justification for knowing was matching the evidence to the expected results. Students' results were incorrect if they did not match the expected results. An example of the focus on the expected answer occurred in LI-1's class (this scenario was also reported in a previous section):

> The teacher tells them to explain that they didn't see conductance with the amount of solute they used, but if they had used more solute, they would have seen conductance because they know that ions conduct electricity.
> A student asks: "But how do we explain that when we don't see it in our data?"
> The teacher reiterates that they know that ions conduct electricity then leaves the group.
> Student talks to partner: "This systems lab is going to be weird. I don't know really how to relate this since it didn't work. Should we ask him real quick how to relate Part A to Part B?" They call to the teacher. He is busy. They discuss, then go to the teacher and ask: "How do we relate Part A to Part B? In Part A, all of them conducted electricity except for water [but they didn't see conductivity in Part B].
> Teacher: "This is a systems lab. You're going to get a pat answer."

Students were told to accept the teacher's authority concerning the data of the experiment, then they look for his authority for the interpretation of the data. For these students, the teacher had become the source of knowledge and his word was the justification for knowing.

Since the students were enrolled in introductory chemistry to learn the basics of the discipline and since the lecture exams required students to know chemistry content, teachers' emphases on answers that are 'correct' was expected. Both more inquiry and less inquiry teachers required that students learn chemistry content. The difference between the MI and LI teachers was that the MI teachers recognized the validity of the students' data even if it didn't correspond to the expected data. The MI teachers guided the students to closely examine the conditions of their experiments for reasons why their data was inconsistent with the expected data (extraneous variables, experimental error). The LI teachers generally told the students that their data was incorrect, but the teachers did not discuss sources of variability in the data. The implicit message was that the students were incapable of generating 'good data', thus students could not be the source of knowledge.

<u>Research Purpose 2</u>

To describe the students' approaches to learning and their epistemological beliefs about science.

Description of students' epistemological beliefs and learning approaches was guided by the following questions: (a) What approaches to learning do students use in chemistry laboratory? (b) What do students believe about the epistemology of science ? (c) What are the students' perceptions of their experiences in chemistry laboratory? Descriptive statistics were utilized to describe the ways in which the college students in this study approached learning in the chemistry laboratory based on the Learning Approach Questionnaire. Students' epistemological beliefs based on the Science Knowledge Questionnaire were also profiled using descriptive statistics.

Students' perceptions of the laboratory experiences were described based on their responses to the open-ended questions.

Questionnaire Results

Table 2

Descriptive statistics of learning approach and epistemological belief questionnaire scores

	N	Mean	SD	Actual Range	Possible Range
LAQM	232	28.4	5.3	16 - 45	13 - 52
LAQR	230	25.9	4.0	16 - 38	11 - 44
SKQ	232	57.6	8.6	36 - 77	28 - 112

Table 3

Descriptive statistics of learning approach and epistemological belief questionnaire scores by type of instruction

	Instruction	N	Mean	SD	Range
LAQM	more inquiry	130	28.1	5.5	16 - 42
	less inquiry	100	28.9	5.0	16 - 45
LAQR	more inquiry	130	26.0	4.1	16 - 38
	less inquiry	100	25.8	3.8	16 - 34
SKQ	more inquiry	130	57.6	8.8	36 - 77
	less inquiry	100	57.6	8.5	41 - 75

Questionnaire responses were examined for missing data. The questionnaire responses for nine students were missing a response for one question each. The missing value was replaced with that student's mean response on the questionnaire (Tabachnick & Fidell, 1996). Two students did not complete several of the questions that contributed to the rote scale of the Learning Approach Questionnaire; their LAQR scores were not computed. Four students were dropped from the study due to their incomplete responses on all of the questionnaires.

The distributions of questionnaire scores were examined for normality and homogeneity of variance. Skewness and kurtosis values for each of the questionnaires indicated normal distributions. Questionnaire scores are also normally distributed within the groups, more inquiry and less inquiry. Levene's test of homogeneity of variance indicated that group variances did not differ.

Students' scores on the Learning Approach Questionnaire - Meaningful and Rote scales represent a wide range of approaches to learning. Histograms of questionnaire scores are reported in Appendix E. The LAQ-M scores and LAQ-R were normally distributed. Students' LAQ-M scores represent low to moderate meaningful approaches to learning. Students' LAQ-R scores also represent low to moderate rote approaches to learning. The maximum LAQ-M and LAQ-R scores were lower than the highest possible score. The students tended to chose the positions "more-true than untrue" and "more untrue than true" when responding to questions about their approaches to learning. However, some students did score very low on either scale.

Students' scores on the Science Knowledge Questionnaire represented a range of beliefs from received to moderate. The SKQ scores were normally distributed, however the highest score recorded was 35 points below the maximum score possible. Some students showed strong beliefs in the received epistemology of science knowledge. Most students exhibited a view of knowledge in science that incorporated both received and constructed epistemologies. No students held strong beliefs in constructed knowledge in science.

Open-ended Response Questionnaire

Students' responses to the three open-ended questions about the laboratory class revealed some perceptions of their teachers and their experiences.

Question 1: Purpose of the laboratory.

In response to question 1, "What types of things are you supposed to learn from the laboratory portion of Chemistry 1315?" students listed multiple purposes for the laboratory. Most students viewed the laboratory as an opportunity to learn specific chemistry concepts and to learn laboratory skills and techniques. Many students also listed other purposes for the laboratory portion of the course: to reinforce concepts learned in lecture through experimentation, to understand concepts by doing experiments, to apply concepts learned in lecture to real life, and to learn to perform experiments by thinking on your own. The following quotations are examples of students' responses to question 1. The four digit number is an identification number assigned to each student.

(3710)
How to apply the things we learn in the book to everyday situations in the lab.

(1710)
To think for ourselves and generate solutions to problems that are given.

(1822)
Experimental experience. Actually we are supposed to apply what we get in lecture in the lab. Also we are supposed to do experiments on our own. I guess that's cool because one can actually see by himself/herself what is in the book.

(2209)
How to solve a chemistry problem through scientific experimentation.

(1717)
Students should see the actual experiments that the laws they are studying are based on, and the students should learn to open their minds to think of hypotheses.

Question 2: Generate knowledge in laboratory?

In response to question 2, "Do you think that what you do in this laboratory could be described as generating scientific knowledge? Why or why not?", 175 students answered "yes" and 48 answered "no". The students that answered "yes" agreed that they were generating scientific knowledge through their laboratory experiences. The most common reason given equated "generating scientific knowledge" with personal learning about science. The following are examples of the patterns that were found.

(1319)
Yes, because I learned. I generated knowledge in my own brain that I didn't know before.

(2209)
Yes, because we are enhancing our own knowledge in the world of science. So whether or not we increase world knowledge is not the question. We ourselves are learning and generating scientific knowledge.

Some students perceived that since they were using scientific or critical thinking, they were generating scientific knowledge.

(1506)
Yes, I learned how to think scientifically, by observation and experimentation.

(1505)
Yes, because the lab reports made me use critical thinking and helped me understand chemistry.

(1822)
Yes, I think it is scientific knowledge because you are experimenting and deducing where things come from and why they happen.

(2729)
Yes, we had to throughly evaluate and analyze every lab; therefore we generated scientific knowledge in part abstractly.

Some students focused on the role of experimentation in the formation of scientific knowledge.

(2208)
Yes. Through experimentation you are generating scientific knowledge to enrich your science class.

(1816)
Yes, because every experiment you do generates scientific knowledge.

Several students referred to designing their own experiments as their opportunity to generate scientific knowledge. A few specifically mentioned the open inquiry laboratories (systems laboratories).

(1305)
Yes, I had to design an experiment to reach data and then answer questions with the data.

(1306)
Yes, because we first propose what we think is going to happen. Then we do an experiment and see what really happens. Therefore we are gathering knowledge. Then we figure out why it happened.

(3328)
Yes, because the systems labs require a lot of thinking. It is almost as if you're creating your own experiment.

(1529)
Yes, because with the systems labs, for example, you had to come up with your own experiments and do your own research, if you will, so I think so.

(1707)
Yes, because our systems labs required us to come up with our own thoughts and investigate them.

Some students explained that the laboratory activities generated scientific knowledge by verifying previously discovered scientific knowledge.

(1701)
Yes. In lab we set out to prove (theoretically anyway) the theories we are discussing currently. In the process we use our knowledge of the science to explain our results, which hopefully correspond to the theories.

(3724)
Yes, because we are replicating scientific theories and ideas of chemistry that are already known.

(2231)
Yes, it is really regenerating, it is not generating it for the first time.

Most of the students who answered "No" to this question explained that "generating scientific knowledge" means that the knowledge must be new to the entire scientific community. For these students, replicating the previously discovered scientific knowledge was not the same as generating it themselves.

> (3313)
> No, we are proving and looking at ideas that were proved and looked at long ago. We aren't doing any breakthrough research; we're just doing simple labs to help us understand the basic principles of chemistry.

> (3718)
> No, because we are first year students. Nothing we do contributes to science as a whole.

In the opinion of some students, since they didn't think about the experiments, they were not generating scientific knowledge.

> (1514)
> No. Ok, let's see why not? We sit around, follow directions from a book and make reactions. This takes less thought than making instant mashed potatoes.

> (2214)
> No. Most of the time the basic concepts behind the lab were already known, or the lab was conducted but no conclusions were reached. We would just go through the procedures of the lab and couldn't apply it to the lecture.

> (1801)
> No. Mostly the students just mindlessly follow the directions.

<u>Question 3: Generate knowledge without teacher?</u>

In response to question 3, "If you just went into the lab and conducted experiments without a teacher present, would that count as generating scientific knowledge? Why or why not?", 145 students answered "yes" and 75 answered "no". Students who answered "yes" stated that they could still generate or learn personal knowledge, however, many expressed reservations.

> (1322)
> Yes, because you are learning, but you might miss the point of the lab.
>
> (1818)
> Yes, to a certain extent. I think some people would pick up on the things you're supposed to get out of the lab. The systems labs are like that. They make you think and consider what is already going on.
>
> (2224)
> Yes. You would still learn from observing the experiments but a mistake could be made and the wrong assumptions made; learning would go at a much slower pace if there wasn't a teacher.

Other reasons for answering yes to question 3 are similar to the reasons given for answering yes to question 2: students can still perform experiments and the results of experiments are still scientific knowledge. In these reasons, the students often remarked on the role of the teacher in the formation of knowledge during the laboratories.

> (1525)
> Yes, the teacher is there to make sure that we are doing the experiment right or wrong. If we didn't have a teacher we would still be able to do the experiments on our own.
>
> (1816)
> Yes, even if there is no instructor telling us what we were going to learn, I believe you are learning just by doing the experiments.
>
> (2729)
> Yes, the labs are self-explanatory and the TA tried not to tell us too much so we could learn most of it on our own.

(2932)
Yes, because even though he/she is telling us what is going to happen we are still doing the experiment and seeing the process. In some cases, if he didn't tell us, we would probably come out with the wrong information.

(1824)
Yes, our instructor never told us what we were to learn, we just went in and did the labs and figured on our own (or with a little help) what we were looking for.

(2724)
Yes, in a way. Yes, because science is based on experiment and analysis. By doing labs on your own, you're in a way experimenting with knowledge. By having to ask yourself 'What can I get out of this?' you will better understand your own conclusions. Realistically though, without a road map, or an indication on where you are headed, you'll probably never get there. But after you've been there once (with help) you can go back on your own and even farther.

Some students responded that they would be more actively engaged in the laboratories without an instructor present, they would have to think more independently and they might learn more from each laboratory.

(2903)
Yes, because then we're generating experiments and knowledge on our own without someone telling us the correct path. We would have the opportunity to learn more.

(2716)
Yes, that would force you to learn what you are doing.

(2228)
Yes, because you would actually have to think about what you are doing.

(1726)
Yes, because we would have to apply our minds to learn.

(1731)
Yes, we would more actively be using our brain to think about how to conduct the experiment; therefore, a greater scientific knowledge would be generated.

(1514)
Yes, you would be learning things for yourself - not just following a recipe for science experiments.

(1529)
Yes, again you have to use your brain to figure things out, you have to almost become a scientist.

Some students answered "No" to question 3 because their experiments would not result in new information for the scientific community.

(2203)
No, we would still be finding things already known.

(1503)
No, my papers aren't being filed away in the chemistry library. A year from now neither I or anyone else will have any recollection of what I did in this lab. Heating things with a bunsen burner doesn't constitute generating scientific knowledge in my opinion anyway.

(1815)
No, but it would be more realistic. We still wouldn't be contributing to the overall body of scientific knowledge, but it would be a lot more interesting.

Most students answered "No" to question 3 because the students would get the 'wrong' answer if the teacher wasn't present to confirm the findings and make sure the experiment was performed correctly. These students were expressing their need for guidance in order to learn in this laboratory setting.

(2711)
No, I wouldn't do the experiments as detailed and he wouldn't have the opportunity to spur thoughts in my head.

(1307)
No, because we might do the experiment wrong and may not have the correct outcome.

Some students expressed the need to be told what to find and what to learn.

> (1310)
> No, I would not acquire such knowledge because in doing experiments, you would not know what to find. In experiments certain things can happen thus making different people look for different things.
>
> (1510)
> No, many times I do not realize what I am supposed to be learning from the labs, but having a teacher tell me what I'm learning helps me to look at my experiments and know what I need to pay attention to.

Other students' reasons explained that understanding the experiment is important to the generation of scientific knowledge.

> (1314)
> Maybe, if you understood the lab and what happened, you have learned. If you have not understood at all what just happened and why, then it is not.
>
> (2905)
> Not necessarily. The lab would have been completed even if little was learned.
>
> (1715)
> No, I think generating scientific knowledge is completely understanding what is being done.

Summary of Open-Ended Responses.

Student responses to open ended question #1 indicate varied notions of the purpose of the laboratory: to some students the lab is just a place to repeat what was learned in lecture, to others the lab is where the connection to real life is, to many students learning laboratory techniques is important, and to some students the laboratory represents an opportunity to engage in independent thinking.

In response to question #2, some students say knowledge is generated in the laboratory, others say it is not. The students' responses seem to depend upon their definition of *scientific knowledge*. Some students say yes if "generating scientific knowledge" means personal construction of understanding. In contrast, other students say no if "generating scientific knowledge" means that something is discovered/figured out that is new to the entire scientific community. A few students identify both positions as valid. Many students agreed that they were generating scientific knowledge in the laboratory because they were performing experiments and thinking scientifically. Other students responded that they did not generate scientific knowledge because they did not think about the experiments.

In response to question #3, most students stated that they did or did not generate scientific knowledge in laboratories for the same reasons as they gave for question #2. Many students were concerned that they would get the answer "wrong" if the teacher was not present to confirm the findings and make sure the experiment was performed correctly. Some students responded that if the teacher did not tell them what to learn, they wouldn't gain knowledge from the experiments

Research Purpose 3

To explore possible relationships among students' epistemological beliefs, the type of instruction and approaches to learning in chemistry laboratory classes; and to determine if these variables are predictors of learning approach.

Correlational statistics were used to examine the relationships among type of instructional experience, the students' epistemological beliefs and learning orientations as measured by the Science Knowledge Questionnaire and the Learning Approach Questionnaire. Type of instructional experience was coded as 1 = more-inquiry and 2 = less-inquiry. Pearson's point-biserial correlation coefficients were computed for all continuous variables. A correlation coefficient was considered to be significant only if $p < 0.05$.

Table 4

Point-biserial correlation of questionnaire scores and type of instruction

	LAQR	SKQ	INSTR
LAQM	-.023	.055	.078
LAQR	---	-.143*	-.031
SKQ		---	.002
INSTR.			---

* $p < 0.05$

The correlation of -.023 indicates that students' use of meaningful learning approaches was not related to their use of rote learning approaches (Table 4). This finding indicates that meaningful and rote learning are unique and unrelated approaches to learning. Students who use meaningful learning strategies may or may not also use rote learning strategies. Likewise, students who use rote strategies may or may not call upon meaningful learning strategies.

Meaningful learning approach was not related to students' epistemological beliefs as measured by the Science Knowledge Questionnaire. Students reported using meaningful approaches to learning regardless of beliefs in knowledge as more reasoned or more received. A measure of the strength of association, eta squared = .185 was calculated for the LAQ-M and SKQ scores of the sample of students in this study. Rote learning approach and epistemological beliefs were correlated (p = .03) at a level which indicates a small effect size (Cohen, 1988). For this sample of students, LAQ-R scores and SKQ scores had a strength of association of eta squared = .186. Students who believe in the constructed nature of science knowledge used fewer rote approaches to learning than students who believe in the received nature of knowledge.

Type of instruction experienced, more inquiry or less inquiry, was not significantly related to epistemological beliefs, meaningful learning approach or rote learning approach.

The exploration of variables that may predict students' learning approaches was guided by the following question: To what extent and in what manner can variation in students' approaches to learning be explained by the students epistemological beliefs and the type of instruction experienced? Since the students were not randomly assigned to laboratory sections, the possibility existed that students in some laboratory sections had mean pre-test scores on the Learning Approach Questionnaire that differed from the mean pre-test scores of students in other sections. Data from the pre-test administration of the LAQ was analyzed using analysis of variance to determine if there were any differences among the groups of students in each section. Since there were no differences among sections (LAQ-M $\underline{F}$ = .782, $\underline{p}$ = .538; LAQ-R $\underline{F}$ = .600, $\underline{p}$ = .663) , only post-test scores were used in subsequent analyses.

Heirarchical regression analyses were performed to determine if either type of instruction, epistemological beliefs or the interaction of instruction and epistemological beliefs predicted students' rote or meaningful learning approaches. The dependent variables for the analyses were students' scores on the LAQR and the LAQM. The independent (prediction) variables were, type of instruction experienced (more inquiry or less inquiry) and students' scores on the SKQ. To reduce the chance of multicollinearity, scores for epistemological beliefs were centered about the mean prior to calculation of the interaction term. A regression coefficient was considered to be significant only if $p < 0.05$.

Table 5

Regression of the independent variables, epistemological beliefs (SKQ) and type of instruction (more inquiry, less inquiry) with the dependent variable, learning approach - meaningful (LAQM).

Predictor	Change R^2	F change	sig.	B	Beta	t	sig.
SKQ	.003	.688	.408	-.020	-.033	-.387	.699
Instruction	.006	1.413	.236	.833	.078	1.192	.235
Interaction	.011	2.522	.114	.130	.136	1.588	.114

* $p < .05$

Total R^2 for the three predictor model is .02, or 2 percent of the variance in LAQ-Meaningful scores explained by the predictors. This R^2 is not significantly different from zero. None of the individual variables were significant predictors of LAQM. It is not possible to gain insight into predicting Meaningful Learning Approach scores from this study.

Table 6

Regression of the independent variables, epistemological beliefs (SKQ) and type of instruction(more inquiry, less inquiry) with the dependent variable, learning approach - rote (LAQR).

Predictor	Change R^2	F change	sig.	B	Beta	t	sig.
SKQ	.021	4.775	.030*	-.098	-.212	-2.479	.014*
Instruction	.001	.221	.639	-.249	-.031	-.471	.0638
Interaction	.007	1.575	.211	-.078	.108	1.255	.211

* $p < .05$

Students' epistemological beliefs, as measured by the Science Knowledge Questionnaire, was the only significant predictor of rote learning approach. Students' SKQ scores explained a significant percentage of the variance in scores on the LAQ-Rote (2.1 percent). Neither type of instruction or the interaction of SKQ scores and instruction contributed to the prediction of rote learning approach. The direction of the predictive relationship indicates that students who had beliefs in the received nature of knowledge in science were likely to use rote approaches to learning. Students who tended to believe that knowledge comes from an external authority were more likely to attempt to memorize the information than to try to "make sense" of the information for themselves.

Chapter V: Discussion and Conclusions

This study explored students' meaningful and rote approaches to learning in a college chemistry laboratory class. It was hypothesized that the epistemological assumptions of the laboratory instruction and the student's personal epistemological beliefs about science would influence the student's meaningful or rote learning orientation.

Research Purpose 1

To characterize the instructional experiences that students have in a college chemistry laboratory setting.

The authors of the laboratory curriculum described three main goals of their laboratory program in the introduction to the student manual: "the experiments are designed": (a) "to help you learn some of the laboratory techniques and procedures that scientists use to investigate nature", (b) "to introduce you to some of the basic concepts in chemistry." and (c) "to give you experience with some of the processes (collecting data, interpreting data, forming hypotheses and generating explanations) that a scientist uses when doing research." (Abraham & Pavelich, 1991, p. 3). In this study, all students had the opportunity to gain familiarity with basic laboratory techniques independent of the teachers' instruction. All students explored some basic concepts in chemistry, however in the less inquiry classes, students were frequently given the concept before engaging in the experiment. In the more inquiry classes, students constructed understanding of the concept through their experimentation. The students in the less inquiry classes had fewer experiences engaging in the processes of scientific inquiry than students in the more inquiry classes.

Observations of five teachers' laboratory instruction revealed differences in how the inquiry-based curricula was implemented. The differences in the teachers' actions included varying introductions to the activities, the nature of the directions given to the students, presence or absence of explicit discussion concerning issues of experimentation, and the ways in which the teachers interacted with their students during the laboratory. Two patterns of curriculum implementation emerged from the data, less inquiry and more inquiry.

The epistemological messages inherent in less inquiry instruction included: (a) information gathered by experimentation was only valid if it agreed with the text or the teacher, (b) the student was not capable of designing experiments or generating scientific knowledge, and (c) the experimental evidence that the student gathered was most often incorrect for reasons that the student did not know. The epistemological assumptions of less inquiry instruction represented a view of knowledge as received from authoritative others. Since experimental data could be incorrect for inexplicable reasons, the justification for knowing stemmed not from interpretation of evidence, but only from the opinions of authority figures.

The epistemological messages inherent in more inquiry instruction included: (a) the student was capable of forming a question and designing an experiment; (b) the student could interpret the experimental evidence to answer the question; and (c) if the student's results did not correspond to the results of others, the student was capable of examining the experiment for sources of variability. The epistemological assumptions of more inquiry instruction represented a view of knowledge as constructed by the student through experimentation and reasoning. Therefore, the student could serve as the source of scientific knowledge and the justification for knowing stemmed from logical interpretation of evidence in the more inquiry classes .

Research Purpose 2

To describe the students' approaches to learning and their epistemological beliefs about science.

Discussion of students' approaches to learning

Students' scores on the Learning Approach Questionnaire - Meaningful and Rote scales represent a wide range of approaches to learning. Only a few students scored in the top one-third of possible scores on the LAQ-M, therefore there were few students with strong meaningful learning orientations. In this study, some students used both meaningful and rote approaches to learning, some used meaningful approaches, some used rote approaches, and other students reported using few meaningful or rote approaches to learning. This finding is in contrast to the assumption of earlier research that a student would use either meaningful or rote approaches to learning (Donn, 1989).

The reported use of meaningful and rote learning strategies may reflect the students' perceptions of the demands of the course. Perhaps the design of the laboratory experiments provided opportunities for students to use more meaningful learning strategies. The demands of the exams given in the lecture part of the course may have encouraged some students to use rote learning strategies to learn chemical terms and definitions. This interpretation is supported by Entwistle and Ramsden (1983), who argued that students may need to use both meaningful and rote learning strategies to attain complete understandings.

Discussion of students' epistemological beliefs

Students' scores on the Science Knowledge Questionnaire represent a range of beliefs from received to moderate. No students scored in the top one-third of possible scores on the SKQ, meaning that there were no students who believed strongly in reasoned knowledge in science. Most of the students in this study were college freshmen and sophomores who believed in received knowledge or held a midrange view of knowledge. This finding agrees with the results of several studies that indicated that beginning college students have lower level epistemological beliefs (Jehng, 1991; King & Kitchener, 1990; Perry, 1968). Hofer and Pintrich (1997) suggest that " individuals may retreat to safer, more established positions when in new environments and that there may be affective issues involved, such as the effects of anxiety and negative feelings associated with challenges to strongly held ideas" (pg. 122). The introductory chemistry course could be an anxiety-provoking experience that encourages students to rely on more received epistemological beliefs.

Perhaps the students who scored moderately on the SKQ have some epistemological ideas that are more received and some that are more reasoned. Edmondson's (1989) findings also indicated moderate epistemological views among college students. The majority of students in her study held epistemological positions which were combinations of differing epistemological perspectives. Hofer and Pintrich (1997) suggested that epistemological theories are not necessarily cohesive, but are composed of ideas about the certainty of knowledge, the simplicity of knowledge, the source of knowledge and the justification for knowing. Schommer (1993) demonstrated that students can hold more mature beliefs about come components of epistemology while simultaneously having more naive beliefs about other aspects of epistemology. Although the SKQ appeared to measure only one dimension in this study according to internal consistency analysis, if students held differing beliefs about the components of epistemological theories their SKQ scores could be moderate.

However, the moderate scores may also reflect students' avoidance of the choices "Strongly Agree" and "Strongly Disagree". These students may be so unfamiliar with epistemological issues in science that they chose not to commit too strongly to any statement. Several students were dropped from the study when they refused to complete the SKQ. One student remarked, "This is too hard, I don't know the right answers."

Another possible explanation for students' midrange scores is that students' epistemological beliefs may be in flux. Perhaps the students' beliefs are being challenged by the inquiry laboratory format, even in the less inquiry classes. If so, students' epistemological views may be confused or evolving.

Longitudinal study of students' epistemological beliefs about science could describe how epistemological ideas may change through college science experiences.

Discussion of Open-ended Response Questionnaire

Evidence from the observations and the open-ended responses indicated that some students perceived epistemological messages in their instruction. Many students identified the teacher as the authoritative source of knowledge in the laboratory, perhaps due to their prior experiences in science classes. Students may come to class with preconceptions about science laboratory classes formed from their previous experiences. Students' perceptions of the laboratory class may be filtered through their expectations of learning and teaching in science classes. When students described the laboratory as a place to confirm or reinforce what was learned in the lecture, they were expressing their preconceptions of science laboratory classes. In fact, the lecture and laboratory portions of the course were coordinated so that concepts were explored in the laboratory before they were mentioned in the lecture. Thus, the students' responses to the question about the purpose of the laboratory course reflect not only their experiences in this laboratory class, but also their preconceptions of science laboratory classes.

However, several students in the more inquiry classroom commented that the teacher did not tell them what to do. The students who declined assistance from their more inquiry instructors were asserting their own authority as sources of knowledge. Many students described designing their own experiments during the open-inquiry laboratories; some of these students were in less inquiry classrooms. These less inquiry students saw themselves as “doing science”, regardless of the type of instruction identified through observations. Possible explanations for the perceptions of these students are discussed below.

Students tended to equate personal learning of science with “generating scientific knowledge”. This connection may exist because the students related their experiences with science with their classroom experiences. Larochelle and Desautels (1991) reported difficulty distinguishing students' ideas about science from their representations of school-based science learning during interviews with 25 high school students. Other researchers have also linked ideas about knowledge with ideas about learning (Baxter Magolda, 1992; Roth & Roychoudhury, 1994; Schommer, 1990, 1993). Hofer and Pintrich (1997) proposed that, “beliefs about learning and teaching are related to how knowledge is acquired, and in terms of the psychological reality of the network of individuals' beliefs, beliefs about learning and teaching are probably intertwined” (pg. 116). In the current study, students expressed concerns about finding the correct answers from their experiments. Perhaps the identification of "generating science knowledge" with personal learning of science in a class explains the students' concerns.

Many students who identified "generating scientific knowledge" as discovering something new to the entire scientific community did not see themselves as sources of scientific knowledge. They perceived that their experiments only replicated or verified the findings of others. For these students, the source of scientific knowledge may have been professional scientists.

Other students equated experimentation and critical thinking with the generation of scientific knowledge. These students identified themselves as sources of scientific knowledge when they used critical thinking and performed experiments. For these students, the justification for knowing may have been the act of experimentation and thinking.

Some students responded that they could generate scientific knowledge without the teacher because they would have had to think more actively about the experiment. Some students equated their laboratory experiments with "following a recipe"; saying that the experiments required little thought. These statements may indicate that these students engaged in the laboratory experiments only to the extent necessary to complete the course requirements. Perhaps students' perceptions of the laboratory assignment influenced the students' meaningful learning sets. If students perceived that the experiment required only following directions, then they might not have found it necessary to attempt to make sense of the experiment. In contrast, if students perceived that successful completion of the laboratory required that they make sense of the experiment, then they may have attempted to cognitively engage in the activity. Therefore, students' perceptions of the potential meaningfulness of the task may influence whether they chose to utilize a rote or meaningful learning approach.

Research Purpose 3

To explore possible relationships among students' epistemological beliefs, the type of instruction and approaches to learning in chemistry laboratory classes; and to determine if these variables are predictors of learning approach.

Type of Instruction and Epistemological Beliefs

Type of instruction was not correlated with epistemological beliefs as measured by the SKQ. Previous research concerning epistemological beliefs demonstrated that change in epistemological beliefs is gradual (Perry, 1968; King & Kitchener, 1990). In the present study, if students' epistemological positions developed throughout their life experiences with science (particularly with school science), brief, recent experiences may not have been sufficient to influence students' responses to questions on the SKQ.

Edmondson's (1989) finding that students simultaneously held conflicting epistemological positions suggests that students do not necessarily integrate the epistemological assumptions of their recent experiences into their previously held positions. Edmondson concluded that students had developed distinct, parallel ways of knowing. Perhaps students answered the SKQ items without referencing their recent experiences in chemistry laboratory because their epistemological views of *science in a classroom* differed from their views of *science as an enterprise and as the work of professionals.* The existence of separate conceptions of science knowledge could explain why some students reported that they generated scientific knowledge during the chemistry laboratories, but also scored very low on the Science Knowledge Questionnaire.

The instruction of the less inquiry teachers may have encouraged the students to conceptually separate the knowledge they gained through direct experiences from knowledge transmitted to them. These teachers directed students to ignore their own experiences (the results they saw in the laboratory) in favor of the "correct" results that they should have observed. The students were left with the choice of disbelieving their own experiences or creating two versions of the phenomenon - *what they saw* and *what they were told*. In contrast, the more inquiry teachers may have helped students reconcile the two sources of knowledge by encouraging and assisting students to find the reasons why their results differed from the results in the text. The more inquiry teachers were supporting students' integration of different ways of knowing.

Type of Instruction and Learning Approach

Type of instruction was not correlated with meaningful or rote learning orientation. Although there were epistemological differences in the ways the two groups of teachers implemented the laboratory curriculum, instruction was not a predictor of meaningful or rote learning orientation. Cavallo and Schafer (1994) also found little effect of type of instruction (reception versus generative) on students' meaningful learning.

The laboratory section is only a part of the chemistry course, the students also attend three hours of chemistry lecture presentations each week. The laboratory experience may not have been a strong enough treatment to influence students' learning orientations in comparison to the lecture portion of the course. Despite written and verbal directions for the students to consider only the laboratory portion of the course when completing the Learning Approach Questionnaire, some of the items refer to lectures, textbook readings and examinations. The students may have been unable to answer these items based solely on their laboratory experiences, thus they may have considered their experiences in chemistry lecture when responding to these items.

Although the two groups of teachers implemented the curriculum differently, the students' lab manual may have been a greater influence on students' perceptions of the instruction than the teacher's behaviors. Pavelich and Abraham (1979) used the LPVI (Appendix A) to describe laboratory instruction based upon students' ranking of descriptive statements. The top one-third ranked statements were considered to characterize several types of laboratory instruction. Students who used the laboratory manual, Inquiries into Chemistry, ranked statements 2, 16, 1, 13, 12, 11, 17, 5 and 20 as best describing their experiences. The students in Pavelich and Abraham's (1979) study focused most on the laboratory reports they had to write, next on the requirements of the laboratory guide, and then on their own activities during the laboratory. Statements that described the instructor were not as highly ranked as statements which described the laboratory manual and the students' own activities. The students' focus on the laboratory manual and their own activities (Pavelich & Abraham, 1979) may explain why type of instruction was not a predictor of meaningful or rote learning approach in the present study. Contact with the teacher during a laboratory was limited due to the number of students in each laboratory section, therefore students relied heavily on the laboratory manual's instructions for assistance during the guided inquiry laboratories. Students also used the laboratory manual when preparing the laboratory reports which were the basis of their grades in the laboratory portion of the course. All students used the same laboratory manual and no differences were detected in the grading of the laboratory reports. If the students in the present study focused more on the laboratory manual and their laboratory reports than on the actions of their teacher, implementation of instruction by the teacher may not have influenced the students' approaches to learning or their perceptions of the instruction.

Meaningful Learning Approach and Epistemological Beliefs

The hypothesized relationship between the epistemological belief in reasoned knowledge and meaningful learning orientation (see Figure 1) could not be supported in this study. Since few students reported highly meaningful learning orientations and no students reported strongly held beliefs in reasoned knowledge, the correlation and regression could only assess the relationship between low-midrange meaningful orientation and received-midrange epistemological beliefs. The relationship between highly meaningful learners and their epistemological beliefs remains unknown. Students reported using low and midrange meaningful approaches to learning regardless of their epistemological beliefs.

The low percentage of shared variance (0.3%) between meaningful learning approach and epistemological beliefs was based upon linear correlation. However, the measure of association (eta squared) of LAQ-M and SKQ scores for the sample of this study indicated shared variability of 18.5%. Although low-midrange meaningful learning approach and received-midrange epistemological beliefs were not related in a linear fashion, they may be jointly influenced by unmeasured variables. Future research should strive to identify variables that influence both meaningful learning orientation and epistemological beliefs.

Rote Learning Approach and Epistemological Beliefs

As hypothesized, students' beliefs in received knowledge in science were correlated with their orientation to learn using rote strategies (see Figure 1). Epistemological beliefs predicted students' rote learning orientation in this study. The direction of the correlation indicates that students who had beliefs in the received nature of knowledge in science were likely to use rote approaches to learning. This result agrees with Edmondson's (1989) findings that male students held more received views of science knowledge and tended to use rote learning strategies. The finding agrees with the theoretical framework of this study. If students believe that knowledge is certain, and the source of knowledge and justification for knowing is an authority, it follows that learning requires only rote strategies such as memorization. If knowledge is simple, there is no reason to try to make connections between new information and prior knowledge.

The percentage of shared variance (2%) between rote learning approach and epistemological beliefs based upon linear correlation may indicate that rote learning orientations are the result of multiple factors. Eta squared, the measure of association of LAQ-R and SKQ scores for the sample of this study, indicated shared variability of 18.6%. It is possible that rote learning orientation and received epistemological beliefs are jointly influenced by unmeasured variables. Further research is needed to identify the factors that influence rote learning orientation and belief in received knowledge.

Meaningful and Rote Learning Approach

The absence of significant correlation between students' LAQ-M scores and LAQ-R scores supports the interpretation that meaningful learning approach and rote learning approach are separate constructs (Cavallo, et. al, 1996). The results show that meaningful learning orientation is independent from rote learning orientation, as measured by the LAQ. In this study, the theoretically opposed learning strategies were not tied to each other. This finding advances the work of other researchers who identified and described students' approaches to learning as meaningful or rote (Cavallo & Schafer, 1994; Donn, 1989; Edmondson, 1989; Entwistle & Ramsden, 1983).

Students' scores may indicate that individuals use a variety of meaningful and rote strategies in response to a learning task. The student may assess the demands of the learning task and utilize a combination of meaningful and rote approaches to learning in order to successfully complete the task. Choice of learning approach may be more situational and contextual than has been considered in the literature previously.

Limitations

As with any study, the methods of data collection and analysis of qualitative data introduce the bias of the researcher into the findings. Observational records of the classroom reflect the items and events that the researcher deems valuable, thus, other potentially important information may have been omitted from the description. Since the researcher constructed her own interpretation of the environment, interactions and occurrences, she acknowledges this in her discussion of findings and implications. This limitation was addressed by the search for evidence that was in conflict with the researcher's interpretations and by the construction of alternative interpretations.

Further research is needed to confirm the findings of this study in other contexts and with other samples.

Conclusions

Students became a source of scientific knowledge for themselves when they were allowed to be and when they were encouraged to do so. When the teacher presented himself as an authoritative source of knowledge, the students accepted him as such. The justification for knowing in the chemistry laboratory appeared to depend upon the perceived source of knowledge. The agreement of a source of authority was the justification for knowing in the less inquiry classrooms. The results of experimentation and logical reasoning were the justifications for knowing in the more inquiry classrooms. Therefore, the epistemological assumptions of more inquiry and less inquiry instruction differed due to the ways the teacher implemented the curriculum. It is notable that students' perceptions of instruction may have been influenced to a greater extent by the laboratory manual or their prior experiences than by their instructor.

The epistemological messages inherent in the two types of instruction did not appear in students' responses to the Science Knowledge Questionnaire. Epistemological beliefs form as a result of an accumulation of experiences; the laboratory experience was of limited duration and may have been confounded by the lecture portion of the course. Considering the results of the SKQ, it is interesting that many students reported that they generated personal scientific knowledge during the chemistry laboratories. Perhaps these students had developed parallel ways of knowing about science.

Although type of instruction was not correlated with learning approach as measured in this study, the open-ended responses point to students' perceptions of classroom tasks as influential in their choice of meaningful or rote learning strategies. Students appeared to assess the demands of a task as presented to them by the laboratory manual and their teacher, and to respond with the learning approach that would accomplish the task. Thus, a student's use of meaningful or rote learning strategies may vary from task to task. This interpretation is supported by the finding that meaningful learning approach and rote learning approach are separate constructs for this sample.

Rote learning approach was predicted by belief in reception of knowledge from authorities for this sample of students. In this study, students who tended to believe that knowledge comes from an external authority were more likely to attempt to memorize the information than to try to "make sense" of the information for themselves. This relationship was hypothesized by Hofer & Pintrich (1997) and Perry (1981) and confirmed through this study.

When an authority presents information to a student, the student makes a choice about how to learn the information. The student may choose to try to reconcile the new information with prior knowledge, but to do so may result in conflict between knowledge from experiences and from the authority source. In order to accept the opinions of authorities which might be in conflict with experiential knowledge, a student may choose to utilize rote approaches to learning. In this case, the student may choose to memorize the new information without attempting to integrate it with prior knowledge. The student rotely learns what the authority presents because this information is needed for evaluation. However, the student also "knows" about the way the natural world works as the result of direct experiences. Therefore, a rote approach to learning information provided by authorities may help a student maintain parallel ways of knowing about science.

Implications of the Study

Proper implementation of inquiry instruction may require that teachers understand the purposes behind the curriculum design. One purpose of science education is to introduce students to the ways scientists investigate the world. When science teachers present themselves as the authoritative source of knowledge, they are not representing the epistemology of scientific knowledge accurately. Scientific epistemology is more accurately portrayed when science teachers engage students in the processes of experimental design and critical analysis of results. Science teacher education should include analysis of the epistemological implications of curricula and instructional behaviors. Teachers need to be aware of the implicit messages their teaching behaviors send to their students.

Fortunately in this study, many students in the less inquiry classrooms appeared to be influenced by the written curriculum to a greater extent than they were by the way their teachers implemented the curriculum. Laboratory courses provide many opportunities for students to work without the direct guidance of the teacher. When students are required to work somewhat independently, they may turn to written curriculum materials for guidance. This finding suggests that curriculum materials are a very important part of laboratory instruction and other types of instruction that involve independent study.

The more inquiry teachers may have helped their students to develop a personal scientific epistemology that more closely reflects the nature of the scientific enterprise. If science teachers were educated to implement inquiry curricula in the "more inquiry" fashion, their students would benefit. If students hold parallel epistemological positions, experiencing more inquiry instruction may help bring their personal scientific epistemologies closer to their ideas about professional scientific epistemology. Then students may find it easier to integrate their parallel knowledge systems into a coherent epistemological theory. Inquiry instruction in introductory chemistry courses in not commonplace in the United States. Identification the benefits of inquiry instruction for students may encourage more colleges to adopt an inquiry curriculum.

The findings of this study contribute to greater understanding of the relationship between students' ideas about learning and knowledge. The shared variability of meaningful learning approach and epistemological beliefs, and rote learning approach and epistemological beliefs indicates that these constructs may be jointly influenced by other factors. This finding provides a direction for future research.

One important result of this study indicates that meaningful and rote approaches to learning are not in opposition. Theoretically, a student would use either meaningful or rote approaches to learning. The findings of this study are not consistent with this theoretical relationship. One interpretation of this finding is that students may use a combination of learning approaches based upon their perceptions of the demands of a task. If so, then teachers who provide meaningful learning tasks and who have the expectation that students learn in a meaningful way may encourage the students to do so.

Further Research

Further research should investigate the relationships between learning approach and epistemological beliefs in other contexts (traditional chemistry laboratory instruction, inquiry biology laboratory instruction, etc.). These relationships may also be investigated in younger and older students to investigate the possible influences of maturity, intellectual development, level of education and types of education experiences on epistemological beliefs and learning approaches. Many factors are hypothesized to influence an individual's epistemological beliefs (Hofer & Pintrich, 1997). Further research should strive to reflect the complexity of influences on epistemological theories.

Future research will analyze students' Science Knowledge Questionnaire scores and open-ended responses to determine if epistemological beliefs differ by gender as suggested by Edmondson (1989). Further analysis will also search for gender-related patterns in students' rote and meaningful learning orientations.

The results of this study suggested that students may utilize independent parallel ways of knowing about science. Further research should search for ways to detect and document the existence of parallel knowledge systems about personal science epistemology, school-based science epistemology or professional science epistemology. If these parallel ways of knowing exist, can using instructional methodology which encourages students to adopt meaningful learning approaches help students integrate their disparate conceptions of knowledge? This question offers a direction for future research.

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Appendix A

Laboratory Program Variables Inventory (LPVI)

Laboratory Program Variables Inventory (LPVI)

1. Students follow the step-by-step instructions in the laboratory guide.

2. Laboratory reports require the interpretation of data.

3. The instructor is concerned with the correctness of the data.

4. Students are allowed to go beyond regular laboratory exercises and do experiments on their own.

5. Laboratory activities are used to develop concepts.

6. The instructor lectures to the whole class.

7. Students are asked to design their own experiments.

8. During laboratory students record information requested by the instructor or the laboratory guide.

9. Laboratory sessions raise new problems or result in data that cannot be immediately explained.

10. The instructor or laboratory guide identifies the problem to be investigated.

11. Laboratory activities require students to solve problems.

12. Laboratory reports require that specific questions be answered.

13. The instructor or laboratory guide requires that students explain why certain things happen.

14. Laboratory is used to investigate a problem that comes up in class.

15. Laboratory experiments develop skill in the techniques or procedures of chemistry.

16. Laboratory reports require that students use evidence to back up their conclusions.

17. Students discuss their data and conclusions with each other.

18. The instructor or laboratory guide asks students to state alternative explanations of observed phenomenon.

19. During laboratory students record the information they feel is important.

20. Students propose their own explanations for observed phenomenon.

21. Students identify problems to be investigated.

22. During laboratory students check the correctness of their work with the instructor.

23. In discussion with the instructor, assumptions are challenged and conclusions must be justified.

24. Students usually know the general outcome of an experiment before doing the experiment.

25. The instructor gives information to individuals in small groups.

Appendix B

Learning Approach Questionnaire

Learning Approach Questionnaire

The following questions refer to your study attitudes and processes in learning science **IN CHEMISTRY LABORATORY**. For each item there is a four point scale ranging from "Always True" to "Never True". Beside each question choose the letter that best fits your IMMEDIATE reaction. Do not spend a long time on each item; your first reaction is probably the best one. Do not worry about projecting a good image. Your answers are confidential. The information is about your study attitude and learning style. There are no "correct" answers.

Always True	More true than untrue	More untrue than true	Never True
A	**B**	**C**	**D**

1. I generally put a lot of effort into trying to understand things which initially seem difficult.

2. I try to relate new material, as I am reading it, to what I already know on that topic.

3. While I am studying I often think of real life situations to which the material I am learning would be useful.

4. I find I tend to remember things best if I concentrate on the order in which the teacher presented them.

5. I find I have to concentrate on memorizing good deal of what I have to learn.

6. I go over important topics until I understand them completely.

7. Teachers shouldn't expect students to spend significant amounts of time studying material everyone knows won't be examined.

8. I feel that virtually any topic can be highly interesting once I get into it.

9. I often find myself questioning things that I hear in lectures or read in books.

10. I find it useful to get an overview of a new topic for myself, by seeing how the ideas fit together.

Always True	More true than untrue	More untrue than true	Never True
A	B	C	D

11. After a lecture or lab, I reread my notes to make sure they are legible and that I understand them.

12. I think browsing around is a waste of time, so I only study seriously what is given out in class or in the course outlines.

13. I set out to understand thoroughly the meaning of what I am asked to read.

14. I tend to like subjects with a lot of factual content rather than theoretical kinds of subjects.

15. I try to relate what I have learned in one subject to that in another.

16. The best way for me to understand what technical terms mean is to remember the textbook definition.

17. Puzzles and problems fascinate me, particularly where you have to work through the material to reach a logical conclusion.

18. I usually don't think about the implications of what I have to read.

19. I learn things by rote, going over and over them until I know them by heart.

20. When I'm starting a new topic, I ask myself questions about it which the new information should answer.

21. I spend some of my free time finding out more about interesting topics which have been discussed in different classes.

22. Often I read things without having a chance to really understand them.

23. Since extra reading on a topic can be confusing, I look at only some of the suggested readings that go with the lectures or labs.

24. I generally restrict my study to what is specifically set as I think it is unnecessary to do anything extra.

Appendix C

Background Information Questionnaire

Background Information Questionnaire

Respond to the following questions by either filling in the blank or by drawing a circle around the appropriate choice. Please be assured that your answers are strictly confidential.

1. Name____

First Middle Last

2. Birth date ______________________________

Month Day Year

3. Classification (circle):

Freshman Sophomore Junior Senior Graduate Other ____________

4. Major____

5. Is Chemistry 1315 a required course for your major? Yes No

6. Is this the first semester you have enrolled in and attended Chemistry 1315?

Yes No

If no, why are you retaking the class? ____________________

7. Is Chemistry 1415 (the second semester of general chemistry) required for your major?

Yes No

8. Do you plan to enroll in Chemistry 1415? Yes No

9. Do you plan to enroll in any other science or engineering courses?

Yes No

10. Have you studied chemistry before taking Chemistry 1315, either in high school or at another college or university?

Yes No

Appendix D

Science Knowledge Questionnaire

SCIENCE KNOWLEDGE QUESTIONNAIRE

All questions refer to your experiences in
this Chemistry Laboratory Class.

Each question of this questionnaire consists of a statement related to knowledge in science or learning in **chemistry laboratory**. These statements express a particular view on the topic. You may happen to agree strongly with this view; you may happen to disagree strongly with this view; or your own position may be in between the two. There are no "right" answers; this is not a test. I simply want to understand what your position is on a number of topics about science knowledge and learning in **chemistry laboratory**.

INSTRUCTIONS TO STUDENTS:

- Read the statement carefully.

- Think to yourself whether you agree or disagree with the statement.

- Pick the position that comes closest to your own position.

  A = strongly agree
  B = generally agree more than disagree
  C = generally disagree more than agree
  D = strongly disagree

- Carefully mark the scantron sheet with your answer.

PLEASE DO NOT MAKE ANY MARKS ON THE QUESTIONNAIRE

Strongly Agree	Agree more than disagree	Disagree more than agree	Strongly Disagree
A	B	C	D

1. Scientific knowledge is unchanging.

2. Scientists should make the decisions about things like types of energy to use because they know the facts best.

3. Scientific theories are discovered, not created by people.

4. Today's scientific laws, theories and concepts may have to be changed in the face of new evidence.

5. The laws, theories and concepts of biology, chemistry and physics are not related.

6. Relationships among the laws, theories and concepts of science do not contribute to the explanatory and predictive power of science.

7. The various sciences contribute to a single organized body of knowledge.

8. A piece of scientific knowledge will be accepted if the evidence can be obtained by other investigators working under similar conditions.

9. Scientists' observations are affected by the ideas they have about their subject.

10. The evidence for scientific knowledge need not be open to public examination.

11. Scientific beliefs do not change over time.

12. Theories help scientists interpret their observations: facts do not speak for themselves.

13. Science is always subject to adjustment in the light of solid, new observations.

14. Scientific knowledge expresses the creativity of scientists.

Strongly Agree	Agree more than disagree	Disagree more than agree	Strongly Disagree
A	B	C	D

15. The truth of scientific knowledge is beyond doubt.

16. Because of the validity of the scientific method, knowledge obtained by its application is determined more by nature itself than by the choices the scientists make.

17. Scientific knowledge is subject to review and change.

18. The scientific enterprise is situated in specific historical, cultural and social settings; thus, scientific questions, methods, and results vary according to time, place and purpose.

19. Scientific knowledge need not be capable of experimental test.

20. Scientific truths are discovered by a few experts.

21. A scientific law is an exact report of the truth about our universe.

22. Scientific knowledge is a product of human imagination.

23. Those scientific beliefs which were accepted in the past, and since have been discarded, should be judged in their historical context.

24. Scientific knowledge is constructed from discovered facts.

25. Consistency among test results is not a requirement for the acceptance of scientific knowledge.

26. Scientific knowledge is a changing and evolving body of concepts and theories.

27. The laws, theories and concepts of biology, chemistry and physics are interwoven.

28. The evidence for scientific knowledge must be repeatable.

Strongly Agree	Agree more than disagree	Disagree more than agree	Strongly Disagree
A	**B**	**C**	**D**

29. We do not accept a piece of scientific knowledge unless it is free of error.

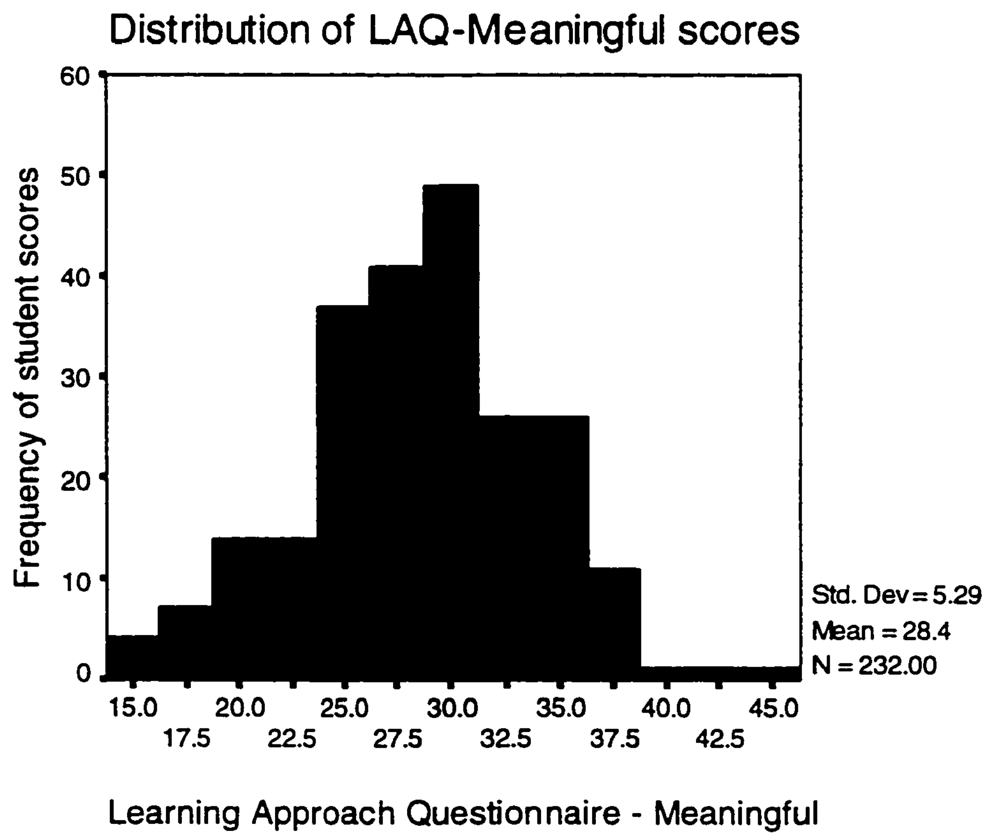
30. Disagreements among scientists can occur when different scientists interpret the facts differently (or interpret the significance of the facts differently). This happens because of different scientific theories.

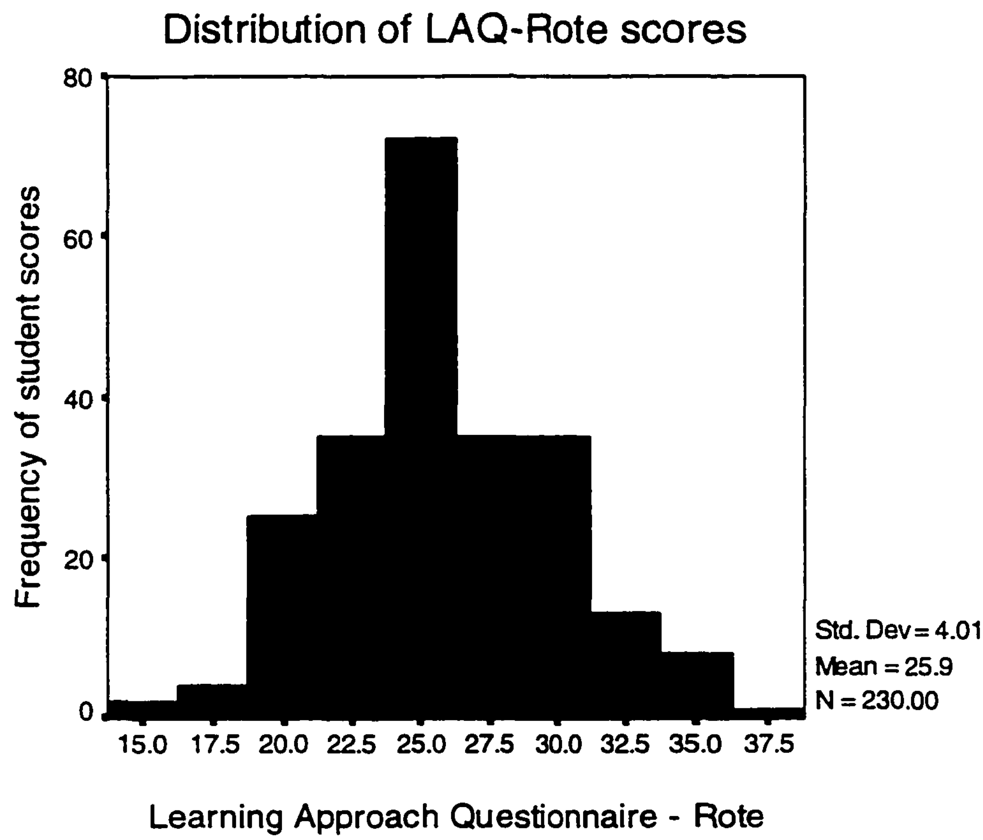
31. A phrase such as "Many scientists believe.." misrepresents scientific inquiry because scientists deal in evidence.

32. When scientists disagree on an issue (for example, whether or not low-level radiation is harmful), they disagree mostly because they do not have all the facts.

Appendix E

Frequency histograms for LAQ-M, LAQ-R, and SKQ scores.


Distribution of LAQ-Meaningful scores
Frequency of student scores
60
50
40
30
20
10
0
15.0
17.5
20.0
22.5
25.0
27.5
30.0
32.5
35.0
37.5
40.0
42.5
45.0
Std. Dev = 5.29
Mean = 28.4
N = 232.00
Learning Approach Questionnaire - Meaningful


Distribution of LAQ-Rote scores
80
60
40
20
0
Frequency of student scores
15.0 17.5 20.0 22.5 25.0 27.5 30.0 32.5 35.0 37.5
Std. Dev = 4.01
Mean = 25.9
N = 230.00
Learning Approach Questionnaire - Rote

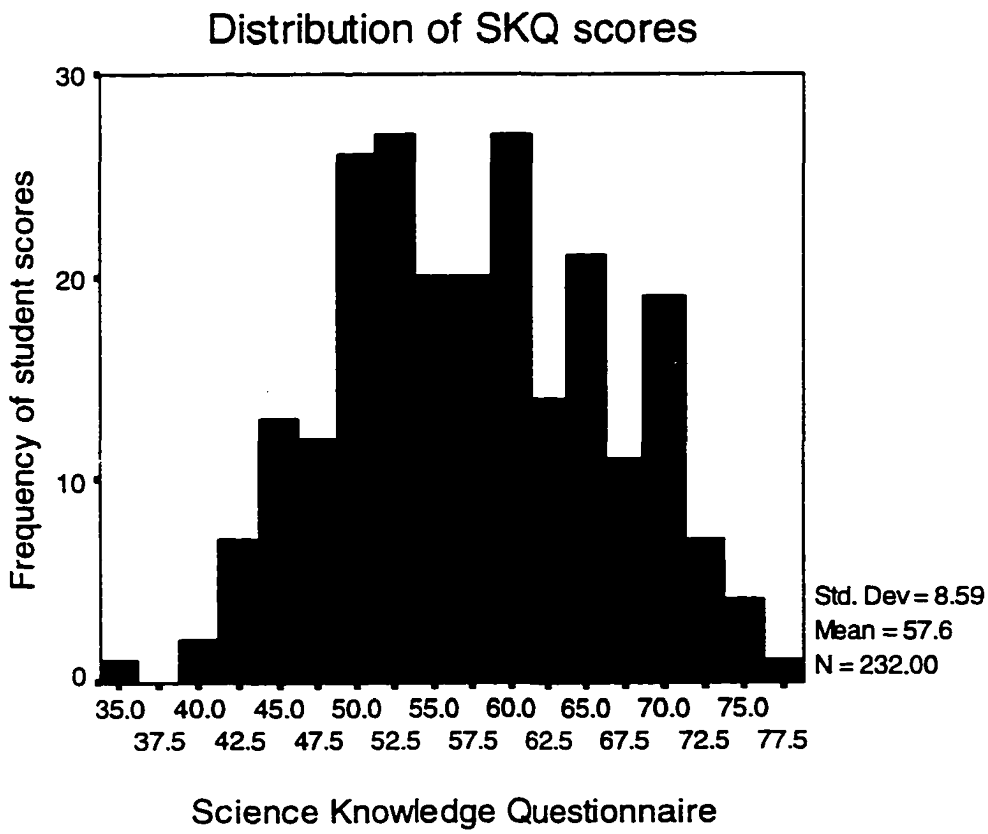
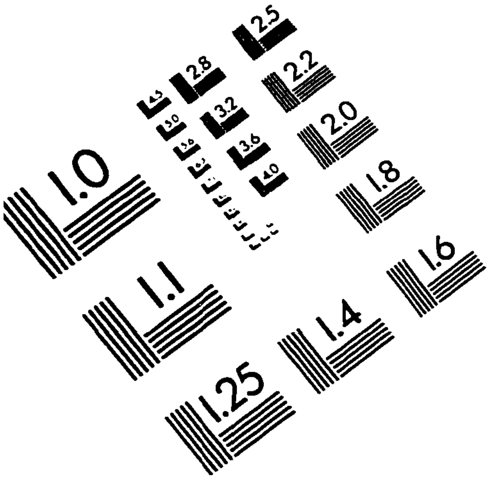
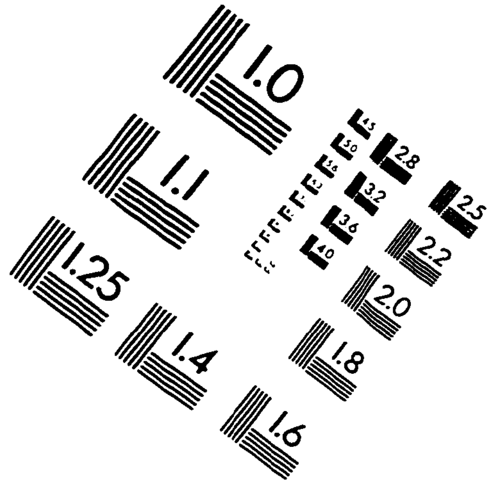
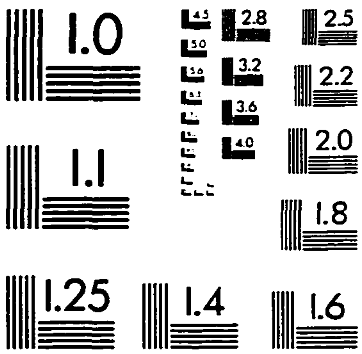
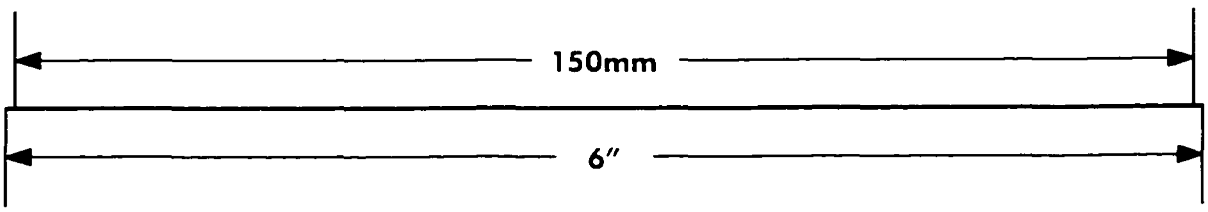

Distribution of SKQ scores
30
20
10
0
Frequency of student scores
Std. Dev = 8.59
Mean = 57.6
N = 232.00
35.0 40.0 45.0 50.0 55.0 60.0 65.0 70.0 75.0
37.5 42.5 47.5 52.5 57.5 62.5 67.5 72.5 77.5
Science Knowledge Questionnaire

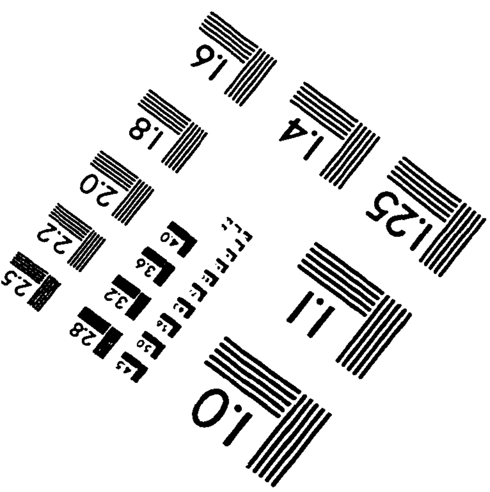
IMAGE EVALUATION TEST TARGET (QA-3)

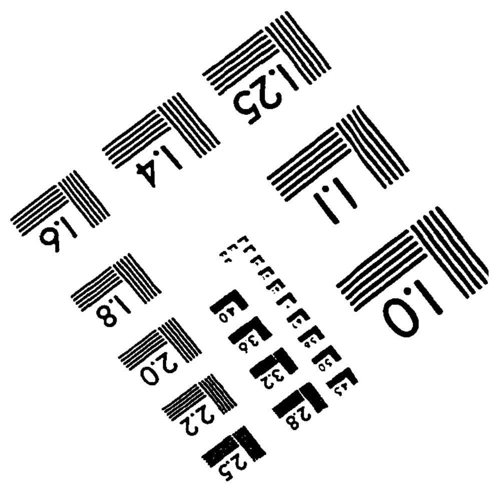












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